# STUDY OF THE SOUTH AFRICAN NANOTECHNOLOGY SYSTEM

**DERRICK LOUIS VAN DER MERWE**

**99159032**

A research project submitted in partial fulfilment of the requirements for the degree of

**MASTER OF TECHNOLOGY MANAGEMENT**

in the

FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY

UNIVERSITY OF PRETORIA

October 2004



The financial assistance of the Department of Labour (DoL) towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at, are those of the author and are not necessarily to be attributed to the DoL

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

# PROJECT REPORT SUMMARY

# STUDY OF THE SOUTH AFRICAN NANOTECHNOLOGY SYSTEM

**DERRICK LOUIS VAN DER MERWE**

**99159032**

**Supervisor** : Prof. A.J. Buys

**Department** : Department of Engineering and Technology Management
UNIVERSITY OF PRETORIA

**Degree** : MEng (Technology Management)

## Abstract

The study of the nanotechnology system in South Africa is an analysis of the South African nanotechnology innovation system, with a discussion of background information regarding nanotechnology awareness, involvement, funding, personnel, education, networking and equipment, and illustration of the level of nanotechnology activities for each product life cycle and per institution. The document contains a classification of nanotechnology industries regarding time to market, market potential, disruptiveness and complexity, identifies innovation hampers for the South African nanotechnology community and ranks nanotechnology national and international nanotechnology buyers, suppliers, competitors and relationships. Lastly, innovative strategies are formulated from information gathered on internal South African nanotechnology strengths and weaknesses, and external nanotechnology opportunities and threats.

## Acknowledgements

The author of the research project was fortunate enough to meet Mr. Manfred Scriba, the convenor and project coordinator of the South African Nanotechnology Initiative (SANi). Without him, the research project would not have been a success. Mr. Manfred Scriba is an invaluable asset to any South African nanotechnology-related study. He possesses a great deal of knowledge regarding the South African nanotechnology national system of innovation, technical knowledge on a number of nanotechnology fields and collaborations with many of the South African nanotechnology community members. In January 2004, the research project author and the author of the CSIR baseline questionnaire, Mr. Manfred Scriba, reached an agreement regarding the bidirectional usage of data gathered, analysed and discussed in both studies.

The author especially would like to thank all the South African nanotechnology participants who took part in the research project and CSIR baseline studies for their time and effort. The research project is a huge success because of them, in supplementing the current South African nanotechnology strategy, providing new information on, new perspectives of and strategies for the South African nanotechnology community regarding future nanotechnology industries, innovation hampers and nanotechnology actors.

The author is grateful for all the research guidance from Prof. A.J. Buys and Prof. M.W. Pretorius, who inspired the bold research project on the South African nanotechnology system of innovation, and Prof. L.A.G Oerlemans for helping in the statistical analysis. Finally yet importantly, the author would like to thank his family, girlfriend and friends for supporting him through long hours in front of the laptop, amongst other things supplying him with a lot of biltong and coffee…

*"All of the information which all of mankind has ever recorded in books can be carried in a pamphlet in your hand–and not written in code, but a simple reproduction of the original pictures, engravings and everything else on a small scale without loss of resolution."*

*Richard Feynman 1959, the father of nanotechnology.*

# Abstract

The study of the nanotechnology system in South Africa is an analysis of the South African nanotechnology innovation system, with a discussion of background information regarding nanotechnology awareness, involvement, funding, personnel, education, networking and equipment, and illustration of the level of nanotechnology activities for each product life cycle and per institution. The document contains a classification of nanotechnology industries regarding time to market, market potential, disruptiveness and complexity, identifies innovation hampers for the South African nanotechnology community and ranks nanotechnology national and international nanotechnology buyers, suppliers, competitors and relationships. Lastly, innovative strategies are formulated from information gathered on internal South African nanotechnology strengths and weaknesses, and external nanotechnology opportunities and threats.

*"Nature already operates at a nano scale level and, by being able to operate ourselves at that level, we will get a greater understanding of the things that nature can do."*

*Dr. Peter Doyle, Unilever*

# Table of contents

## List of figures

## List of tables

# 1 Introduction and background

This chapter provides background information on the technological, industrial and organisational setting, the rationale, problem definition and objectives of research project.

## 1.1 Introduction

Imagine the emergence of a technology capable of complementing or replacing every known industry, improving the quality of minerals threefold, reducing the size of modern computers, realising novel approaches to drug creation and delivery. This is the reality of nanotechnology.

*"The convergence of nanotechnology with information technology, biology and social sciences will reinvigorate discoveries and innovation in many areas of the economy."*

*George W. Bush, President of the United States*

Nanotechnology is set to change the rules by which product and process development are governed, just type in 'nanotechnology' into any internet search engine and there are bound to be more than 1,500,000 entries returned from all ends of the earth. In essence, nanotechnology enables through new tools and techniques to control the basic properties of materials, such as strength, weight and purity. Nanotechnology creates endless opportunities through exciting new materials, pushing the current limits of technical innovations in many products, processes and services.

De Wet (2000) regards South Africa as a technology colony capable of performing applied research, exporting that technology, and then through importing or licensing manufacture and sell similar products. Industry is never in a position to exploit the incremental innovations and cannot create opportunities by itself due to the lack of research and development (R&D).

The trend has, however, shifted. South Africa does possess R&D competencies in many nanotechnology fields and is capable of developing all the product life cycles (from research to marketing). The South African nanotechnology community has been active in developing fundamental nanotechnology knowledge, skills and expertise in fuel cells, water membranes, catalysis and material beneficiation for the last five years. In the process receiving good funding from a variety of sources, building relationships with overseas tertiary institutions and devising a national strategy.

The South African nanotechnology community does, however, need more support to prevent the formation of a South African nanotechnology technology colony.

This document briefly describes the history of nanotechnology, defines and classifies nanotechnology segments, and investigates national and international nanotechnology figures. The discussion then moves on to the literature review on innovation and technology management publications, and research methodology used. The report concludes with a discussion, analysis and summary of the gathered data on the current South African nanotechnology innovation system and some future nanotechnology aspects.

## 1.2 Brief history of nanotechnology

Nobel Prize winner Richard Feynman delivered an inspiring speech at the American Physical Society on 29 December 1959. His speech was called: "There's plenty of Room at the Bottom: An Invitation to Enter a New Field of Physics" In his speech he envisioned a new technology whereby the entire twenty-four volumes, 25,000 pages, of the 1959 Encyclopaedia Britannica could be written on the head of a pin (Forbes/Wolfe Nanotech Report, 2002:4). Chemistry would become a matter of literally placing atoms one by one in exactly the arrangement you want (National Science and Technology Council, 1999:4).

In 1974, Norio Taniguchi created the term 'nanotechnology' and in 1981, IBM Zurich researchers, Heinrich Rohrer and Gerd Binnig, invented the scanning tunnelling microscope (STM). The microscope enables researchers to view individual molecules at atomic resolution. Research into nanotechnology duly increased, with the discovery of quantum dots and fullerenes (refer to Figure 1-1). Each fullerene ball consisted of sixty carbon nanometer atoms, symmetrically bonded, which appeared to be stronger than steel but lighter than plastic, and could conduct electricity and heat.

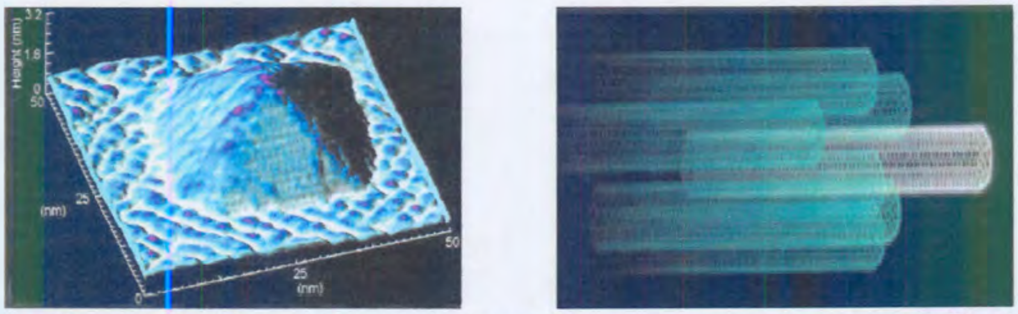


**Figure 1-1. Quantum dot (Nanoscale pyramid of germanium atoms on top of a ground of silicon) and nanotubes formed out of fullerenes (National Science and Technology council, 1999).**

In 1986, IBM researchers Cal Quate, Christophe Gerber and Gerd Binnig invented the atomic force microscope (AFM), which enabled the manipulation of individual atoms. Dr. Eric K. Drexler presented his ideas on molecular nanotechnology, outlining some of the opportunities and threats. In 1989, IBM used the AFM to spell out the now famous 'IBM' with 35 Xenon atoms (refer to Figure 1-2).

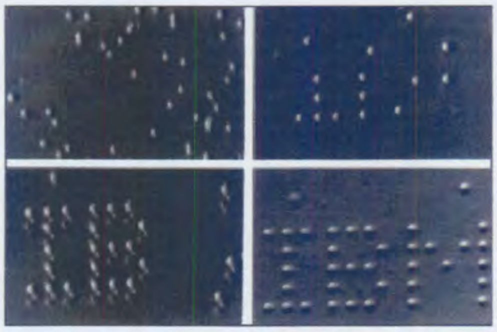


**Figure 1-2. 'IBM' in 35 Xenon atoms (National Science and Technology council, 1999:6).**

In the 1990s, a number of new and high technology solutions emerged such as computer chips potentially 4,000 times faster than modern personal computers and nanoscale storage devices 40 times greater than current hard drives. Arguably these developments were only the beginning.

## 1.3 Definition of nanotechnology

"Nanotechnology is the popular term for the construction and utilization of functional structures with at least one characteristic dimension measured in nanometers. Such materials and systems can be rationally designed to exhibit novel and significantly improved physical, chemical, and biological properties, phenomena, and processes because of their size. When characteristic structural features are intermediate in extent between isolated atoms and bulk materials, in the range of about $10^{-9}$ to $10^{-7}$m (1 to 100 nm), the objects often display physical attributes substantially different from those displayed by either atoms or bulk materials." (International Technology Research Institute, 1999: vii). Figure 1-3 visually illustrates the size of nanotechnology.

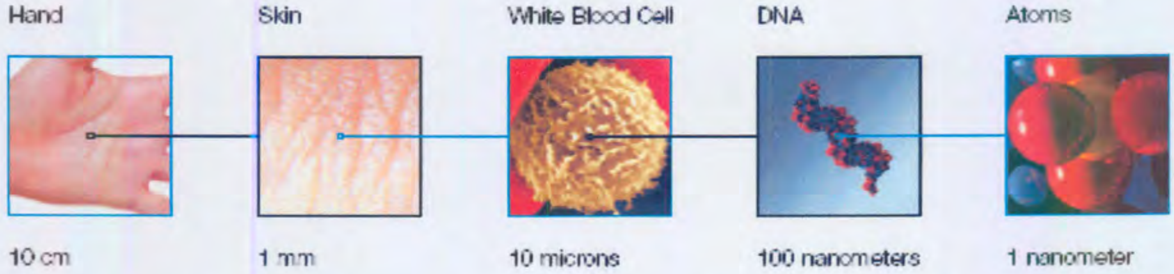



**Figure 1-3. Illustration of the size of nanotechnology (Gann, 2003).**

"Nanotechnology is the manipulation, precision placement, measurement, modelling, and creation of sub-100 nanometer scale matter. Most simply, it's placing molecules and atoms where you want, when you want, to achieve the functionality that you want" (LuxCapital, 2004:11). Nanotechnology is the eventual convergence of solid state engineering (Microelectronics and Micro-electromechanical systems (MEMS)) and synthetic chemistry (atoms, molecules and DNA) to create stronger, more conductive, smaller, lighter materials, etc. (Gordon, 2002:2).

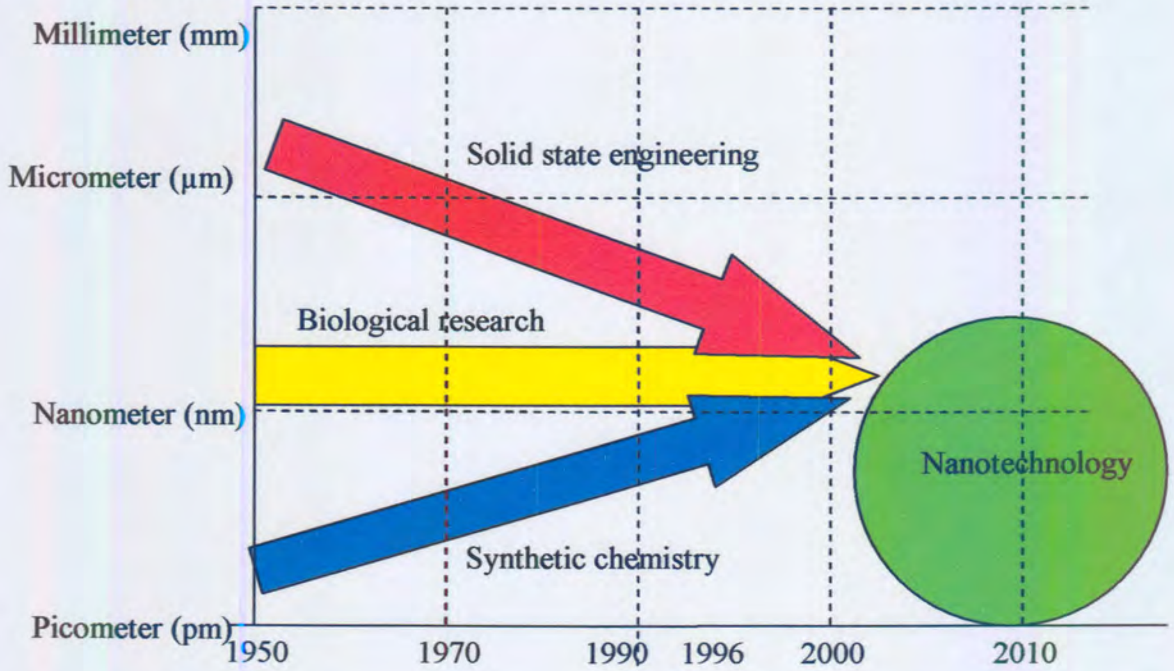



**Figure 1-4. Convergence of different technologies towards nanotechnology (LuxCapital, 2003).**

## 1.4 International nanotechnology industry

### *1.4.1 International nanotechnology funding activities*

From the late 1990s, government funding and venture capital have played a significant role. The total amount of international funding has started to increase exponentially, with just under $750 million in 1999 to $3.1 billion in 2003 (refer to Figure 1-5).

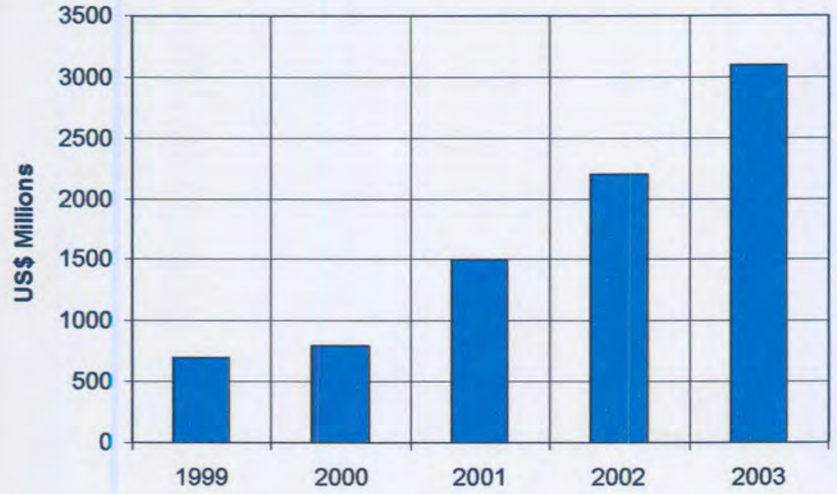



**Figure 1-5. Bar chart of the total international nanotechnology funding from 1999 to 2003 (NanoInvestorNews, 2004).**

In 2001, the European Union (EU) allocated roughly €1.3 billion ($1.2 billion) from 2002 to 2006 towards nanotechnology research under the EU Sixth Framework work (FP6) and President G.W. Bush increased the National Nanotechnology Initiative's funding to $519 million for 2002 (Forbes/Wolfe Nanotech Report, 2002:5). Venture capitalists invested $325 million in 2003 and $386 million in 2002 (LuxCapital, 2004).

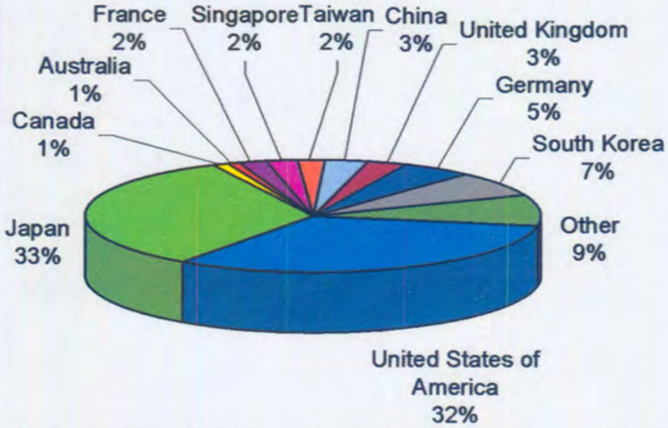



**Figure 1-6. Pie chart of governments' role in the international nanotechnology funding (NanoInvestorNews, 2004).**

The United States of America and Japanese governments have arguably taken the initiative in nanotechnology funding, each contributing an estimate of $500 million (refer to Figure 1-6). The South-Korean government allocated an estimate of $110 million for nanotechnology development and Singapore allocated the highest US$/capita (8.5) than any other country (NanoInvestorNews, 2004).

| Public funding (government) | | | Private funding (firms) | | |
|---|---|---|---|---|---|
| Percentage | Amount | Country | Percentage | Amount | Country |
| 35% | $1.6 billion | North America | 46% | $1.7 billion | North America |
| 35% | $1.3 billion | Asia | 36% | $1.4 billion | Asia |
| 28% | $1.6 billion | Europe | 17% | $650 million | Europe |
| 2% | $133 million | Rest of the world | 1% | $40 million | Rest of the world |

**Table 1-1. Estimated distribution of nanotechnology funding for 2004 (LuxCapital, 2004)**

LuxCapital estimates that governments, firms and venture capitalists will allocate internationally more than $4.6 billion to the nanotechnology R&D in 2004. The role of government in the funding of nanotechnology R&D will decrease, due to the shift in trend from basic research to product and process developments. Firms will start to increase their funding in nanotechnology development to $3.16 billion (refer to Table 1-1).

### *1.4.2 International nanotechnology technical output activities*

Increasing international nanotechnology funding activities, most probably, led to an increase in international awareness generation and nanotechnology activities. This fact is evident in the exponential increase of international patents and publications featuring nanotechnology, related technology and information (refer to Figure 1-7).

The occurrence of the word 'nanotechnology' increased from 190 publications in 1995 to 7,316 publications in 2003 and LuxCapital predicts more than 12,000 in 2004. More than 60% of the nanotechnology patents are American. An interesting fact is that there are more than 300 nanotechnology academic programmes (200 in the United States of America and 100 internationally), with an estimated 7,000 nanotechnology specialists awarded degrees since 2000 (LuxCapital, 2004).

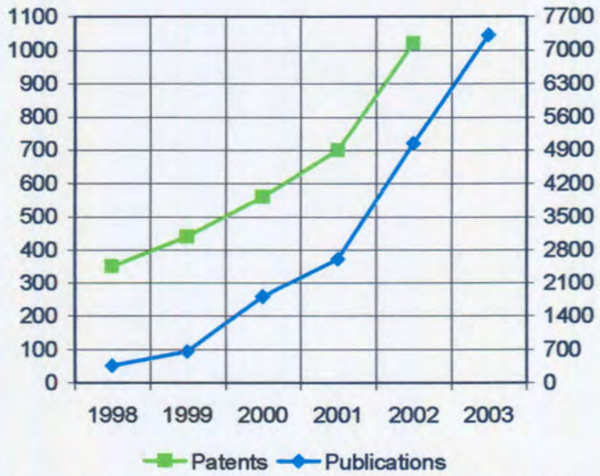



**Figure 1-7. Interactive plots for the number of international patents (Y-axis on the left) and the number of publications (Y-axis on the right) mentioning 'nano' from 1998 to 2003 (LuxCapital, 2004).**

### *1.4.3 International nanotechnology industries*

In 1999, the National Nanotechnology Initiative discovered 227 firms involved in R&D of nanotechnology in materials, electronics, biotechnology, tools and assemblers (refer to Figure 1-8). In 2003, an estimate of 500 firms were involved in one or more fields of nanotechnology (refer to Figure 1-9). The international nanotechnology industry is growing in leaps and bounds with approximately 1,500 firms announcing their involvement in nanotechnology of which 80% are new ventures (LuxCapital, 2004). The majority of the international nanotechnology firms are currently active in developing and manufacturing nano-instruments, nanobiotechnology, nanodevices and nanopowders.

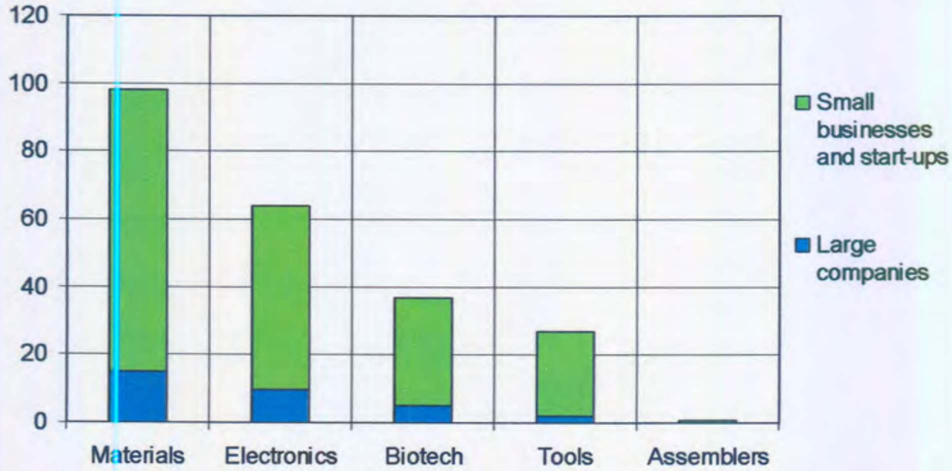



**Figure 1-8. Bar chart of the number of start-up, small and large businesses active in various nanotechnology industries in 1999 (In Realis, 2002).**

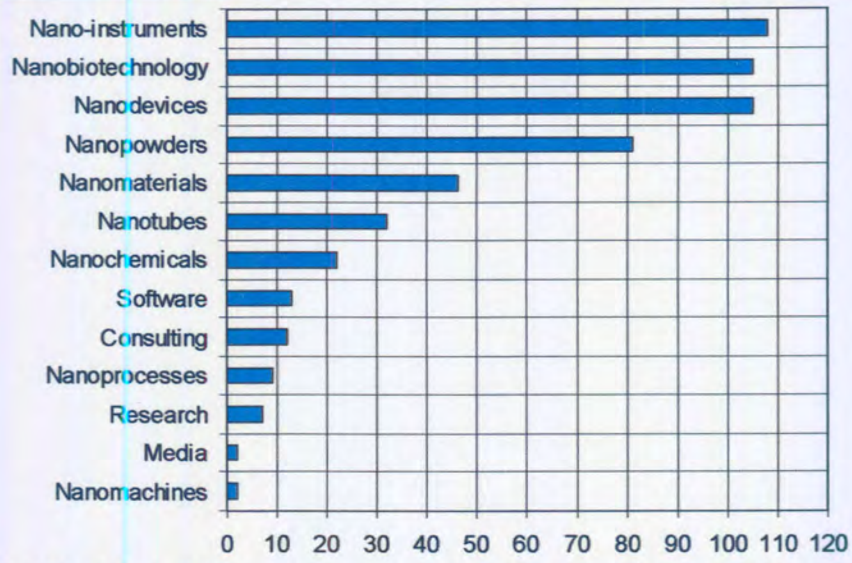



**Figure 1-9. Bar chart of the number of international firms involved in various nanotechnology segments in 2003 (NanoInvestorNews, 2004).**

Venture capitalists also tend to invest more in nanobiotechnology and nanodevices, than nanomaterials and nanotools (refer to Figure 1-10). From 1999 to 2003, venture capital nanotechnology funding has created about 1,700 jobs (LuxCapital, 2003:11).

Nanotools have high capital requirements and low acquisition prices, but could be the best short-term investment opportunity. Nanodevices and nanobiotechnology could be the best long-term investment opportunities. Nanomaterials have received the greatest overall amount of venture capital, although perceived as one of the worst nanotechnology industries from a venture standpoint. Nanomaterials as an industry are sustainable, but due to high capital requirement and reduced profit margins the industry is perceived as one the worst nanotechnology industries (LuxCapital, 2003:11).

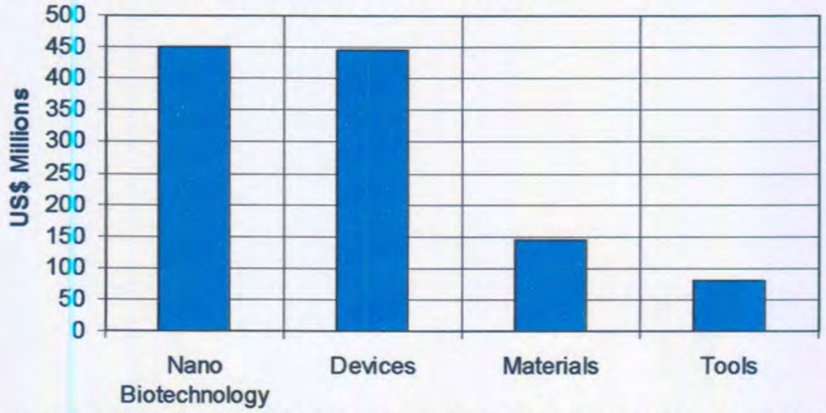



**Figure 1-10. Bar chart of international venture capital investments (LuxCapital, 2004:v).**

| |
|---|
| Babolat tennis rackets lightened and strengthened with Nanoledge nanotubes, and Wilson Double Core tennis balls containing InMat nanomaterials to lock in air |
| Acticoat bandages from NuCryst using nanocrystalline silver to kill microbes; more than 100 of the 120 major burn treatment centres in North America use these bandages to treat life-threatening burns |
| An organic LED screen (OLED) on a digital camera twice as big as the industry average, on Kodak's (EK) Easy Share camera |
| Nucelle sunscreen enhanced with titanium dioxide nanoparticles from Nanophase (NANX) |
| Wrinkle- and stain-resistant fabrics courtesy of Nano-Tex, now found at Eddie Bauer, Mark's Work Wearhouse, Gap (GPS), Old Navy, Perry Ellis, and Tiger Woods' Nike (NKE) clothing |
| Ultrathin ski wax from Nanogate that adapts to snow conditions, making it a favourite product of the Canadian national ski team |
| L'Oreal's Plenitude Revitalift face cream, which uses nano-engineered capsules to transport Vitamin A deep into skin layers |
| Anti-reflective, anti-fog sunglasses courtesy of nanofilm |

**Table 1-2. Some nanotechnology incorporating products (LuxCapital, 2004).**

The perception exist that Japanese nanotechnology firms will be the first large-scale producers and manufacturers of nanotechnology incorporating products, processes and services. Japanese firms tend to focus more towards product and process development rather than basic nanotechnology research, like firms and universities in the United States of America tend to do (LuxCapital, 2004). Some products with incremental nanotechnology improvement have already reached the international market (refer to Table 1-2).

## 1.5 Nanotechnology investment survey results

NanoInvestorNews conducts an on-going non-random online survey of their readers' perception of some interesting nanotechnology developments and investment topics. As shown in Figure 1-11 and Figure 1-12 nanotechnology biomedical applications and electronics are perceived as having the greatest market potential and the first purely nanotechnology firms could reach $100 million in sales during the next two to four years.

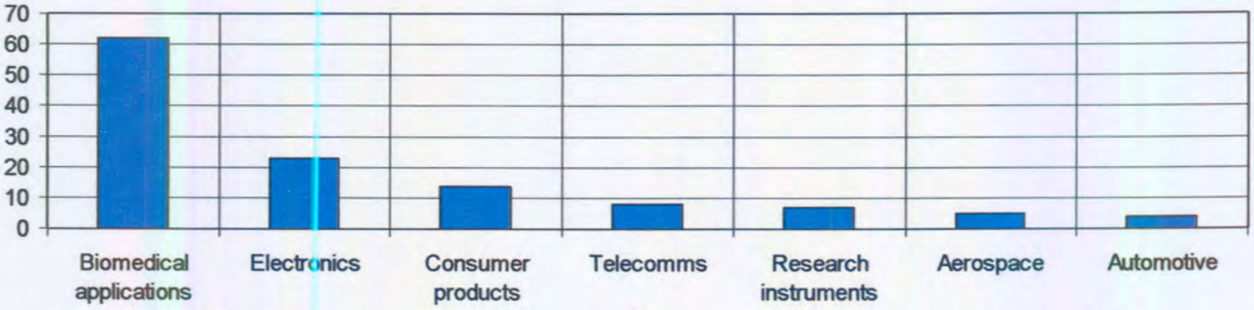



**Figure 1-11. Bar chart of the greatest perceived investment returns per nanotechnology industry (NanoInvestorNews, 2004).**

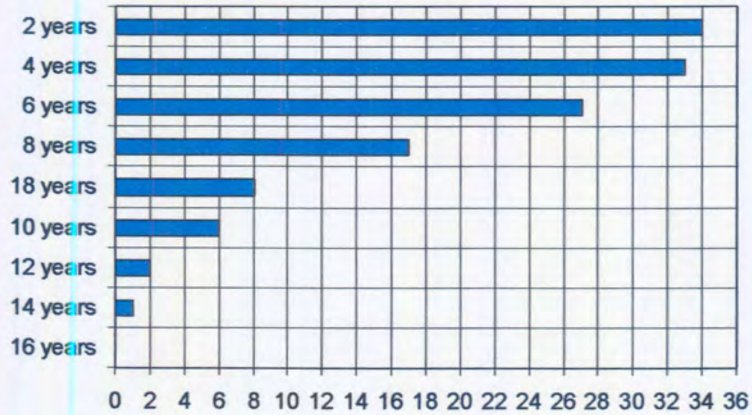



**Figure 1-12. Bar chart of time estimate of when the first pure nanotechnology firm will reach $100 million in sales (NanoInvestorNews, 2004).**

The period for which investors would invest in nanotechnology is (NanoInvestorNews, 2004):

- 50% replied they would invest in short and long-term offerings
- 47% replied they would invest in long-term offerings
- 3% replied they would invest in short-term offerings.

Lastly, the investors noted that they are watching for entry points into the nanotechnology markets (54%), actively buying (26%), observing with no intent of buying at this point (12%), day trading (3%) and selling (2%) nanotechnology shares.

## 1.6 South African nanotechnology industry

### *1.6.1 South African nanotechnology strategy*

On 25 October 2002, after a call for expression of interest from the EU's FP6 programme, key members of the South African nanotechnology community met and created the South African Nanotechnology Initiative (SANi), with the aim of facilitating synergy in identified South African nanotechnology fields of expertise.

In April 2003, the Department of Science and Technology (DST) met with the SANi committee to discuss the creation of strategic nanotechnology planning and funding structures. With the strategy in mind, a group of experts from the industry, academia, labour and government assembled in Gauteng, South Africa, from 15-18 July 2003. SANi recognised that South Africa would have to formulate and implement well-funded and organised strategies, to become internationally competitive and realise the opportunities of emerging innovations in nanotechnology. Figure 1-13 illustrates the key interventions, Table 1-3 summarises some of the key components, and Table 1-4 describes the six nanotechnology focus areas of the South African Nanotechnology Strategy.

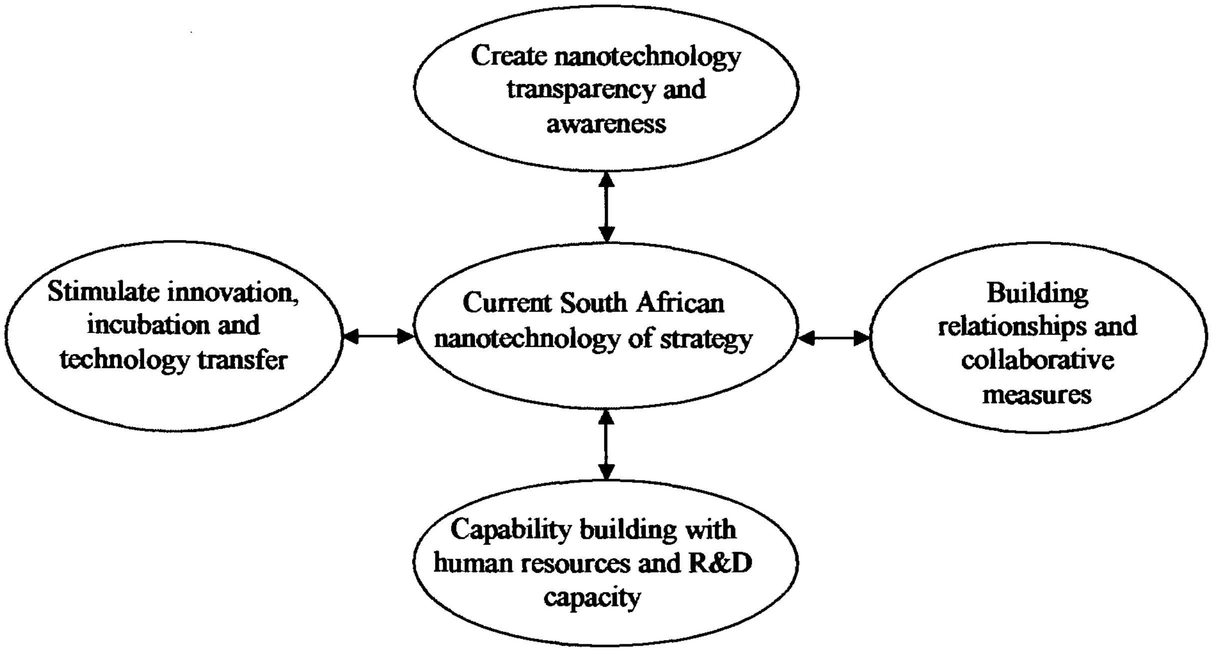



**Figure 1-13. Five South African Nanotechnology Strategy interventions (SANi, 2003a:2).**

| Goals |
|---|
| 1. Gain business and competitive advantages<br>2. Provide better quality of life to everyone<br>3. Move towards a knowledge economy<br>4. Build a technology base for future development<br>5. Create technology awareness in the South African industry and public<br>6. Facilitate involvement of South African industry in nanotechnology |
| **Propositions** |
| 1. Any industry not investigated and strategising around nanotechnology runs a great business risk.<br>2. Any developing country that fails to invest in nanotechnology will hasten the technology divide and is at risk of marginalizing its technological infrastructure and exports.<br>3. To ensure global competitiveness South Africa must respond to global trends, with wealth creation as a function. These global trends include nanotechnology.<br>4. Positioning South Africa as an informed participant, even a leader, in nanotechnology could lead to greater global competitiveness, wealth creation and technological independence. |
| **Assumptions** |
| 1. Developing countries lag behind the rest of the world concerning investments in capacity building<br>2. Developed countries are high-end technology or knowledge economies.<br>3. Education and knowledge are key characteristics of developed countries.<br>4. Developed countries invest heavily in new technology<br>5. Innovation is the key to the successful implementation of new technologies. |

**Table 1-3. The South African Nanotechnology Strategy's national goals, propositions and assumptions (SANi, 2003a).**

| Social development cluster | Some examples |
|---|---|
| Energy | Solar energy<br>Low cost distribution or portable power generation<br>Alternative fuels |
| Water | Disinfection<br>Purification<br>Toxic element and organic pollutants' removal |
| Health | Drug carriers and delivery<br>Biomaterials (prostheses)<br>Cosmetics and sunscreens |
| **Industrial development cluster** | **Some examples** |
| Processing | Cost effective processing<br>Emission and effluent control |
| Mining and minerals | Beneficiation and other alternative value adding advanced tools and materials |
| Materials and manufacturing | Advanced coatings and paints<br>Improved processes for current materials<br>Advanced and functional textiles and composites |

**Table 1-4. South African Nanotechnology Strategy's (SANi, 2003a) focus areas.**

According to SANi, there are a number of government and industry institutions performing R&D activities regarding membranes, synthesis of nanoparticles for medicine, solar cells, fuel cells, cosmetics, catalysts and surface hardening. Companies like ESKOM and SASOL have realised the importance of nanotechnology to remain competitive and provide improved products and services.

"Any developing country that fails to invest in this technology (nanotechnology) will hasten the technological divide and runs the risk of marginalisation and obsolescence of its technological infrastructure and exports" (SANi, 2003a:8).

The strategy, and therefore the nanotechnology focus areas, complements other national strategies addressing poverty alleviation, wealth and job creation, and science and technology development.

SANi has developed a virtual network of universities, government departments and industry and noted that the South African nanotechnology community is fragmented and might not be able to compete internationally in its current state.

### *1.6.2 South African nanotechnology products and services*

SANi proposes that nanotechnology development is not evolving rapidly enough, even with the support of government initiatives and other funding organisations. Most of the South African nanotechnology community focus towards basic research and technology development.

Figure 1-14 illustrates the South African nanotechnology focus areas, as stated by some of the SANi members. Universities and science councils perform the bulk of the nanotechnology product life cycle activities. South African industries are largely unaware of the nanotechnology opportunities and threats, and only a small number of industry actors are interested in energy distribution, catalysis, beneficiated minerals, the environment, etc.

Nanoparticles, biomaterials, catalysis, composites and drug delivery are the most significant South African nanotechnology focus areas. All the nanotechnology segments seem to be more orientated towards nanotools and nanomaterials, with the exception of drug delivery and self-assembly.

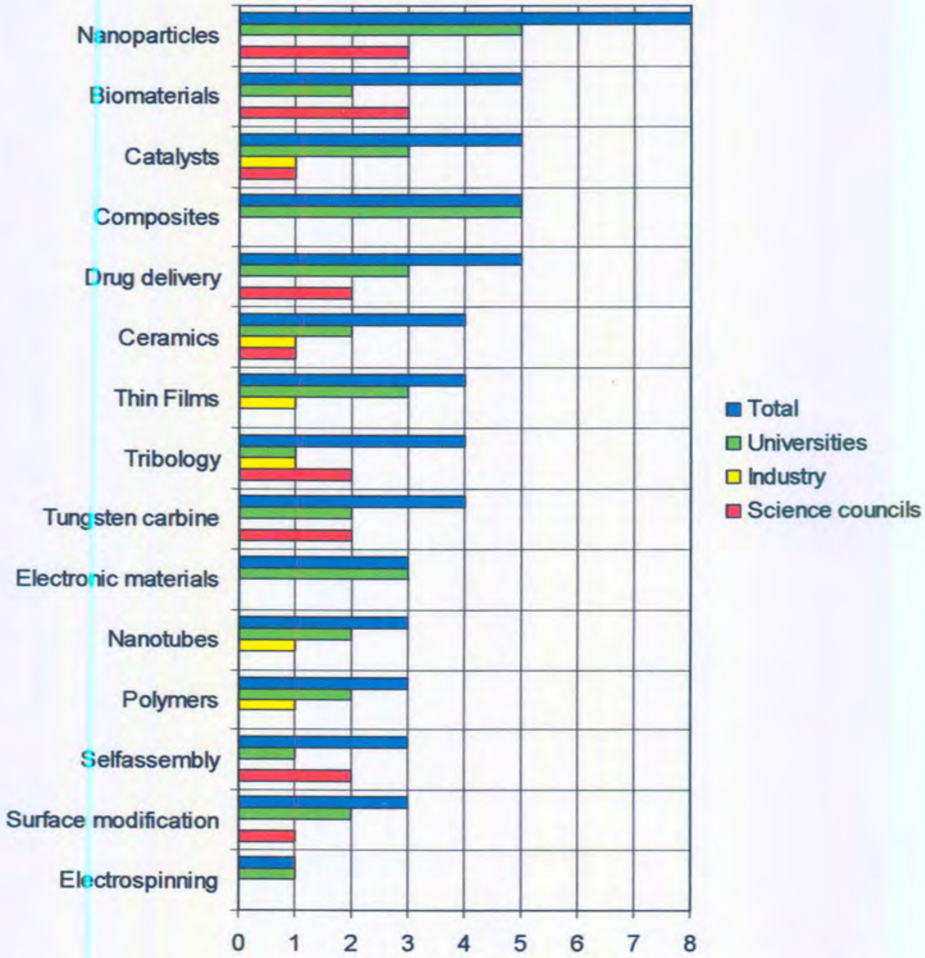



**Figure 1-14. Bar chart of South African nanotechnology involvement by universities, industry and science councils (SANi, 2003b:11).**

Universities focus more on nanoparticles and composites, together with a lesser but equal amount of focus on catalysis, drug delivery, electronic materials and thin films. The University of the Witwatersrand focus on the greatest amount of nanotechnology areas (12), followed by the University of Stellenbosch (7), University of Cape Town (6) and the University of the Western Cape (6).

Only two SANi industry members (SASOL and Element Six) stated their nanotechnology involvement. Only one South African product (SASOL in their catalysis process) features incremental nanotechnology improvements (SANi, 2003b:11). The other industrial nanotechnology involvement areas are collaborations between universities and firms.

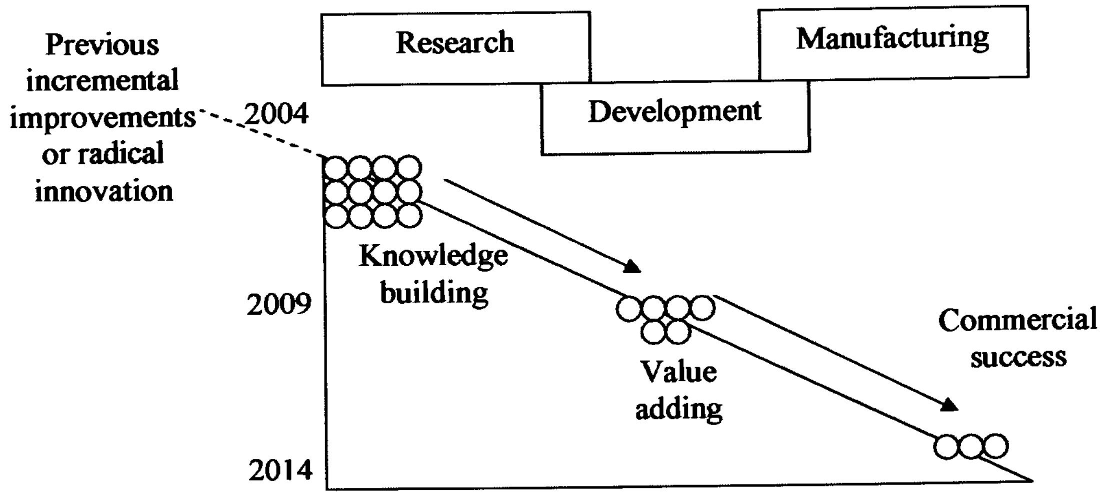



**Figure 1-15. Illustration of new technology growth as seen by Mr. Manfred Scriba of the CSIR.**

Mr. Manfred Scriba, convenor of and project coordinator for the South African Nanotechnology Strategy, discussed the model illustrated in Figure 1-15 during a preliminary interview. The model encompasses three phases, namely research, development and marketing. An action characterises each phase. The six focus areas, described in Table 1-4, define the commercial success. Research describes the building of a knowledge base in a technology. The knowledge base serves as a stepping-stone to adding value in terms of process technology that supports product technology. In adding value, the focus narrows to fewer products than in the research phase and again narrows in commercialisation.

### *1.6.3 South African nanotechnology strengths, weaknesses, opportunities and threats*

SANi (2003a) discussed the placement of the South African Nanotechnology Strategy within the "South African strategic landscape". The South African National R&D Strategy, Integrated Manufacturing Strategy (IMS) and Advanced Manufacturing Technology Strategy (AMTS), amongst others formed part of the South African strategic landscape.

SANi (2003:9-11) compiled its own strengths, weaknesses, opportunities and threats (SWOT) analysis (refer to Table 1-5 and Table 1-6). The SANi SWOT analysis is thorough, but does not describe any of the nanotechnology knowledge fields, in which the possible strengths and weaknesses are present, or those nanotechnology fields that create opportunities and threats that can be capitalised or avoided by the South African nanotechnology community.

| Strengths | Weaknesses |
|---|---|
| **Economical** | |
| Low production costs<br>Good economic infrastructure<br>Long-term economic vision towards 2014<br>Good concept to market skills<br>Well-developed marketing sector<br>Incentives for small, medium and micro enterprises | Great distance from world markets<br>Unattractive fluctuation of the Rand value<br>Shortage of start-up support<br>Shortage of venture capital<br>High interest rates<br>Lack of tax breaks |
| **Technological** | |
| Technologically sound manufacturing base<br>Abundance of natural resources and well-developed related infrastructures<br>Well-developed and strong energy sector<br>World-class expertise in several areas (for example catalysis, water, mining and agriculture research)<br>Technology sector not over-regulated and fairly well developed | Low awareness and understanding of nanotechnology<br>South Africa mainly a technology importer, thus usually pays high licence fees<br>Limited industrial scale-up knowledge or design capability in South African industry<br>Lack of industrial R&D culture, coupled with low technology diffusion rate |
| **Relational** | |
| Good network and database formed by SANi<br>Still building trade and other relations<br>Gateway to Africa via bilateral agreements and NEPAD | |
| **Human** | |
| High levels of grass roots participation<br>Small nucleus of highly skilled workforce<br>Open and forward-thinking entrepreneurial society, which are willing to take risks<br>Relatively cheap and efficient R&D workforce | Large and almost completely unskilled workforce<br>Losing skilled workforce (brain drain) mainly due to the lack of opportunities and security<br>Demographically skewed science and technology base<br>HIV/Aids has huge impact on the workforce |
| **Governmental** | |
| Pace-setting government, which is positive to change and growth<br>Strong governmental science policy<br>Political stability | |

**Table 1-5. Some strengths and weaknesses (SANi, 2003:9-11).**

The Advanced Materials Technology Core Team (2002) as part of the AMTS discussed the working of SANi and provided its version of the nanotechnology SWOT analysis.

Table 1-7 illustrates the AMTS' SWOT analysis. The AMTS' SWOT analysis tends to be more generic, focussing on elements external to the nanotechnology community.

| Opportunities | Threats |
| --- | --- |
| Focus on application of nanotechnology to develop small-scale, flexible, and low-cost technologies (sector can be grouped as either industrial or social development)<br><br>Various South African universities, science councils and industrial companies active in nanotechnology, focussing on membranes, synthesis on nanoparticles, carbon nanotubes, solar cells and fuel cell technology development, catalysis and surface hardening and nanoemulsions<br><br>South African niche markets include African and other developing countries' needs (developing nations with knowledge-based solutions in education and skills transfer, water treatment, low-cost energy, low-cost electronics, drug delivery, security and monitoring, chemicals and plastics processing, new materials value addition to resources, and standardisation and metrology)<br>Environmental nanotechnology applications | Limited access to fundamental chemistry and physics training<br><br>Limited development of technically feasible materials and processes<br><br>Thus far South Africa has been unable to build critical mass of R&D capacity in nanotechnology<br><br>South Africa pays substantial annual technology licence fees to manufacture goods, pharmaceuticals, chemicals, etc. and runs the risk to continue in that trend<br><br>Industrial awareness and support of nanotechnology<br><br>Fragmented nature of the South African research landscape<br><br>Multidisciplinary nature of nanotechnology<br><br>Patchiness of mechanisms to facilitate the transfer of technology<br><br>High cost and risk of experimenting with unfamiliar technology, covering a wide range of disciplines thus companies merely observe academic research and do not perform their own exploratory and experimental developments<br><br>Limited private sector support of nanotechnology R&D<br><br>Uncoordinated funding |

**Table 1-6. Some opportunities and threats (SANi, 2003:9-11).**

| Strengths | Opportunities |
| --- | --- |
| Raw materials<br>Climatic conditions<br>Mining industry<br>Culture of innovation<br>Pockets of excellence<br>SANi<br>Modern characterisation facilities | Emerging technologies<br>Focus on niche markets<br>Development of Africa (NEPAD)<br>Mining industry and quality specific mineral product manufacture<br>Combination of minerals and polymers |
| **Weaknesses** | **Threats** |
| Lack of infrastructure<br>Lack of people<br>Too diverse (interest fields)<br>Lack modern equipment<br>Lack of networking<br>Lack market info<br>Lack of obvious market pull<br>Lack of money and commitment | Funding issues<br>Networking<br>Funding ignorance<br>International patents<br>Skills shortage (brain drain)<br>Global competition<br>Socio-economic threats<br>Lack of R&D funding in minerals and metals industries |

**Table 1-7. SWOT analysis from the Advanced Materials Technology Core Team (2002:161)**

## 1.7 Research project problem definition

The problem is that nanotechnology is an emerging technology and not enough codified knowledge about the current or future South African nanotechnology components, relationships and their attributes exist to formulate effective South African innovation and technology management strategies and policies.

## 1.8 Research project rationale

The strategic intent of the research project is to act as a basis, together with the South African Nanotechnology Strategy (SANi, 2003a), to facilitate the transformation of South Africa into an international nanotechnology competitive force.

The South African Nanotechnology Strategy (SANi, 2003a) provides background information on the current South African nanotechnology community, a preliminary SWOT analysis, future South African nanotechnology focus areas and key interventions in achieving these strategies. The research project supplements the strategy documentation with an analysis of the current South African nanotechnology system of innovation, identifying future nanotechnology innovation hampers, exploring future nanotechnology industries and extrapolating the current South African innovation and technology management strengths and weaknesses with future nanotechnology opportunities and threats.

Many developing countries, including South Africa, still pay for extensive inward international technology transfers (De Wet, 2000), which hampers local entrepreneurship, industrial growth, development and capability building. Only through analysing, formulating, implementing and re-evaluating new effective innovation and technology management strategies and policies will South Africa become a technological gateway to the rest of Africa. Through combining small and cost-efficient nanotechnology R&D with numerous national and international industry actors, South Africa could relinquish its status as technology dependent colony, and begin to alleviate poverty, stimulate job creation, and develop science and technology capabilities.

## 1.9 Research project objectives

The South African Nanotechnology Strategy (SANi, 2003a) postulates that South Africa does possess the potential strengths to take hold of growing opportunities, and combat imposing threats in various nanotechnology industries.

The research objectives is to codify and to gain greater knowledge of the South African nanotechnology system of innovation (identifying internal strengths and weaknesses) and future international nanotechnology trends (identifying external opportunities and threats), thereafter using a recognised innovation strategy framework to develop a nanotechnology strategy for South Africa.

The research project is a theory-application based explorative study, with a survey and expert-opinion research design. The primary research questions that guided the research project were:

1. Who are the South African and international actors playing a role in the development and diffusion of nanotechnology?
2. What are the relationships and roles of the South African and international actors?
3. What nanotechnology products, processes and services do South African universities, firms and science councils research, develop, manufacture, market and sell?
4. What are the nanotechnology innovation hampers?
5. What innovation strategy can the South African nanotechnology community adopt given current strengths, weaknesses, and future opportunities and threats?

Two factors that limit the research project are the amount of cooperation from South African universities, firms and science councils, and the amount of time available in gathering accurate qualitative primary data.

## 1.10 Deliverables

The document delivers the following information:

- A classification of future nanotechnology industries regarding time to market, market potential, disruptiveness and complexity.
- An identification of innovation hampers for the South African nanotechnology community.
- A ranking of national and international nanotechnology buyers, suppliers, competitors and relationships.
- An analysis of the South African nanotechnology innovation system.
    - Discussion of background information regarding nanotechnology awareness, involvement, funding, personnel, education, networking and equipment.
    - Calculation and illustration of figures on the level of nanotechnology activities for each product life cycle per nanotechnology segment and institution.
- Formulation of innovative strategies from information gathered on internal South African nanotechnology strengths and weaknesses, and external nanotechnology opportunities and threats.

The inputs from the analysis processes also couple with secondary information from national and international publications, databases, websites, etc. to construct an evaluation of the significant strengths and weaknesses of, and opportunities and threats to the South African nanotechnology community.

The proposed strategy and recommendations is a framework, which might guide the South African nanotechnology community into an international nanotechnology competitive position.

# 2 Theory and research review

This chapter provides a comprehensive review of the theory and research that represents the most authoritative scholarship in the fields related to the research problem.

## 2.1 South Africa as a technology colony

The majority of the activities occur within the first three stages of the one-directional linear innovation process. In the characterisation of the National System of Innovation (NSI) Oerlemans, Pretorius, Buys and Rooks (2003) confirmed that:

- 91% of South African organisations distribute, market and sell,
- 81% manufacture and service,
- 34% process improvement activities, and
- 48% product or service improvement activities.

The NSI can be presented as a linear innovation process, with each block representing a subsystem (refer to Figure 2-1). Buys (2001) (2002) formulated three linear NSI capability development processes:

- Forward integration - Development based on entrepreneurship, process started by invention, then product or process development, then production and manufacturing and lastly the marketing and selling of the product. Generally, a characteristic of most early developed countries.
- Concurrent integration - Concurrent development of all NSI subsystems. Rapid technological improvements of large-scale industries occur.
- Backward integration - A five-stage process from the distribution, marketing, sales and services to the research subsystem. The stages are as follows.
    - Local distribution, marketing, sales and after-sales services of foreign products and services. The transfer of products and processes to the local NSI is the most important interaction between the local and foreign NSI.
    - Local production and manufacturing of foreign products and services. The transfer of production know-how to the local NSI (through production licenses) is the most important interaction between the local and foreign NSI.

- Local improvement of foreign products and processes. This is the local improvement of products and processes to suit the local market; there must be an innovative climate and strategic intent. Note: the problem might arise that foreign investors might see the developing colony as a threat.
- Local development of new products and processes. Emphasis must be placed on human resource development, increasing R&D, financial support and building relationships between actors in the local innovation system.
- Local technology development. Emphasise knowledge generation for local technology development.

Buys (2003) classified South Africa as a Stage 3 technology colony, because of the fact that 87% of the innovating organisations were involved in incremental innovations (improvements). South Africa does not classify as a Stage 4 technology colony because of the lack of local research and technology development.

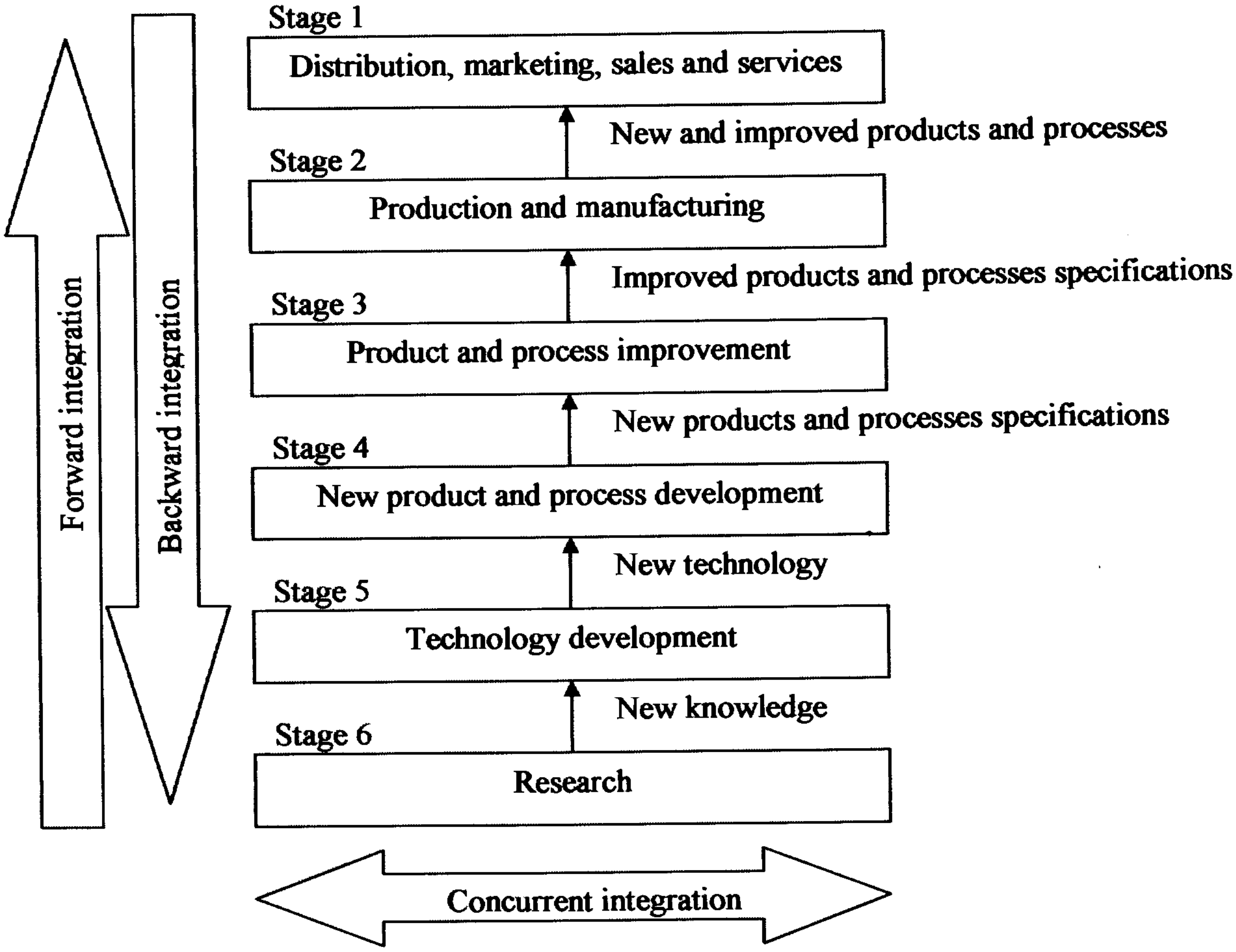



**Figure 2-1. The one-directional linear model of the innovation process (Buys, 2001).**

De Wet (2000) described general features of the technology colony (refer to Figure 2-2):

- Activities centre on the end of the product life cycle, namely the manufacturing and selling of licensed products. The industrialised countries tend to illustrate a gradual accumulation of activities from research to selling within the product life cycle.
- Limited research in the product life cycle is performed mainly through tertiary institutions, R&D institutions and minimally through industry.
- Technology transfers within the NSI are mostly inward in the form of licensing products, designs, processes, subassemblies and final products.

Oerlemans, Pretorius, Buys and Rooks (2003) noted that the marketing, sales and production functions were the most important internal sources of information. Exhibitions and competitors were the most important external sources of information, and the most important innovation partners were foreign and domestic suppliers and own overseas groups. Finally, relatively few innovative funds and subsidies were used. South Africa is a successful imitator or follower, being more cost-effective than many of their foreign competitors. Cost-efficiency, however, might not provide a sustainable competitive advantage.

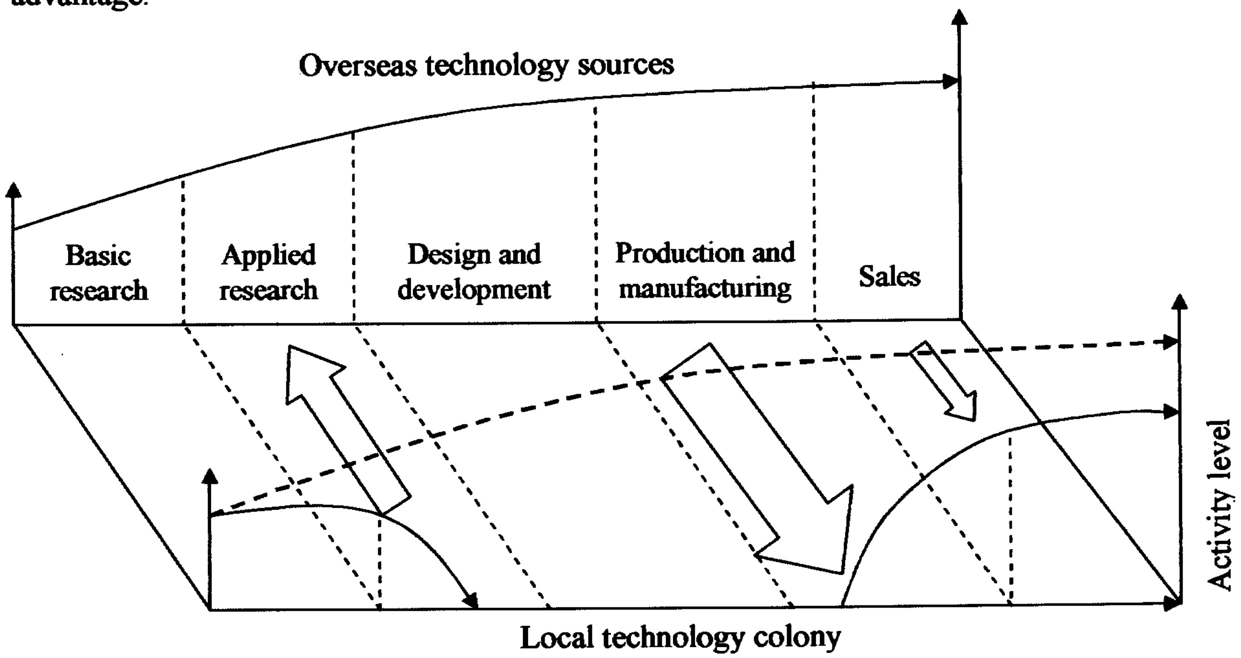



**Figure 2-2. Product life cycle model in the case of technology colony, illustrated against the backdrop of the product life cycle of a developed overseas country (De Wet, 2000).**

The problem created forces most of the industry into searching overseas for technology transfers, the transfer from local research institution remains to be low. The problem in turn suffocates local research institutions and R&D departments, spending huge amount of money and not building the necessary absorptive capabilities of the local industry.

Nolte and Pretorius (2002) express the dilemma in terms of the technology domino effect, dominant design features, improvements and the technology colony. There is a lack of industry and product structure, compounded by the insufficient relationships between research institutions and industrial leaders. The writers emphasised the following problems:

- Industry is never in a position to exploit the incremental innovation of dominant designs. Most incremental improvements are once again licensed.
- Industry cannot create opportunities by itself due to the lack of R&D.
- The technology domino effect might also not be applicable because of a limited range of resources available and the lack of knowledge that could contribute to product development or support technology innovation.

However, there seems to exist no direct correlation between product and industry structures before the emergence of a dominant design, thus it is possible that a technology colony could invest in emerging technologies not found in a dominant design and compete with the rest of the world.

De Wet (2000) classifies technology colonies as being either human resource or commodity (minerals) providers. Human resource providers tend to be more competitive in international markets, due to improved, cheaper process technology advances and the instability of natural resource markets. South Africa is more orientated towards a commodity provider, so unless the necessary product and process infrastructures and relationships are developed, South Africa will not be competitive in the future global arena.

## 2.2 Classification of nanotechnology segments

Gordon (2002) created seven nanotechnology segments by noting that they may be classified in terms of their market potential, value addition, complexity, time to market and risk (refer to Table 2-1).

| Nanotechnology segment | Further description | Some applications |
|---|---|---|
| Tools | Microscopy, techniques and tools<br>Software | Visualisation and manipulation<br>Modelling and computational analysis |
| Raw materials | Anti-microbial<br>Catalysis<br>Biocompatible materials and coatings<br>Drug and gene delivery<br>Protective creams | Water or air purification and treatment<br>Pharmaceuticals, CO emissions<br>Prostheses and implants<br>Oral, inhaled or injected<br>UV creams and cosmetics |
| Structures | Nanocapsules<br>Nanofilters<br>Quantum dots<br>Dendrines | Time or chemical released drugs<br>Filtration of targeted molecules<br>Force atom to occupy discrete energy states<br>Drug delivery, filtration and chemical markers |
| Nanotubes and fullerenes | Nanotubes<br>Buckeyballs | Injection needles, flat screen televisions<br>Medical treatment and drug delivery |
| Devices and systems | Bio-sensors and detectors<br>Drug delivery systems,<br>Electro-mechanical systems | Trace bacteria and biological hazards<br>Implantable reservoirs of chemicals<br>Heart pacemakers and surgical devices |
| Intelligent materials | Intelligent materials | Sense external stimuli and altering properties |
| Machines | Molecular machines and assemblers<br>Nanobots | Construct materials atom-by-atom, mass-production possible<br>Robotics |

**Table 2-1. Simplified classification of nanotechnology segments by Gordon (2002).**

In Realis (2002) similarly segmented their investment guide into the following categories:

- Tools. Commercialisation to pursue is fundamental advances in nanoscale techniques for visualisation, manipulation and measurement, but promises of very large short-term revenue opportunities, competing on the basics of microscopy and semiconductor capital equipment should be avoided.
- Materials. Commercialisation to pursue is disruptive new material applications and arbitrary long nanotubes, but rapid growth expectations, high investment requirements, random "nanopowder companies" should be avoided.

- Electronics. Commercialisation to pursue is disruptive new electronic applications with unique nanomaterial properties, but sustaining developments in microprocessors and other ordered transistor arrays should be avoided.
- Biotech. Commercialisation to pursue is tools that help in identification and understanding of disease mechanisms, but promises of rapid success in new drug delivery processes by undifferentiated products should be avoided.
- Assemblers. No assembly has been identified and private investment should definitely be avoided.

In R&D In Realis (2002) noted that science and engineering lie at the heart of nanotechnology and the understanding of the nature of the R&D processes is critical in the forecasting of future potential. The authors stated that four themes should be carefully investigated in terms of R&D:

- scale and pace,
- adequacy of theory,
- commercialisation, and
- intellectual property.

The minimum requirement for efficient research in a target nanotechnology field could be relatively small, stating that three to five researchers with $500,000 of equipment (like the scanning probe microscope, a vacuum chamber, etc.) would most probably be sufficient. The research project lifetime could be measured it terms of weeks – not months.

In commercialisation, the big question seems to be what the best application of the nanotechnology R&D would be, not whether nanotechnology could be useful in some applications. The question concerns the timing of investments, product placement, supplier and customer adoption rates.

Key uncertainties on nanotechnology market evolution was identified by In Realis (2002):

- Mix between sustenance and disruption. The role which nanotechnology plays is relative to the technology it complements, and eventually replaces?
- Time to commercialisation and mass scale. When will laboratory activities translate into mass production and market success?

- Supplier/buyer adoption rates. How quickly will buyer and intermediaries change from current technologies and products?
- Net economic effect. How will productivity and growth of current and new markets be affected by the exploitation of nanotechnology?
- Output of basic research. When and where will widespread adoption of nanotechnology techniques, tools and theory be applied?
- Breadth of application. How many products, organisations, markets and industries will be influenced by nanotechnology?
- Economic uncertainty outside of nanotechnology. What are the effects of nanotechnology on national and international economies?

## 2.3 Innovation theories, models and methods

### *2.3.1 Definition of innovation*

Pavitt (1989) stated that innovation not only consists of new products and processes, but also of new forms of organisations, new markets and new sources of raw material. Khalil (2000:33) added by describing innovation as the process of renewing or altering current technologies, products, processes, services and markets for commercial gain.

Burgelman, Maidique and Wheelwright (2001:5) illustrated relationships between key concepts of technological innovations and defined innovation as the entire process from conception to commercialisation; innovation, therefore, encompasses conception, invention and exploitation.

### *2.3.2 Stages of innovation*

Khalil (2000) provides a valuable description of the different stages of innovation:

1. Basic research. The process of generating new knowledge, without any application and focussed on technical success.
2. Applied research. Research directed at solving an identified problem, thus focussed on an application or eventual commercial success (Burgelman, Maidique and Wheelwright, 2001:3)

3. Technology development. Converting knowledge into physical hardware, software or service. May include building and testing prototypes.
4. Technology implementation. A set of activities in the introduction of a product into the market. The first use of the product by society.
5. Production. A set of activities involved in the widespread conversion of ideas into products, thus manufacturing, production control, logistics and distribution.
6. Marketing. A set of activities to ease the adoption and diffusion of the product into the marketplace.
7. Proliferation. Strategy and associated activities aimed at gaining market dominance, thus exploiting the technology to its fullest value.
8. Technology advancement. Incremental development or improvement of the implemented technology, in the aim to maintain competitiveness.

According to Burgelman, Maidique and Wheelwright (2001:4) the knowledge generated may be tacit (feeling, experience, etc.) or codified (publication, patent, etc.).

### *2.3.3 Types of innovation*

Henderson and Clark (1990) designed a framework for defining and distinguishing the different innovation types (refer to Table 2-2). Note that in the evolution of innovations, a dominant design emerges after great initial R&D (experimentation) periods. The innovation processes can either be product or process technology related, whereby the rate of major innovation of process technologies follows the evolution of the product technology (Abernathy and Utterback, 1978).

| | | Core concepts | |
|---|---|---|---|
| | | Reinforced | Overturned |
| Linkages between core concepts and components | Unchanged | Incremental innovation | Modular innovation |
| | Changed | Architectural innovation | Radical innovation |

**Table 2-2. A framework for defining innovation (Henderson and Clark, 1990).**

Burgelman, Maidique and Wheelwright (2001:4) and Christensen (1992a)(1992b) also defined the different innovation types as:

- Radical innovations – Innovations involve entirely new product, process or service technologies, and is a completely new way of achieving old goals and/or generating completely new standards. It forces organisations to ask a new set of questions, draw on new technical and commercial skills and employ new problem-solving approaches.
- Incremental innovations – Innovations involve improvements in old or existing product, process or service technologies and are techniques in achieving old goals faster and more efficient or improving old goals marginally. It reinforces the capability of established organisations.
- Architectural innovations – Innovations taking a systems approach, whereby an innovation might be component and/or architectural of nature. A system comprises of different components, each with its own specific function and relationships with other components, thus a component or relationship within the architectural design can be innovated. Component innovation relates to performance enhancement and architectural innovation aims at functional enhancements.

Christensen (1992b) took note of three factors regarding architectural innovations:

- the redefinition of the functions of a product or process,
- the technology improvement might occur in a new or remote market segment, and
- the technology improvement may invade existing established markets when reaching a level of maturity.

Henderson and Clark (1990) focussed on the role of communication channels, information filters, and problem-solving strategies in managing architectural knowledge. The authors emphasised that communication channels are the interpretation of organisational linkages between components in an architectural design, using filters to cope with the complexity of available data and gathering knowledge to find solutions to specific component and architectural problems.

Since the architectural knowledge is embedded within the communication channels, filters and knowledge, organisations might be tempted to modify them, instead of replacing them. The reason is to avoid conflict, but the problem created is how do you know which communication channels, filters and knowledge or strategies to change?

This could explain the emergence of smaller organisations. These organisations do not face the difficulty of reassessing their core competencies with the emergence of new technologies. They are flexible.

A dominant design is characterised by components and architectural designs, which embodies a set of core concepts performing major product functions. After the dominant design has been standardised the components and architectural designs can be refined and elaborated, creating a basis for competition between organisations in an establishing market. Organisations must therefore build new knowledge regarding alternative components and their integration. With the dominant design, the architectural structure most likely would be set in stone and the basis of competition would rely on the evolution of the components within the architecture, thus modular innovation – a concept not yet mentioned.

Gann (2003) briefly discusses the disruptive (radical) and incremental nanotechnology considerations, and Linton and Walsh (2003) emphasise the important relationship between product and process technology in the field of nanotechnology.

### *2.3.4 Systems of innovation*

Carlsson, Jacobsson, Holménb and Rickne (2002) focus on the analytical and methodological issues arising from various innovation system concepts. A system is a set of interrelated components working towards a common objective. The components are the various operating parts of the system, which possess identifiable relationships and links between them. Both the components and relationships have attributes associated with them. The function of the innovation system is to generate, diffuse and utilise technology. Some of the innovation systems concepts described are:

- Input/Output analysis. One of the first and simplest views of innovations is the one-directional linear model of innovation. Within the innovation model, one subsystem transfers knowledge, product or process technology to the next subsystem (Buys, 2001).
- Development blocks. Defined by Dahmen in the 1950s, whereby sequences of complementarities by a way of a series of structural tensions may result in a

balanced situation. The basic idea is that an innovation creates opportunities, but cannot be realised until the prerequisite inputs and products are in place. Each innovation thus causes structural tension.

- National system of innovation (NSI). An approach focussed at national level, taking into account factors such as national policies, tertiary institutions, government departments and industries. The system expanded from merely an input/output system, to one with actors, attributes and relationships between them.
- Technological system. A disaggregated and dynamic approach, whereby many technology systems are present within one country. The system involves market and non-market interaction within three types of networks, namely buyer-supplier (input/output) relationship, problem-solving and informal networks.

The basic assumptions are that the system as a whole will be analysed, which is dynamic, where global technological opportunities are unlimited and components within the system are constrained through limited resources, information, etc. Gann (2003) offers insight into the national nanotechnology built environment innovation system of the United Kingdom, in which the writer discusses the roles and relationships of the components and their attributes.

Abernathy and Utterback (1978) focussed on the patterns of industrial systems' innovation providing a valuable framework focussing on issues like competitive emphasis, stimulated innovation, predominant types of innovation, product line, production processes, equipment, materials, plant and organisational control.

Carlsson, Jacobsson, Holménb and Rickne (2002:237) discussed three evaluation methodological issues of technological systems:

- The level of analysis - Three levels of analysis apply to the systems approach, namely to a technology in the sense of a technology field, a product or artefact and lastly a specific market and/or the system of actors and institutions supplying products to the market (refer to Figure 2-3). Depending on what the research objective might be, the focus of a study might fall on only one of the levels.

- The system boundaries - Identify the boundaries of the technology and the actors external and internal to the systems. Both issues deal with the dynamic character of the system.
- The system performance - Measure system performance based on the analysis level and maturity of the system (with the aid of some generation, diffusion and use of knowledge indicators).

In deciding on system boundaries, we need to understand what the boundaries of the knowledge field are, but this cannot be done unless the researcher is familiar with the technological fields and interacts a great deal with the technological experts (Carlsson, Jacobsson, Holménb and Rickne (2002:239). Three questions may be asked relating to the system boundaries:

- What can be classified within a particular knowledge field (technology)?
- How to deal with the dynamic character of the system?
- How to identify actors within the system?

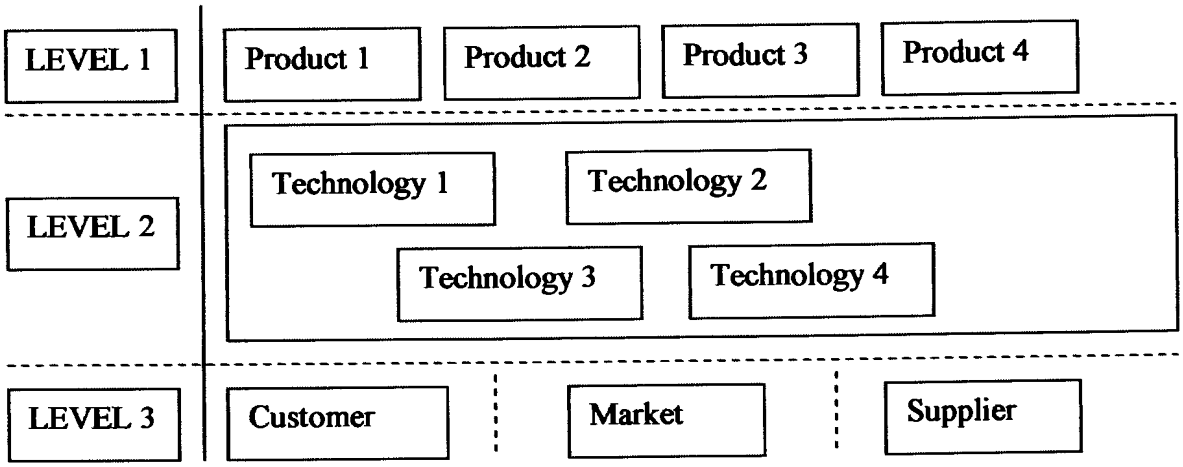



**Figure 2-3. Three of level of analysis technology systems within the NSI.**

The primary question of system performance is how do you measure system performance? A technological system consists of a number of actors. To evaluate the performance of a system means to evaluate each of these actors, not as single entities, but connected to the entire system (Carlsson, Jacobsson, Holménb and Rickne, 2002:242). The choice of performance measures depends on the level of analysis and maturity of the system.

### *2.3.5 Innovation strategies*

#### 2.3.5.1 Strategy selection and implementation

In an industry, one is faced with the dilemma of how to manage and initiate change and growth within such industry without fragmenting it. How does one control innovation, through strategy, without stifling it? Burgelman and Grove (1996) provided a theoretical framework of five dynamic forces that drives an organisation's evolution and from which strategic dissonance emerges (refer to Figure 2-4). These five dynamic forces are evaluated and transformed.

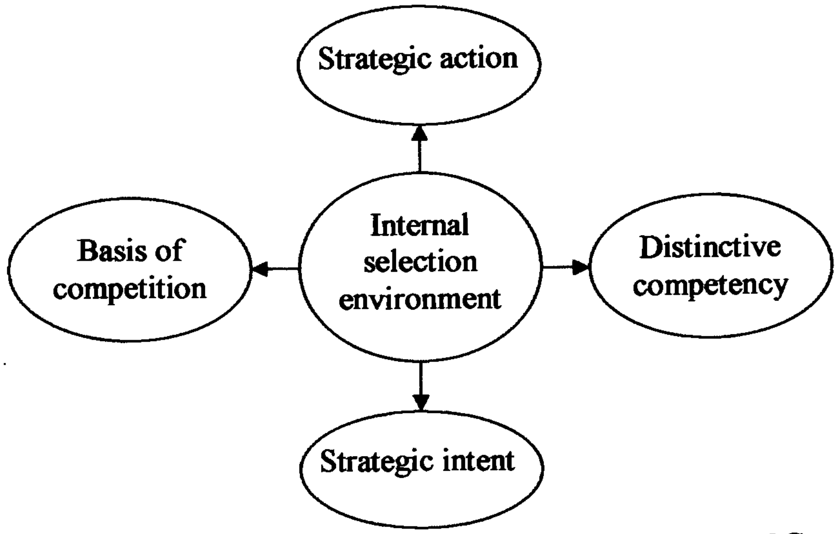



**Figure 2-4. Dynamic forces in an organisation's evolution (Burgelman and Grove, 1996).**

Burgelman (1991) emphasised that the internal selection environment must reflect the external selective pressures from the environment. Positive performance incentives may provide a cushion during the alignment and transformation of factors. Strategic processes might be either induced (strategic initiatives originating within the organisation) or autonomous (strategic initiatives most likely realised by personnel in direct contact with current technology or originating outside of the organisation's scope of strategy).

An important aspect envisioned by Drejer (1996) is that the reason why traditional approaches to management of technology fail are because technology absorption rates are relatively low, a high rate of implementation failure and poor handling of social consequences of new technology. Various factors can, however, contribute to these reasons mentioned – most of them attributed to management skills, technology integration and strategic alignment.

#### 2.3.5.2 Core competency driven

In the past, an organisation could simply direct its effort into a new product line and would most probably become a world leader. However, market boundaries are now ever-changing, targets are elusive and technology is evolving at a rate not previously conceived. The only certainty a company might possess is its portfolio of competencies (relating to absorptive capacity and innovative capabilities) – these competencies are developed and nurtured through time and could be the only boundary against competitor entry into a new market (Prahalad and Hamel, 1990).

Innovative capabilities are the characteristics of the organisation that facilitate and support innovation strategies (refer to Figure 2-5). The combination of the five categories determines the strength of the strategy formulation and implementation, and are characterised by time to market, technical leadership, scope and rate of innovativeness.

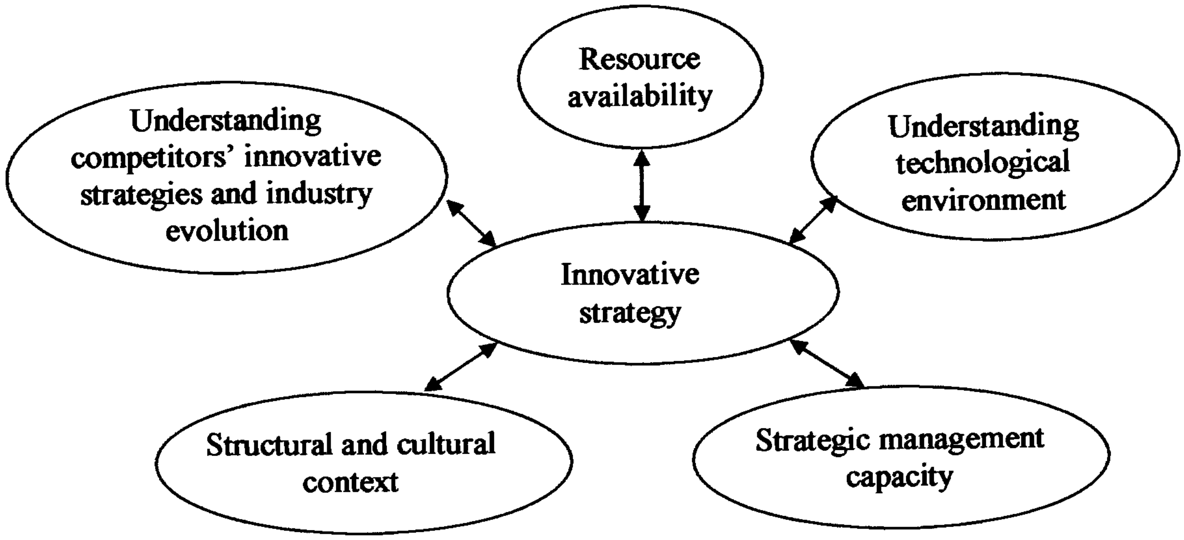



**Figure 2-5. Framework for evaluation of innovative capabilities (Burgelman, Maidique and Wheelwright, 2001:11).**

In the auditing of core technology capabilities a model was developed by De Wet (unknown) whereby an organisation could audit according to the system life cycle (research, design, development, production, support and use) and the system hierarchy levels (material used, components, subsystem, product, product system and user system). An audit must address three questions (Burgelman, Maidique and Wheelwright, 2001:10):

- What is the organisation's history in innovative activities? (History)

- How well are the organisation's core competencies and strategies aligned with the innovative capabilities? (Present)
- What innovative capabilities are needed to survive and flourish in the end? (Future)

An organisation's technology opportunities and threats are governed by their absorptive capacity (Cohen and Levinthal, 1990) though R&D spending. Another critical theory brought forth by the writers is that technical knowledge is an accumulation of one's own R&D, spillovers of competitors' knowledge and extra-industry knowledge, which is directly proportional to the organisation's absorptive capacity.

### 2.3.5.3 Technology and the competition driven

Competitive collaborations (Hamel, Doz and Prahalad, 1989) have increased over the years. These collaborations have long-term consequences, which could benefit entire industries. According to the authors, collaborating firms must adhere to the following principles:

- Competition is competition in a different form.
- Harmony is not the most important measure of success.
- Cooperation has limits. Companies must guard against competitive compromise.
- Learning from partners is of paramount importance.

Roberts and Berry (1985) elaborated on the different forms of collaborations (refer to Table 2-3).

| | | Technology | | |
|---|---|---|---|---|
| | | Existing | New but familiar | New and unfamiliar |
| Market | New and unfamiliar | Joint venture | Venture capital<br>Venture nurturing<br>Educational acquisition | Venture capital<br>Venture nurturing<br>Educational acquisition |
| | New but familiar | Internal market development<br>Acquisition | Internal venture<br>Acquisition<br>Licensing | Venture capital<br>Venture nurturing<br>Educational acquisition |
| | Existing | Internal development or acquisition | Internal product development<br>Acquisition<br>Licensing | "New style" joint venture |

**Table 2-3. Framework for choosing the appropriate form of collaboration (Roberts and Berry, 1985).**

Porter (1979) discussed the forces acting on the competitive environment (refer to Figure 2-6) and formulated three strategies based on positioning the company, influencing the balance and exploiting industry change.


**Figure 2-6. The competitive forces model (Porter, 1979).**

Porter (1988) added to the competitive forces model with the generic strategies relating to leadership and differentiation. Table 2-4 summarises the generic strategies.

| | Technological leadership | Technological followership |
|---|---|---|
| **Overall cost leadership** | First mover on lower cost product or process technology | Lower cost of product or process through learning from leader experience |
| **Overall differentiation** | First mover on unique product or process that enhances product performance or creates switching cost | Adapts product or delivery system more closely to market needs (or raises switching costs) by learning for the leader's experience |
| **Focus – lower segment cost** | First mover on lowest cost segment technology | Afters leader's product or process to serve particular segment more efficiently |
| **Focus – segment differentiation** | First mover on unique product or process tuned to segment performance needs, or creates segment switching cost | Adapts leader's product or process performance need of particular segment, or creates segment switching costs |

**Table 2-4. Generic leadership and differentiation strategies (Porter, 1988).**

First-mover opportunities may arise from an organisation's ability to possess some unique capabilities and foresight, or from just plain luck. Table 2-5 illustrates the first-mover versus imitator selection criteria.

| | | Scope | |
|---|---|---|---|
| | | Full | Selective |
| Leadership | Leadership | Full line technology leader | Niche player |
| | Followership | Technology follower | Technology rationaliser |

**Table 2-5. Technology strategy types (Narayanan, 2001:255).**

The mechanisms leading to the first-mover advantages are (Lieberman and Montgomery, 1988):

- Technological leadership. Advantages gained trough faster learning curves (costs fall with cumulative output) and R&D or patents (protecting trade secrets).
- Pre-emption of assets. The acquisition of scarce assets – input to processes such as natural and human resources, locations in geographic and product characteristic space, and finally investment in plant and equipment assets.
- Buyer switching costs. Initial transaction costs in adapting to seller's product, costs due to supplier specific learning by the supplier and intentional contractual switching costs.

Some of the disadvantages to technology leadership might be that imitation costs are lower than the innovation costs, market uncertainty can be decreased, shifts can occur in the technology or market need, or incumbent inertia on behalf of the first-mover organisation.

## 2.4 Technology

### *2.4.1 Definition of technology*

De Wet (2000) defined technology as three consecutive corners of a triangle, namely people involved, tools used and knowledge implemented. The sides of the triangle represent the education, training, and/or algorithms used in linking the three technology corners. Burgelman, Maidique and Wheelwright (2001:4) also defined technology as the theoretical and practical knowledge, skills and artefacts used to develop products and services as well as their production and delivery systems. Change in the technology is the change in one or more of the input, processes, techniques or methodologies that improve the level of performance of an identified product, process or service (Christensen, 1992a).

### *2.4.2 Technology diffusion and adoption*

The basic theory of the technology S-Curve model is that during an amount of time or engineering effort spent on a product its performance increases in the form of an S-Curve (Christensen, 1992a). Table 2-6 provides a description of the stages associated with the S-Curve model.

| Stages | Description |
| --- | --- |
| Embryonic | The rate of progress is slow. Technology yet to be understood, diffused and controlled. Much time or engineering effort is spent on increasing product performance. |
| Growth | The rate of progress increases. Technology starting to be understood, diffused and controlled. A dominant design emerges and key technologies are identified. Product performance increase exponentially, with less time or engineering effort. |
| Mature | The rate of progress decreases. The technology is therefore fully diffused, reaching its natural or physical limit. Thus, more time or engineering effort is spent on gaining product performance, through incremental improvement, or by technology being replaced. |
| Aging | The rate of progress stops. |

**Table 2-6. Description of the stages associated with the S-Curve model (Khalil, 2000:81).**

Moore (1993) and Khalil (2002:83) discussed four stages of a market evolution within a business ecosystem, which linearly correlates with the three stages of the technology S-Curve:

- Birth (technology development and applications launch) - Work with the customers and suppliers in defining the product, process or service, while protecting ideas and resources.
- Expansion (application growth) - Achieve market coverage and improve on competitive product, process and service.
- Leadership (application growth and mature technology) - Create visionary status in market and maintain strong bargaining power.
- Self-renewal (technology substitution and technology obsolescence) - Cooperate with innovators and maintain barriers to entering business ecosystem.

Managers should actively identify new product and process technologies at the inflection point of the S-Curve model. Growth occurs in one of two ways; the current technology is either improved (incremental change) or the organisation has to make the jump to new technology (radical change) before the current technology reaches maturity. Incremental change may be in the form of improving component technology performance, or change in the relationship of the components within the architecture.

Cooper and Schendel (1976) noted that after the introduction of the new technology the sales of the old technology did not decline immediately, but expanded, despite the growth in sales of the new technology. The new, expensive and crude technology creates new markets (not available to the old technology), invading traditional markets by capturing sub-markets (niche markets) and not necessarily following the standard S-Curve.

Within an architectural innovation, it is important to note that each component embodies a certain technology and each of these technologies represents an S-Curve in terms of level of maturity (Nolte and Pretorius, 2002). Technology hierarchies exist within technology architectures. Any change within any of the hierarchies causes a changes both upwards (product development) and downwards (supporting technologies), known as the technology domino effect.

Christensen (1992b) and Sahal (1981) provided the theory of technology maturity, which stated that the rate of technological performance declines in direct relation to the complexity involved in enhancing it. The only way to overcome this decline is through radical system redefinition.

Diffusion models attempt to analyse the adoption process of an innovation throughout a determined social system (Nieto, Lopez and Cruz, 1998). The technology adoption life cycle can be categorised by its rate of diffusion and actors involved in the diffusion (refer to Table 2-7).

| Life cycle | Forecasting activities | Competitive advantage |
|---|---|---|
| Emerging technology | Scanning and monitoring | Technology has not demonstrated the ability to become the basis for competition. |
| Pacing technology | Monitoring and evaluating | Technology proving itself the leader of a new paradigm |
| Key technology | Identifying and harnessing | Technology providing the "key" to a technology competitive advantage |
| Base technology | Continuous monitoring | Basis of all competitive technology, but common to all competitors |

**Table 2-7. The technology life cycle and the competitive advantage (Khalil, 2000) (Burgelman, Maidique and Wheelwright, 2001:11) (Gerybadze, 1994).**

The diffusion process can be divided into five groups, each with their own characteristics, strengths and weaknesses (refer to Figure 2-7). Moore (1999) identified that when moving between early adopters (visionaries) and majority adopters (pragmatics) most companies failed by not focussing on market niches and core competencies. This phase of the adoption life cycle is known as the innovation chasm.

Lead users are the innovators. Thomke and Nimgabe (1998) classified lead users as a representation of targeted markets with similar needs and listed the benefits of performing a lead-user research project as:

- having access to rich reliable information,
- being able to develop better products, and
- accelerating product and service development.

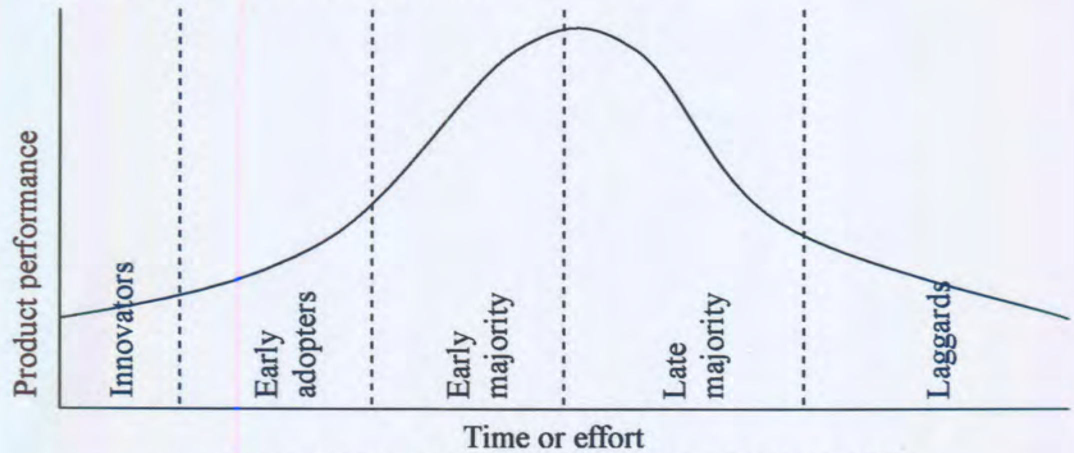
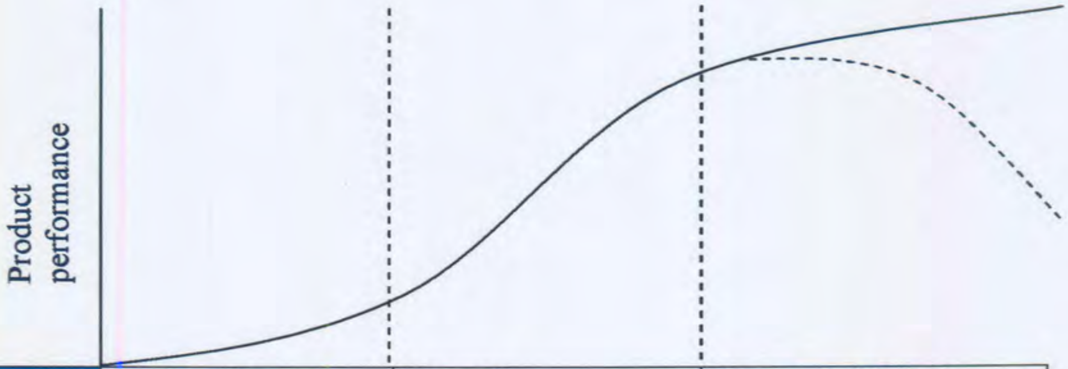



**Figure 2-7. The technology adoption life cycle (Moore, 1999).**

Two models form the theoretical foundations of the S-Curve model (Nieto, Lopez and Cruz, 1998), namely the diffusion model and life cycle model. Figure 2-8 summarises the key factors of each theory. The Y-axis, once again, represents the product or technology performance and the X-axis the time or functional effort exerted.




| | | | | |
|---|---|---|---|---|
| **Time** | Embryonic | Growth | | Mature and Aging |
| **Technology** | Emerging | Pacing | Key | Mature |
| **Sales** | Low | Rapid growing | Start declining | Declining |
| **Competition** | None of importance | Growing | Many rivals competing | Few competitors |
| **Customer** | Innovators/lead users | Early adopters | Early majority | Late majority |

**Figure 2-8. An S-Curve illustration of technology life cycle and diffusion characteristics combined (Zikmund and d'Amico, 2002).**

Gerybadze (1994) states, however, that there are two problems in trying to classify a technology as an emerging, pacing, key or base technology:

- Most technologies do not follow a nice "ballistic trajectory" or S-Curve. They display stochastic movements.
- Information can be distorted and misunderstood, thus decreasing the value of the information and competitive differentiation as more actors enter the system.

Gerybadze also discusses the new approach to technology forecasting as need and value driven, emphasising sources of competitive differentiation and communication channels between actors that possess complementary knowledge. The aim of technology forecasting should be to identify emerging technologies which, combined with complementary assets, enables the actors within the innovation system to exploit some competitive advantage.

Canton (2001) provides a framework of possible national nanotechnology scenarios. The scenarios described are as follows:

1. Brave New World (Timeline: 2020 – 2050). Nanotechnology integrated into the economy due to a number of factors, where the nation is characterised by high

productivity and industrial growth. The outlook is positive, with increased market share and investment opportunities.

2. Playing Catch Up (Timeline: 2020 – 2050). Nanotechnology is partially integrated due to low readiness and inadequate strategic planning, where the nation is characterised by a poor education, training and investment climate. The outlook is optimistic if large positive change facilitators are in place.
3. The Bumpy Road (Timeline: 2020 – 2050). Low nanotechnology integration whereby a loss of markets and profits is eminent. The outlook is bleak and global leadership will have to be sacrificed.

Gingrich (2001) discusses the age of transitions involving biology, nanoscience and information technology representing the concept as a radical transition from old to new innovation paradigms.

## 2.5 Models and methods used in strategic analysis and decision making

### *2.5.1 Technology and innovation strategy development*

Khalil (2000), David (2001) and De Wet (1992) identify a number of methods in the strategic analysis and decision-making processes. The purpose of the methods is to generate feasible alternative strategies, and not to select or determine which strategies are the best.

- Strategic Position and Action Evaluation (SPACE) matrix. Taking into account the internal and external strategic position of an organisation, industry or country the SPACE matrix indicates whether aggressive, conservative, defensive or competitive strategies are the most appropriate. The axes are made up out of financial strength, environmental stability, competitive advantage and industry strength.
- Market-Growth-Market-Share Analysis matrix (BCG Matrix). Matrix representation portraying the differences among division, business units, technologies or products in terms of relative market share position and industry growth rates. The matrix consists out of four quadrants each with specific characteristics and implementation strategies associated with them.

- Product-Positioning Maps. After segmenting markets, the task of the organisation is to investigate the needs and wants of potential customers. The product-positioning maps reflect how competitors' product and services compare and emphasises the dimension most important to success in the industry.
- Technology Balance Statement (TBS) and Technology Income Statement (TIS). The models illustrate the relations between markets, products, technologies, processes used, product phases and technology diffusion. From this information, strategies may be developed that are cross-functional and incorporate technology forecasting.
- Strengths, Weaknesses, Opportunities and Threats (SWOT) Analysis. This tool aids in developing four types of strategies. Strength-Opportunity strategies (SO) – using the organisation's internal strength to take advantage of the external opportunities. Weakness-Opportunity strategies (WO) – taking advantages of external opportunities to overcome internal organisational weaknesses. Strength-Threat strategies (ST) – using the organisation's internal strengths to avoid or reduce the impact of threats. Weakness-Threat strategies (WT) – defensive tactics to avoid external threats and reduce internal weaknesses.

### *2.5.2 Technology forecasting techniques*

Organisations need to know the direction of future component and architectural technologies. The primary reason why organisations do lose economies of scale and leadership in an industry can be attributed to their inability to forecast and map the growth of emerging technologies in their and other non-related industries.

A tendency exists to focus on improving maturing technologies – although these technologies might possess a natural or physical limit – and to know why and when alternative technologies (component or architectural) could influence, or destroy, the current dominating technology.

Khalil (2000) mentions five general methods of technology forecasting – providing descriptions, assumptions, strengths, weaknesses and uses (refer to Table 2-8).

| | Strengths | Weaknesses | Uses |
|---|---|---|---|
| Monitoring | Large amount of information from wide range of sources | Information overload without filtering | To maintain current awareness or provide information useful in structuring a forecast |
| Expert opinion | Can provide high-quality models | Difficult to identify experts | To forecast when identifiable experts exist and where data are lacking and modelling is difficult |
| Trend analysis | Substantial database forecast of quantifiable parameters | Requires a significant amount of good data | To project quantifiable parameters and to analyse adoption and substitution |
| Modelling | Exhibit future behaviour of complex systems simply by isolating important aspects | May obscure faulty assumptions and favour quantifiable data | To reduce complex systems to manageable representations |
| Scenarios | Present rich pictures of possible futures, and incorporating qualitative and quantitative information | May be more fantasy than forecast | To integrate critical quantitative and qualitative information. Provide a forecast when data are weak. Useful in communicating complex highly uncertain situations |

**Table 2-8. Comparison between different forecasting techniques' strengths, weaknesses and uses (Khalil, 2000).**

### *2.5.3 Technology and innovation roadmaps*

Actors in the national system of innovation use roadmaps to portray the relationships between science, technology and products. Roadmaps help identify gaps and opportunities in science and technology programs. The roadmapping process provides a way to identify, evaluate and select strategic alternatives to reach desired objectives (Willyard and McClees, 1987).

Kostoff and Schaller (2000) provide a taxonomy of roadmaps, discussing the roadmap process as expert, computer or hybrid-based. In an expert-based roadmap, a team of experts convenes, identifies and develops attributes for the nodes and links of the roadmap. The limitation is that only after the roadmap completion, the appropriate level of expertise will be realised.

Computer-based roadmaps are more objective and generate the network at all points in time simultaneously from the source database. The limitation is that large relevant databases and extracting computational approaches are yet to be compiled and developed. Hybrid-based roadmaps are a combination of the previous two roadmaps mentioned.

### *2.5.4 Technology audits*

Auditing is a tool used in the evaluation of an organisation's current condition or status. A technology audit is an analysis performed to identify the strengths and weaknesses of the technological assets; the aim is to compare these strengths and weaknesses to those of competitors (Khalil, 2000:273).

According to Ford (1988) a technology audit should provide the answers to following questions:

1. What are the technologies and know-how on which the business depends?
2. How does the company's technology position compare to that of its competition?
3. What is the life-position on which the organisation depends?
4. Where is the company's strength?
5. Is the company protecting its core competencies?
6. What emerging technologies (inter or intra) could influence its technological position?
7. What value does the customer of the organisation attach to the technology?
8. Does the organisation possess the necessary procedures and structures to exploit (inter and intra) technologies?
9. Does the organisation have some technological assets it can share with other organisations?
10. What emerging technology is changing market and customer profiles?
11. What social, political or environmental factors might hinder technological plans?

The technology auditor should analyse an organisation's internal technologies, map external and basic technologies, and identify technology gaps. Other tasks include reviewing technology strategies, timing into markets, consistency between core competencies, R&D, marketing, analysing collaborative organisational measures and reviewing technology transfer procedures (Khalil, 2000: 274).

# 3 Theoretical framework

This chapter provides the current theories, conceptual models, and deductions of new theoretical propositions, substantiated by references from real-world observation and past scholarship.

## 3.1 Current theories, models and methods applicable to study

### *3.1.1 Technological system with focus on South African nanotechnology*

In the previous section a number of innovation system approaches were mentioned, including those of the technology colony (De Wet, 2000), national system of innovation (NSI) (Buys, 2001) and technological system (Carlsson, Jacobsson, Holménb and Rickne, 2002). The author proposes combining the technology colony theory with the linear NSI model to form a technological system with South Africa as the focal point. Remember that technology is defined as people, knowledge and tools. Figure 3-1 and Figure 3-2 illustrate the De Wet-Buys model and the levels of analysis Carlsson, Jacobsson, Holménb and Rickne (2002:237).

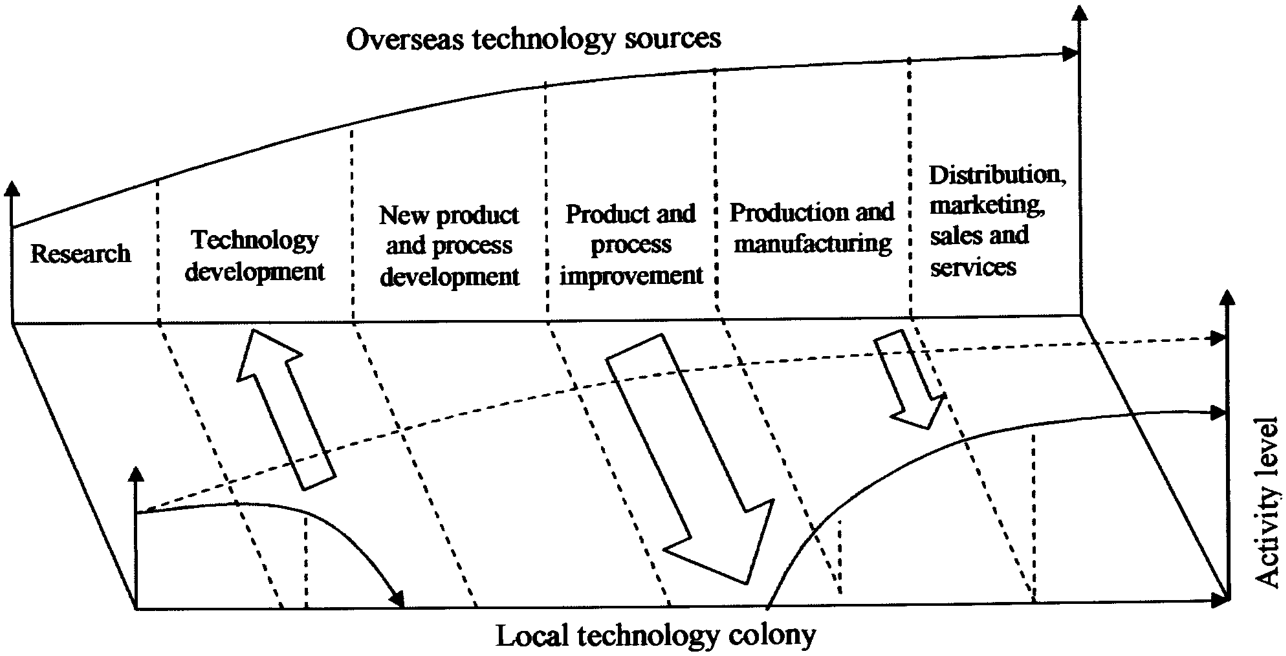



**Figure 3-1. Product life cycle model in the case of technology colony according to the stages declared by Buys (2001), illustrated against the backdrop of the product life cycle of a developed overseas country (De Wet, 2000).**

The new De Wet-Buys model combines the stages and strategies from the Buys (2001) and De Wet (2000) models. The reasons for the proposed model are:

- Basic and applied research from De Wet (2000) transforms into research and technology development from Buys (2001). Note that the Collins School dictionary defines 'fundamental' as 'basic' or 'central'.
- Design and development from De Wet (2000) are vague descriptions of the actual product life cycle activities. The technology development, new product and process development, and product and process improvement provide more quantifiable product life cycles.
- The De Wet (2000) model encompasses the bidirectional transfer of knowledge, technology, products and/or processes between the technology colony (South Africa) and international suppliers, buyers and competitors.
- Buys (2001) describes the building of capabilities through the dynamic nature of backward, forward or concurrent integration.
- Both models touch on the significance of building the capabilities through, for instance, information exchange between actors within the NSI and/or with international actors.

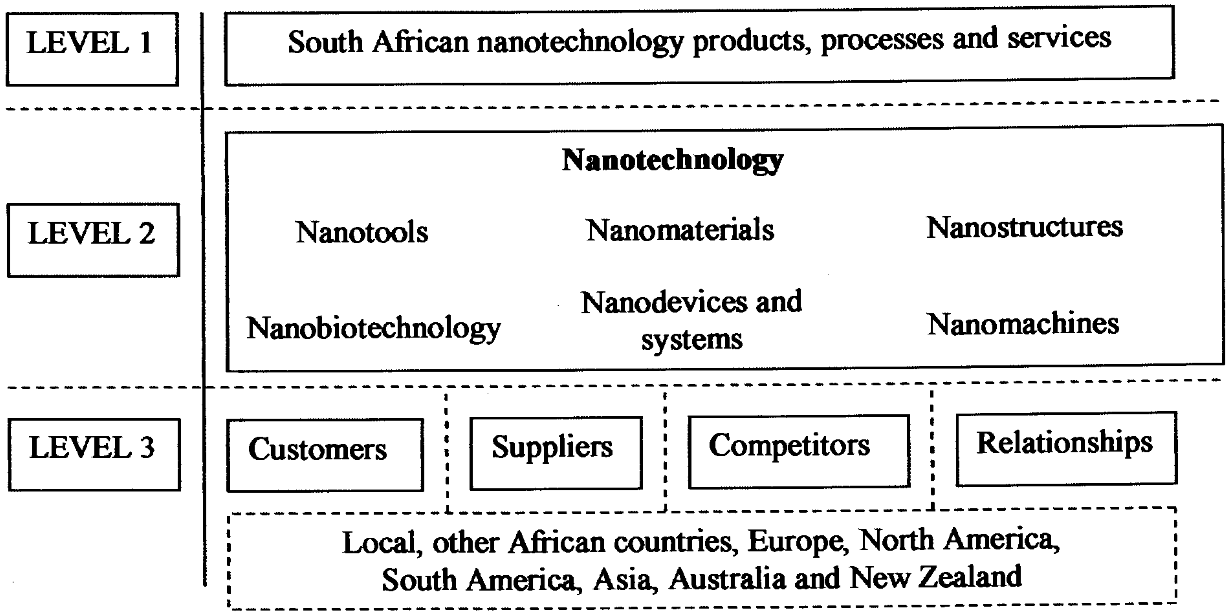



**Figure 3-2. Level of analysis of the South African Nanotechnology system of innovation**

Universities, firms and science councils, mentioned in SANi (2003a) (2003b) will participate in the assessment of the South African nanotechnology innovation.

Knowledge about the South African products, processes and services is unknown at this point. The only relevant products are those bought, researched, developed, manufactured, marketed and/or sold by the South African nanotechnology community. The emphasis is on South Africa as a developer of nanotechnology related products and services. The technologies are based on the classifications provided by Gordon (2002) and classified in terms of their market potential, value addition, complexity, time to market and risk (refer to Figure 3-3).

Figure 1-8 and Figure 1-9 confirm the time to market and number of firms involved in the nanotechnology segments. In Realis (2002) and NanoInvestorNews (2004) classified current international industries, similarly to that of Gordon (2002). Venture capitalists are renowned for investing in high-risk, increasingly growing and high investment return technologies and firms. As indicated by Figure 1-10, the development of nanobiotechnology and nanodevices might involve high risks, but contradictory to Gordon (2002) also have a good possibility of high investment returns.

The following conclusions are drawn from Figure 3-3:

- Raw materials: The segment possesses medium to medium-high market potential, with relatively low complexity, risk and time to market. Greatest number of organisations involved in the production, manufacturing and sales of raw materials (36%).
- Tools. The segment possesses medium-low to medium market potential, with low complexity, time to market and risk. Second most number of organisations involved in the manufacturing of tools (28%).
- Nanotubes and fullerenes. The segment possesses good market potential, with medium complexity, time to market and risk. Third most number of organisations involved in the research, design and production (17%).
- Structures. The segment possesses medium market potential, with medium complexity, time to market and risk. Fourth most number of organisations involved in the research, design and production of structures (5%).
- Devices and systems. The segment possesses medium-low market potential, with medium-high complexity, time to market and risk.

- Intelligent materials and machines. These segments possess both low market potential, with high complexity, time to market and risk.

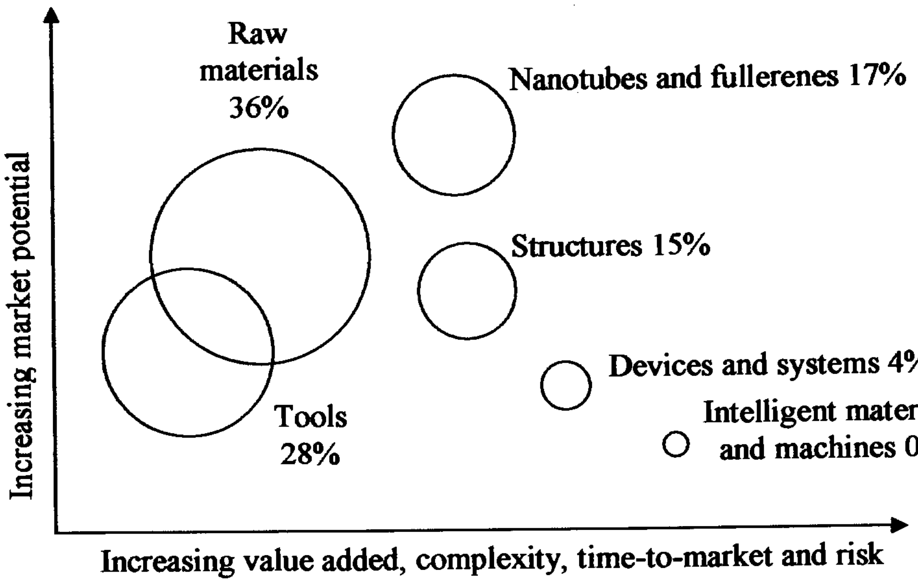



**Figure 3-3. Nanotechnology segments and worldwide percentage of firms involved in each segment (Gordon 2002). Note that the size of the circle depicts the number of organisations registered worldwide in each nanotechnology segment in 2002.**

The third level of analysis is the same as the competitive forces of Porter (1979). The research project uses the same seven countries as Oerlemans, Pretorius, Buys and Rooks (2003), which categorised the South African national and international relationships according to local, other African countries, Europe, North America, South America, Asia, Australia and New Zealand origins. The objective is to maintain uniformity with the Oerlemans, Pretorius, Buys and Rooks (2003) study and to draw correlations between the overall South African innovation and nanotechnology community.

As clearly seen in Figure 1-4, nanotechnology is defined as any technology in the range of about $10^{-6}$ to $10^{-12}$m (0.001nm to 1000 nm). Nanotechnology is the culmination of three diverging knowledge fields, namely solid-state engineering, biological research and synthetic chemistry. The scales are starting to intersect and cross-disciplinary efforts are becoming increasingly more productive (LuxCapital 2003). The nanotechnology system boundaries are thus in the range of $10^{-6}$ to $10^{-12}$m (0.001nm to 1000 nm). Personal interviews with Mr. Manfred Scriba confirmed that the choice of system boundaries was correct.

The fact that the size of the technology relates to the fields of knowledge, somewhat eases the task of dealing with the dynamic nature of the systems and identifying the actors. The inclusion of new sub-technologies may be classified in terms of its size, however, the categorisation of complementary technologies is still difficult. The scope of nanotechnology is enormous, and the possibilities of relationships with current and future technologies are unpredictable.

The same situation exists in terms of actors; the electronics industry and the synthetic chemistry researchers could implement nanotechnology incremental improvements in their designs.

A number of indicators measure the generation and diffusion of knowledge in an innovation system (refer to Table 3-1).

| Indicators of generation of knowledge | Indicators of the diffusion of knowledge |
|---|---|
| Number of patents | Timing or the stage of development |
| Number of engineers and scientists | Regulatory acceptance |
| Mobility of professionals | Number of partners |
| Technological diversity e.g. number of technological fields | Number of distribution licenses |

**Table 3-1. Examples of performance measures for an emerging technological system (Carlsson, Jacobsson, Holménb and Rickne (2002:243).**

For an immature innovation system, several measures may have to be combined, to sufficiently capture the performance of the entire system.

### *3.1.2 South African nanotechnology strategy formulation*

Primary formulation of a strategy will be with the aid of a SWOT analysis. The linear NSI (Buys, 2001), competitive forces (Porter, 1979), generic leadership and differentiation (Porter, 1988) and S-Curve (Nieto, Lopez and Cruz, 1998) (Khalil, 2000:83) (Moore, 1993) models provide secondary techniques for research instruments design and strategy formulation.

The secondary strategy-formulation techniques were chosen, because the author of the research project is not an expert in nanotechnology, nor an actor in the South African nanotechnology community. The strengths, weaknesses, opportunities and threats will be gathered directly from some of the South African nanotechnology experts and through investigation of other South African publications.

Table 3-2 shows the conceptual structure of a SWOT-analysis matrix. The advantage of the SWOT analysis is that one can match key external opportunities and threats, with internal strengths and weaknesses.

There are eight steps in the construction of a SWOT-analysis matrix (David 2001):

1. List the organisation's key external opportunities.
2. List the organisation's key external threats.
3. List the organisation's key internal strengths.
4. List the organisation's key internal weaknesses.
5. Match the internal strengths with external opportunities and record the resultant offensive strategies in the cell.
6. Match the internal weaknesses with external opportunities and record the resultant developmental strategies in the cell.
7. Match the internal strengths with external threats and record the resultant defensive strategies in the cell.
8. Match the internal weaknesses with external threats and record the resultant avoidance strategies in the cell.

| Always leave blank | Strengths – S | Weaknesses – W |
|---|---|---|
| Opportunities – O | Use strengths to take advantage of opportunities<br>Offensive/Aggressive strategies<br>e.g. Market penetration | Overcome weaknesses by taking advantage of opportunities<br>Developmental/Conservative strategies<br>e.g. Capability learning |
| Threats – T | Use strengths to avoid or overcome threats<br>Competitive strategy<br>e.g. Product diversification | Minimise weaknesses and avoid threats<br>Defensive strategies<br>e.g. Restructuring |

**Table 3-2. The SWOT-analysis matrix (David, 2001:206).**

Another interpretation of the SWOT analysis is formulating strategies, which capitalise on strengths, address weaknesses, maximise opportunities and minimise threats.

## 3.2 Hypotheses

The research project is explorative in nature, thus the formulation of hypotheses is rather limited. Figure 3-4 illustrates a proposed South African nanotechnology system against the backdrop of the proposed overseas nanotechnology sources' product life cycle activity level. The dotted arrow of the local technology colony illustrates what the activity levels should be or what the developed countries are performing.

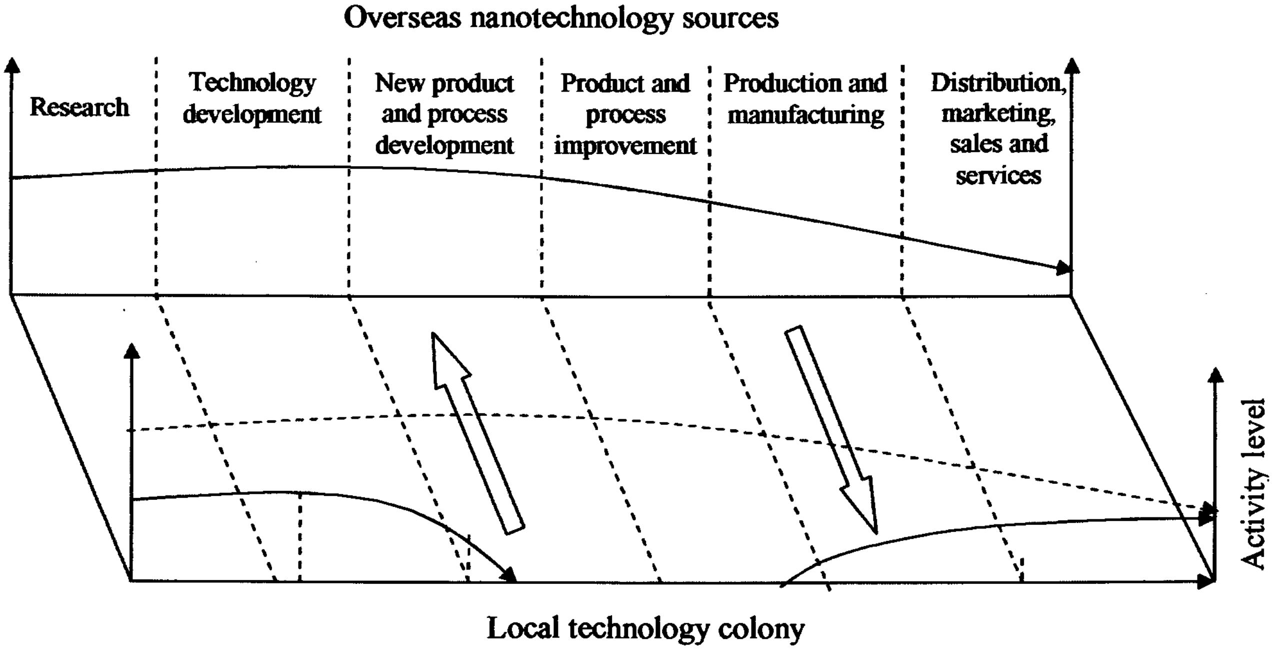



**Figure 3-4. Technological system of the South African nanotechnology system in comparison to overseas nanotechnology sources.**

Some propositions illustrated by Figure 3-4 are:

- Activities are centred at the beginning of the product life cycle, namely the research and technology development of nanotechnology knowledge.
- The industrialised countries currently tend to illustrate a gradual decrease of activities from research to selling within the product life cycle.
- Tertiary institutions, R&D institutions and minimally industry perform nanotechnology research and technology development.
- There are limited transfers of technology between local and international universities, firms and science.

- A small number of nanotechnology product and process imports are improved, manufactured and sold to local markets.

Some key hypotheses have been constructed regarding the South African nanotechnology system (refer to Table 3-3).

| Primary hypotheses | Description of primary hypotheses |
|---|---|
| H0 | Activities are centred on the beginning of the product life cycle, namely the research and technology development of nanotechnology knowledge |
| H1 | Activities are **not** centred on the beginning of the product life cycle, namely the research and technology development of nanotechnology knowledge |
| H2 | Nanotechnology already impacts current products and markets |
| H3 | Nanotechnology **does not** impact current products and markets |
| **Secondary hypotheses** | **Description of secondary hypotheses** |
| H0.1 | Universities perform the most research and technology development activities |
| H1.1 | Universities do **not** perform the most research and technology development activities |
| H0.2 | Funding and equipment are the biggest nanotechnology innovation hampers |
| H1.2 | Funding and equipment are **not** the biggest nanotechnology innovation hampers |
| H0.3 | Europe is the biggest source for international nanotechnology transfer |
| H1.3 | Europe is **not** the biggest source for international nanotechnology transfer |
| H2.4 | Nanotechnology products and processes will emerge within the next 5 years |
| H3.4 | Nanotechnology products and processes will **not** emerge within the next 5 year |
| H2.5 | Nanotechnology does possess better than good market potential |
| H3.5 | Nanotechnology does **not** possess better than good market potential |
| H2.6 | Nanotechnology will complement current technologies |
| H3.6 | Nanotechnology will **not** complement current technologies |

**Table 3-3. Research project hypotheses.**

Hypotheses H0 and H1 regard the South African nanotechnology system of innovation, focussing on the source of the activities (H0.1 and H1.1), the innovations hampers (H0.2 and H1.2), and the source of international technology transfers (H0.3 and H1.3).

Hypotheses H2 and H3 regard the impact of nanotechnology, focussing on the time of impact (H2.4 and H3.4), the market potential (H2.5 and H2.5) and the role of nanotechnology versus current technologies (H2.6 and H3.6).

The problem is that activities centre on the beginning and end of the product life cycle; no activities at product and process development occurs. A low amount of linkages exists between the research and technology development, and the production, manufacturing, distribution, marketing and selling of nanotechnology products, processes or services. The Nolte and Pretorius (2002) dilemma in terms of the technology domino effect still holds true.

# 4 Research design and methodology

This chapter discusses the research design, strategy and methodology followed in the research project in order to investigate the problem.

## 4.1 Research methodology

The research is a theory-application-based explorative study, with a survey and expert-opinion research design. The research project gathers and analyses data on the status of the South African nanotechnology system of innovation and on what the South African nanotechnology experts' perceptions of the future nanotechnology segments, innovation hampers and relationships are.

In purely explorative studies, where the purpose is to uncover as yet unknown variables in theory building, purely qualitative data might be adequate for the purpose (Page and Meyer, 2000:125). The research incorporates both qualitative and quantitative research methods. The combinational research approach serves the following purposes (Leedy and Ormrod, 2001:151):

- Description - To reveal the nature of current and future nanotechnology markets, products, innovation hampers and relationships.
- Interpretation - To enable the author to gain new insights into the South African development of nanotechnology, to develop new concepts or theoretical perspectives on nanotechnology innovation and to discover some of the strengths, weaknesses, opportunities and threats of/to the South African nanotechnology community.
- Verification - To allow the testing of the validity of certain assumptions, claims, theories or generalisations surrounding innovation in the South African nanotechnology system and other high-technology developments in South Africa.
- Evaluation - To aid in evaluating the effectiveness of current South African nanotechnology policies and strategies.

In January 2004, the research project author and the author of the CSIR baseline questionnaire, Mr. Manfred Scriba, reached an agreement regarding the bidirectional usage of data gathered, analysed and discussed in both studies.

The research project questions were ordinal and discrete in nature. The CSIR baseline study questions were nominal and discrete in nature. Judgemental samples – a non-random sample chosen by the researcher, which will provide the best information (Page and Meyer, 2000) – were chosen and due to the limited size of these samples, it was not appropriate to test these figures for significance. The purpose of an explorative study is not to extend the immediate set of data to the research population, but rather to uncover unknown research variables and relationships between these variables.

Due to the newness of nanotechnology and the lack of highly trustworthy and accurate statistics concerning market, product and technology evolution, the opportunities and threats in these areas were primarily induced through the iterative questioning of a South African nanotechnology expert panel. Existing data in terms of narrative and textual studies were used in the identification of current South African nanotechnology development. The degree of control was low and unstructured; the author conducted research on uncontrollable environmental variables.

## 4.2 Research strategy

Five simple elements formed the research project strategy (refer to Figure 4-1), whereby the research project questionnaire and CSIR baseline study questionnaire served as the primary data sources. The secondary data sources consisted of the SANi documentation and database, theoretical and nanotechnology textbooks, online publications and websites.

The CSIR baseline study attempted to gauge the amount of nanotechnology participation in South Africa. The goal was to analyse the products, industries and actors within the nanotechnology community, thus investigating the generation and diffusion of nanotechnology in South Africa. Three groups were questioned, namely South African universities, firms and science councils.

The research project used some of the data gathered through the CSIR baseline questionnaire as background information and analysed the level, focus and origin of nanotechnology activities in South Africa.

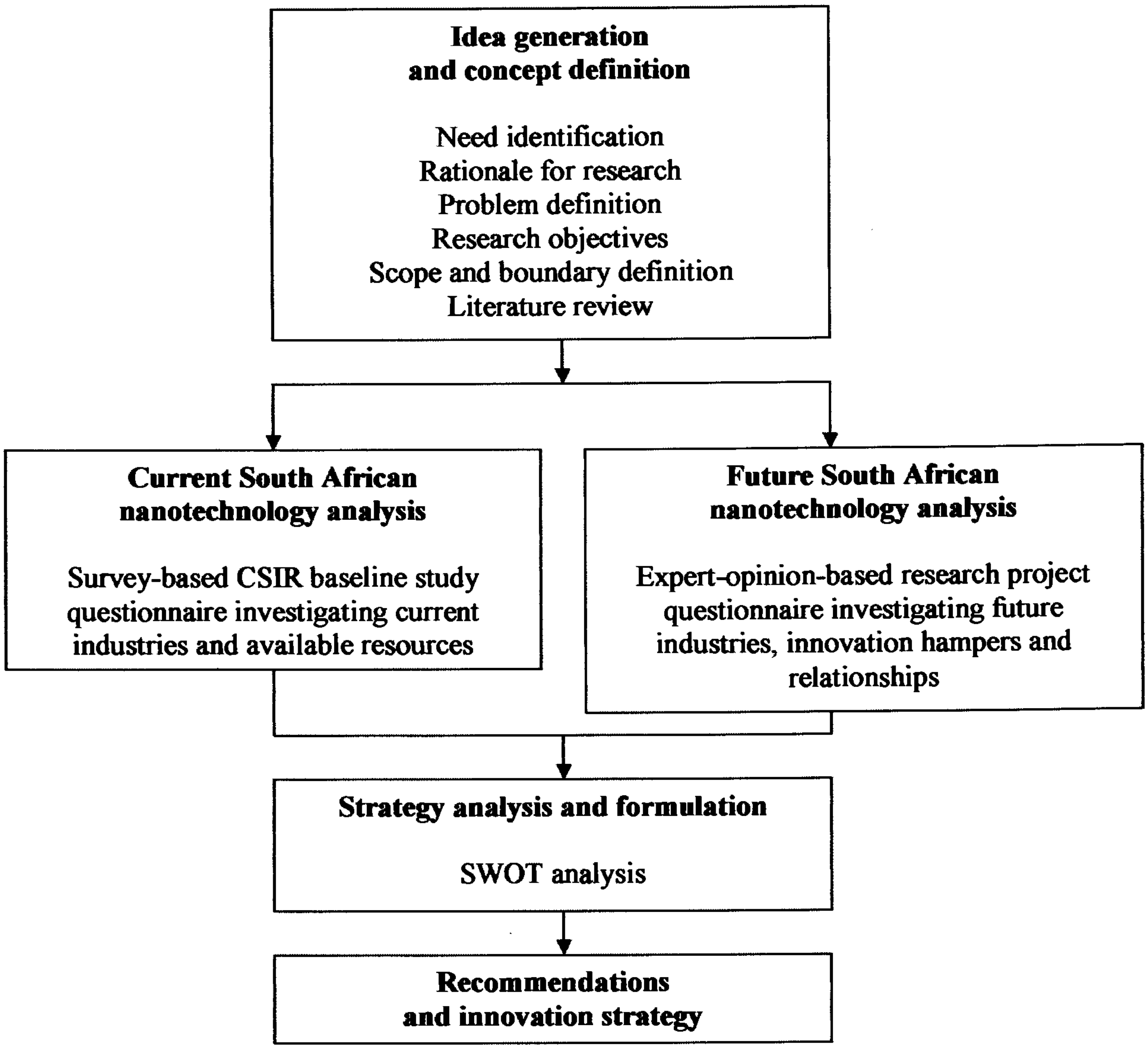



**Figure 4-1. Elements of the research strategy.**

As mentioned in Table 2-8, an expert opinion can provide inputs for high quality models, to forecast when identifiable experts exist, where data are lacking and modelling is difficult. The only difficulty, as stated, is to identify possible experts. Some conclusions from the literature review regarding the South African nanotechnology community were:

- SANi was in the process of organising a national baseline study. The study was supposed to start in 2003, but due to unforeseen and mostly disclosed reasons did not realise. The baseline study would identify the involvement, personnel, funding and equipment status of the South African nanotechnology community.

- The South African nanotechnology community is extremely small in comparison to those in other developed countries; the SANi database and documentation provided the contact details of all SANi members. The SANi documentation also provided the contact detail and experience of some South African nanotechnology experts. The obvious choice was to contact these experts, and try to get their commitment to the research project. The assumption was that the panel of experts were also contacted regarding the CSIR baseline study, and that it would thus be possible for them to spend a great amount of time completing questionnaires.
- The SANi documentation already provided some valuable information regarding the perceived strengths, weaknesses, opportunities and threats surrounding the South African nanotechnology community.
- Mr. Manfred Scriba would be an important facilitator in both the research project and the CSIR baseline study questionnaire.

A variety of data-gathering techniques exists, but the one chosen for the research project questionnaire was the Delphi technique. Delphi is a structured group-communication process, which allows for both individuals and groups to add value by answering a complex problem as stated by Helmer, Linstone and Turoff (2002).

Delphi consists of two or more rounds (Twiss, 1980):

1. Get information, tacit or codified, from a panel of experts. Gather the information though personal interviews, telephone conversations and questionnaires.
2. Determine amongst others, the average and standard deviation of the replies. Ask the same panel of experts to re-evaluate their or other experts' answers. Look for any information that might be unknown to some of the experts.
3. Analyse and recirculate all the answers and new information, and ask the panel to revise and recheck their answers.
4. If further iterations are necessary, follow the same procedures.

The reason why the Delphi method was chosen is that one can assemble participants' opinions collectively without bringing them into the same place or room, thus maybe reducing the overall research costs and minimizing possible direct conflict. The experts' opinion may then provide important insights into the future. The disadvantage of direct conflict is that it could lead to accepting or discarding other opinions without contemplation.

Delphi is inherently labour intensive and time consuming – each individual has to be contacted and his/her commitment gained towards the effort of resolving the complex problem. The questionnaires have to be unambiguous, understandable and of interest to the respondents. There is no guarantee that the questionnaire will be completed and returned.

## 4.3 Research instruments

### *4.3.1 Research project questionnaires*

Two structured questionnaires were designed to establish what the South African nanotechnology experts' perceptions of the future nanotechnology segments, innovations hampers (factors inhibiting innovation) and relationships are (refer to Appendix A.1 and A.2). The research project questions were ordinal and discrete in nature (similar to the example shown in Figure 4-2). Some of the questions had 5-point Likert scales. Table 4-1 illustrates the scale variables used.

| | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 |
|---|---|---|---|---|---|
| a. Variable 1 | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. Variable 2 | ☐ | ☐ | ☐ | ☐ | ☐ |
| c. Variable N | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. Other: | ☐ | ☐ | ☐ | ☐ | ☐ |

**Figure 4-2. Example of ordinal questions used by research project questionnaires.**

| Variable | | Scale used | | | | |
|---|---|---|---|---|---|---|
| Nanotechnology segments | Time to market | Now | 1-5 years | 5-10 years | 10-15 years | 15-20 years |
| | Market potential | None | Small | Medium | Big | Huge |
| | Disruptiveness | No change | Support | Complement | Control | Replace |
| | Complexity | Not complex | Not relatively complex | Relatively complex | Complex | Very complex |
| | Human resources | Nothing | Small | Medium | Large | Huge |
| Innovation hampers | | None | A little | Some | A lot | A great deal |
| Nanotechnology actors | | Disagree | Slightly disagree | No opinion | Slightly agree | Agree |

**Table 4-1. Ordinal scales used in the multiple-choice questions.**

The purpose of the nanotechnology segments' analysis was to explore the distribution of, order and relationships between the time to market, market potential, disruptiveness, complexity and human resources needed for each nanotechnology segment. The nanotechnology segments of Gordon (2002) were used and the questions asked were:

- How long before these nanotechnology segments start replacing the majority of other technologies in current applications, or create completely new technology applications?
- What is the market potential during the next 15 years for these nanotechnology segments – in terms of size and timing on return of investment, sustainable market growth, etc.?
- How disruptive are these nanotechnology segments the next 15 years to other known and familiar technologies? (What role will nanotechnology assume in relation to the technology it ultimately replaces or complements?)
- How complex are these nanotechnology segments to perform basic and applied research on, design, manufacture and market to a potential market? (Keep in mind the nanotechnology segments in relation to each other in terms of knowledge, time, skills, general public's perceptions, etc. needed)
- How much skilled human resources are needed to fully research, develop, manufacture, market and sell each of these nanotechnology segments?
- What is the current and future role (influence) of venture capital and government incentives in the research, development, manufacturing, marketing and selling of each of these nanotechnology segments? (Text field, not multiple choice)

The purpose of the South African nanotechnology innovation hampers' analysis was to identify the degree by which participants feel the hampers would have an impact on South African nanotechnology innovations, and what the greatest innovation hampers might be. Table 4-2 illustrates the innovation hampers used and the question asked was; how much does each of the following factors hamper nanotechnology innovation in South Africa by creating for instance uncertainty in investors?

| Innovation hamper | Description |
|---|---|
| Knowledge gap | Lack of information |
| Technology development | Disruptiveness and unfamiliarity |
| Lack of tools, equipment and techniques | Microscopes, simulation, etc. |
| Lack of qualified personnel | Insufficient training |
| Costs involved | Estimated costs too high |
| Uncertainty of net economic effect | Breadth, growth and impact of nanotechnology unsure |
| Insufficient funding | Lack of appropriate government or other external funding |
| Time to commercialisation | Too long estimated investment return periods |
| Regulations | Governmental or other legal restrictions |
| Supplier/Buyer adoption rates | When to switch from known products to new nanoproducts |
| Technology replacement | Potential for other newer nanoproducts to replace existing nanoproducts |
| Lack of collaborations | Relationships between innovative organisations and other institutions |

**Table 4-2. Innovation hampers used in research project questionnaire**

The purpose of the nanotechnology actors' analysis was to rank countries and investigate the relationships pertaining to the most important sources of buyers, suppliers, competitors and relationships. Table 4-3 illustrates the countries used, and the questions asked were:

- Do you agree that markets in these locations will be important buyers of nanotechnology for the next 15 years? (Consider buying power, size of the market, etc.)
- Do you agree that manufacturers in these locations will be important suppliers of nanotechnology for the next 15 years? (Consider current national strategies, breadth of potential industries, availability of resources, etc.)
- Do you agree that institutes in these locations will be important competitors in the nanotechnology global economy for next 15 years? (Consider the size and amount of potential competitive organisations and industries, etc.)
- Do you agree that South-Africa will have strong relationships with partners (private or public institutes) located in these areas in the nanotechnology global society for the next 15 years? (Consider countries with similar interests than South Africa or current good bonds with South Africa)

| Nanotechnology actors | Description |
|---|---|
| Local | South Africa |
| Other African countries | Namibia, Nigeria, Egypt, Kenya, etc. |
| Europe | United Kingdom, Germany, Netherlands, etc. |
| North America | Unites States of America, Canada, etc. |
| South America | Brazil, Argentina, etc. |
| Asia | China, Japan, India, etc. |
| Australia and New Zealand | No description needed |

**Table 4-3. Nanotechnology actors used in research project questionnaires.**

The purpose of the SWOT analysis was to determine the strengths, weaknesses, opportunities and threats of or to the South African nanotechnology system of innovation. The questions asked were:

- What do you perceive as the most important strengths and weaknesses of South African nanotechnology industries and tertiary institutions focussing on nanotechnology research activities? (Text field, not multiple choice)
- What do you perceive as the biggest opportunities and threats for South African nanotechnology industries and tertiary institutions focussing on nanotechnology research activities? (Text field, not multiple choice)

Comments regarding the choice of the nanotechnology segments, innovation hampers, actors and the overall questionnaire were asked after each section of the questionnaire.

### *4.3.2 Developing the CSIR baseline study questionnaire*

The primary objectives of the CSIR baseline study was to estimate the amount, focus and type of national nanotechnology participation together with the estimation of nanotechnology awareness and the necessary support in terms of knowledge, funding, personnel, partnerships and equipment (refer to Appendix B). The CSIR baseline study questions were nominal and discrete in nature.

If the South African institutions (universities, industry or science council) are aware of and active in developing and manufacturing nanotechnology, the following nanotechnology-related information was gathered:

- Product life cycle involvement – Estimate the amount of involvement in R&D, manufacturing, importing, selling, product and process development.
- Focus areas – Estimate the amount of involvement in identified nanotechnology segments (refer to Table 4-4).
- Funding sources – Estimate the amount of capital the nanotechnology community gained through:
  - Private funding mechanisms – Funding gained through private investors (venture capital).
  - Public funding mechanisms – Funding gained through public initiatives (government departmental initiatives like the DST science and technology grants).
  - Internal funding mechanism – Funding allocated within the organisation.
  - International funding mechanisms – Funding gained through international relations (FP6 initiative).
  - Science council and other sources – Funding gained through research grants (CSIR and NRF development programmes).
- Tertiary programmes and workshops – Estimate the amount and type of educational opportunities.
- Personnel and students allocation – Estimate the amount and demography of personnel, students and postdoctoral individuals.
- Networking and collaborations – Estimate the awareness, amount and origin of national and international collaborations.
- Equipment – Estimate the availability, type, state, amount and funding of nanotechnology-related equipment.

| Nanotechnology focus area | |
|---|---|
| Nanomaterials | Coatings |
| Nanobiotechnology | Fundamental research |
| Membranes | Atomic modelling |
| Drug delivery | Characterisation |
| Catalysis | Implemented some of the above technologies, outsourced others |
| Nanodevices | Other |
| Nano-emulsions | |

**Table 4-4. Nanotechnology focus areas of the CSIR baseline study questionnaire.**

The author of the research project was part of the team that created the CSIR baseline study questionnaire, gathered and analysed the data. The research project questionnaire and CSIR baseline study were separate due to some legal implications identified through personal interviews with Mr. Manfred Scriba.

Another reason for the separation was to keep both questionnaires as short as possible and avoid duplication. The South African nanotechnology community is small and extremely busy. The repetition of questions could result in the lack of answers due to participants stating that they would not have enough time to partake in the rest of the study. Participants could become irritated by the repetition of certain required answers, and frustrated by questionnaires that held no apparent benefits or opportunities for them.

# 5 Data gathered

This chapter provides the data gathered through the research project and CSIR baseline study questionnaire (refer to Appendix C).

## 5.1 Research project questionnaires

Selecting the participants was an experience in itself. The process of contacting, gaining commitment to, distributing and gathering the first-round research project questionnaires started in the end of May 2004, continuing for almost 8 weeks until the middle of July 2004. A success rate of 50% (16) was achieved, with 28% (9) not returning the questionnaires and 22% (7) unreachable. During this time, all the participants also received the CSIR baseline study questionnaire.

The second-round research project questionnaires were distributed, but only two participants replied. Telephone conversations with the participants confirmed that a second round of research project questionnaires would not be feasible, due to work obligations and the amount of time and information required in completing the CSIR baseline study questionnaire.

The participants possess a sufficient range of nanotechnology fields of expertise and are representative of the South African universities, industries and science councils (refer to Appendix C.1.1). Most participants were positive about participating in any nanotechnology study, but were either extremely busy, could not see the benefit of the questionnaire to their business or did not see themselves as having enough expertise to provide accurate answers to the majority of the questions.

### *5.1.1 Agreement with questionnaire nanotechnology segments*

Fifty-six per cent of the participants agree with the chosen nanotechnology segments. The nanotechnology segments' comments confirmed that nanotechnology is a broad definition and experts differ in their descriptions of the nanotechnology segments.

The comments serve as valuable information in the analysis of the data collected. Through the comments, one can make the preliminary conclusion that in trying to converge the opinions of all the participants would generate many segments. Arguably, this only creates more answers that are diverse. What would happen if you combine the perceptions of a hundred nanotechnology experts? All the experts have their own set of experiences and fields of interest, thus diverging opinions.

The goal is to illustrate a relationship between time to market, market potential, complexity or disruptiveness, rather than creating hundreds of segments. Some nanotechnology segments would take more time to research and develop because of increasing complexity (at either basic or applied research level), and many do not have the ideal market potential for South Africa. South Africa needs to support the best nanotechnology segments investments, in terms of timing and amount of investment return.

### *5.1.2 Nanotechnology segments*

The figures below illustrate the nanotechnology segments regarding time to market, market potential, disruptiveness and complexity (refer to Appendix C.1.2 for comments). The time to market for most nanotechnology segments skew towards 1-5 or 5-10 years, intelligent materials have a symmetric distribution around 5-10 years and machines skew towards 10-15 or 15-20 years.

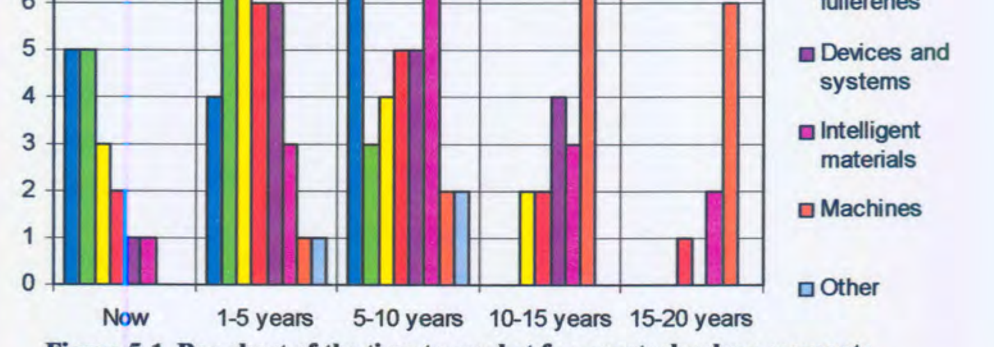



**Figure 5-1. Bar chart of the time to market for nanotechnology segments.**

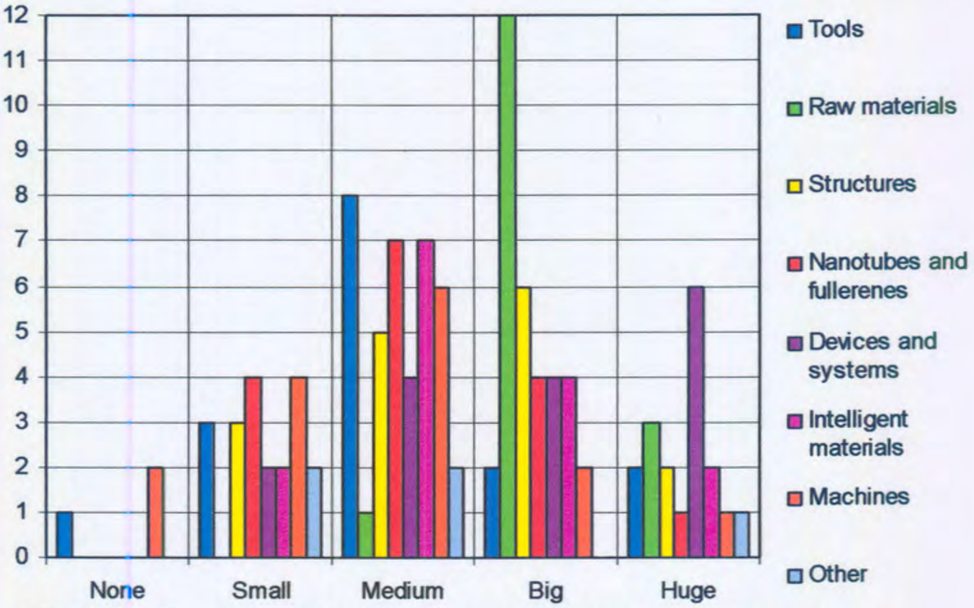



**Figure 5-2. Bar chart of the market potential for nanotechnology segments.**

The nanotechnology segments have a medium market potential, with structures medium to big, raw materials big, and devices and systems medium to huge market potential.

The question regarding disruptiveness unfortunately implemented a nominal scale rather than ordinal scale. The order of the scale was then changed to Complement, Support, No change, Control and Replace, thus creating a Likert scale. This changed the scale from a positive disruption towards a more negative disruption.

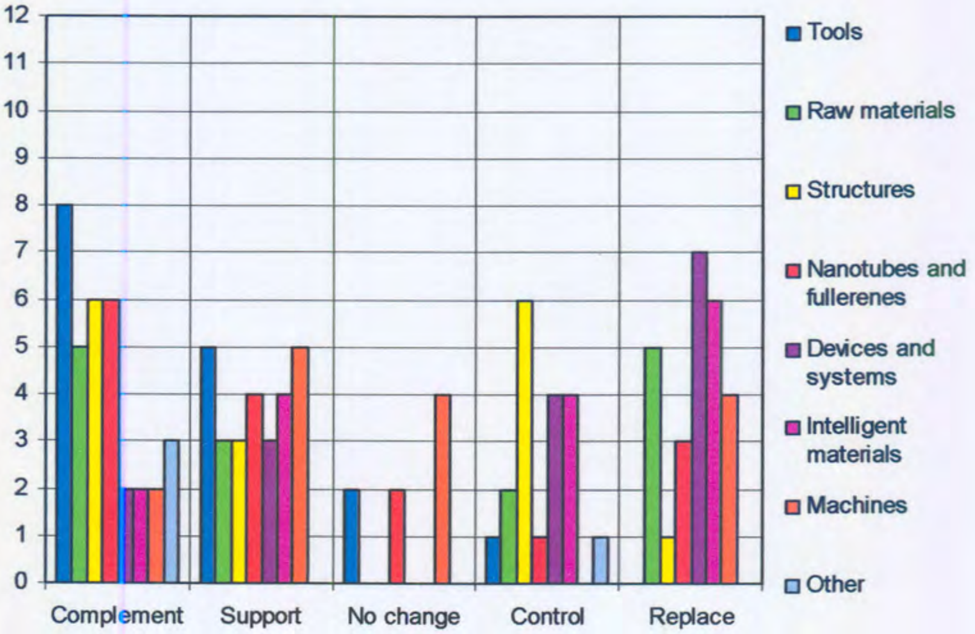



**Figure 5-3. Bar chart of the disruptiveness of nanotechnology segments.**

Nanotechnology segments will definitely have some impact on current technologies, with tools complementing and supporting.

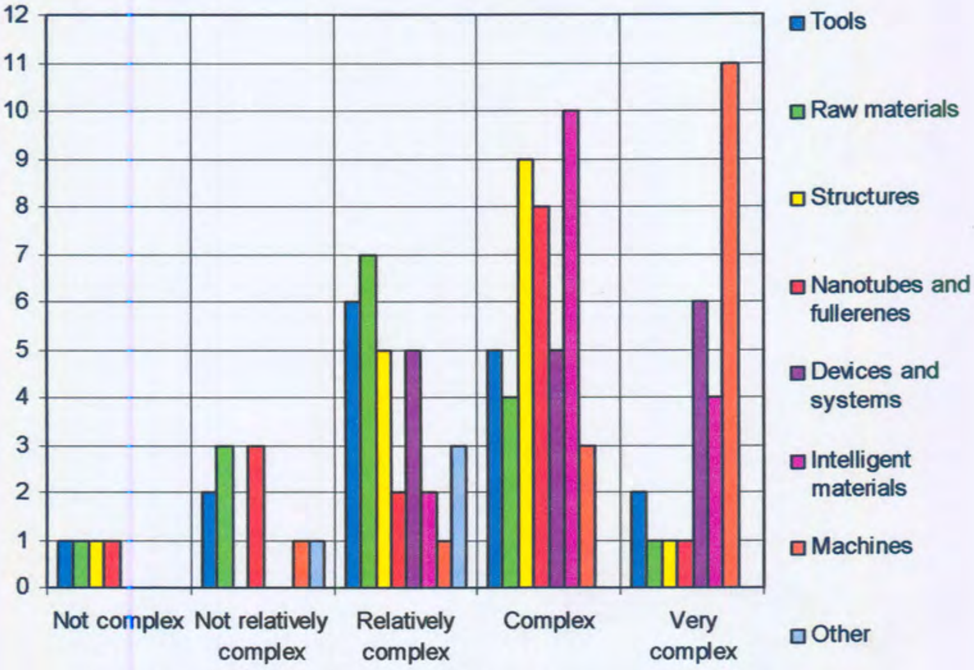



**Figure 5-4. Bar chart of the complexity of nanotechnology segments.**

The nanotechnology segments illustrate, in most cases, a steady increase in complexity with tools and raw materials relatively complex; structures, nanotubes and fullerenes complex; devices, systems and intelligent materials complex to very complex, and machines very complex.

### *5.1.3 Innovation hampers*

Almost all innovation hampers in the questionnaire, except South African regulations, supplier/buyer adoption rates and time for which nanotechnology core designs would remain leading designs, are significant. The insignificant hampers could probably be motivators to partake in nanotechnology developments.

Figure 5-5 illustrates the importance of some current and future nanotechnology hampers (refer to Appendix C.1.3 for comments).

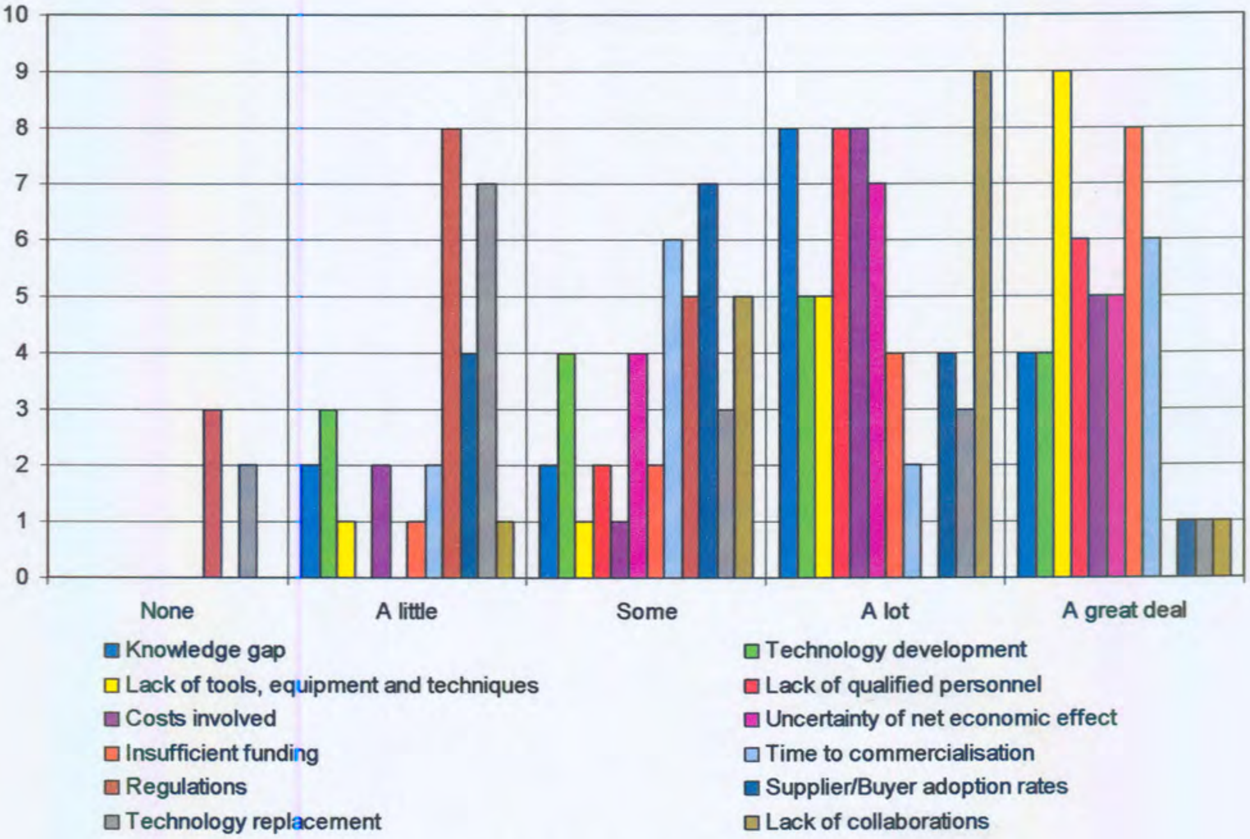



**Figure 5-5. Bar chart of the nanotechnology innovation hampers.**

The participants felt strong that a great majority of hampers are in the way of South African nanotechnology development, which also could be an indication of the negativity of the participants (and for that matter probably the nanotechnology community). Whatever the reason, universities, industry, government and science councils should attend to the innovation hampers.

As the comments indicated, some innovation hampers not mentioned were corruption, the misuse or mismanagement of funds, lack of stakeholder initiatives, the support from government and education of new scientists and researchers that would lead the development of nanotechnology.

### *5.1.4 Nanotechnology actors*

The figures below illustrate the nanotechnology actors regarding buyers, suppliers, competitors and relationships (refer to Appendix C.1.4 for comments).

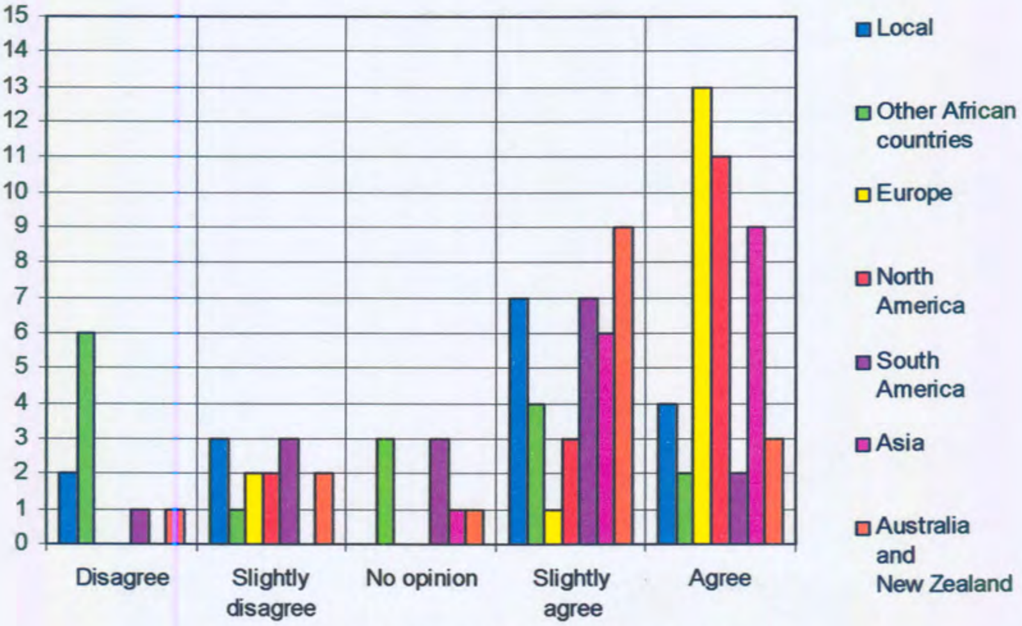



**Figure 5-6. Bar chart of the nanotechnology buyers.**

The participants perceive Europe, North America and Asia as the most important nanotechnology buyers and suppliers, followed by South Africa, South America, Australia and New Zealand. Other African countries, most probably, will not supply nanotechnology products and processes, but there are wide-ranging opinions regarding them as nanotechnology buyers.

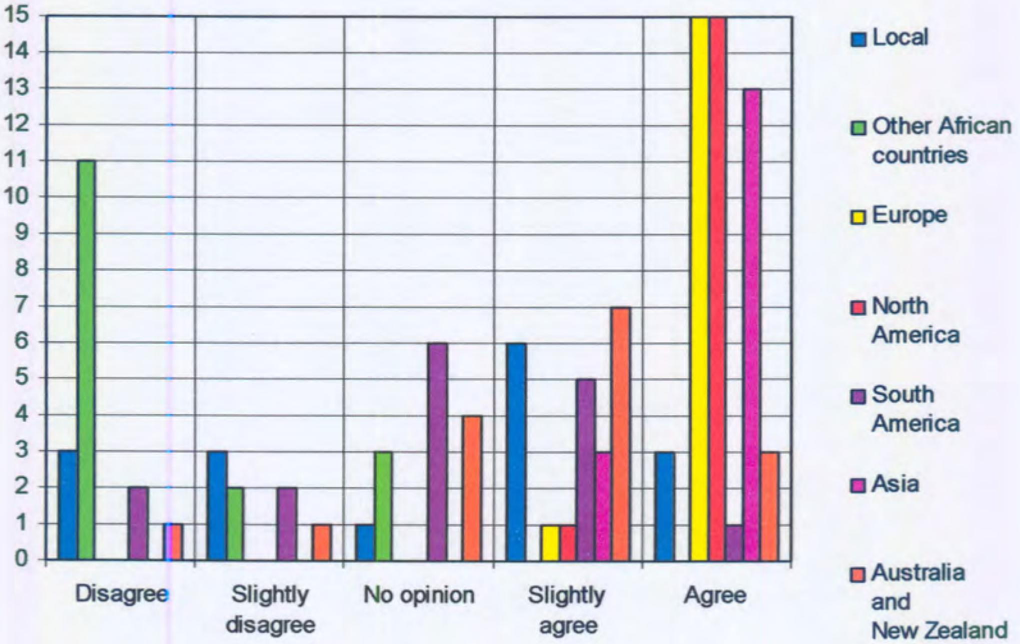



**Figure 5-7. Bar chart of the nanotechnology suppliers.**

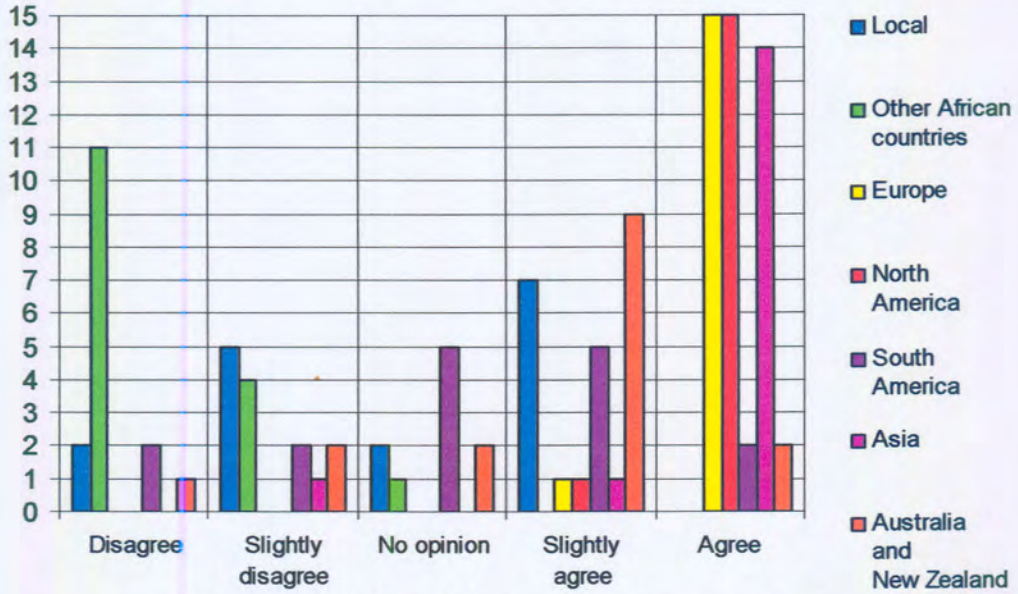



**Figure 5-8. Bar chart of the nanotechnology competitors.**

In terms of competitors, much the same picture is sculpted as the buyer and suppliers, with South Africa undecided and other African countries definitely not being competitors.

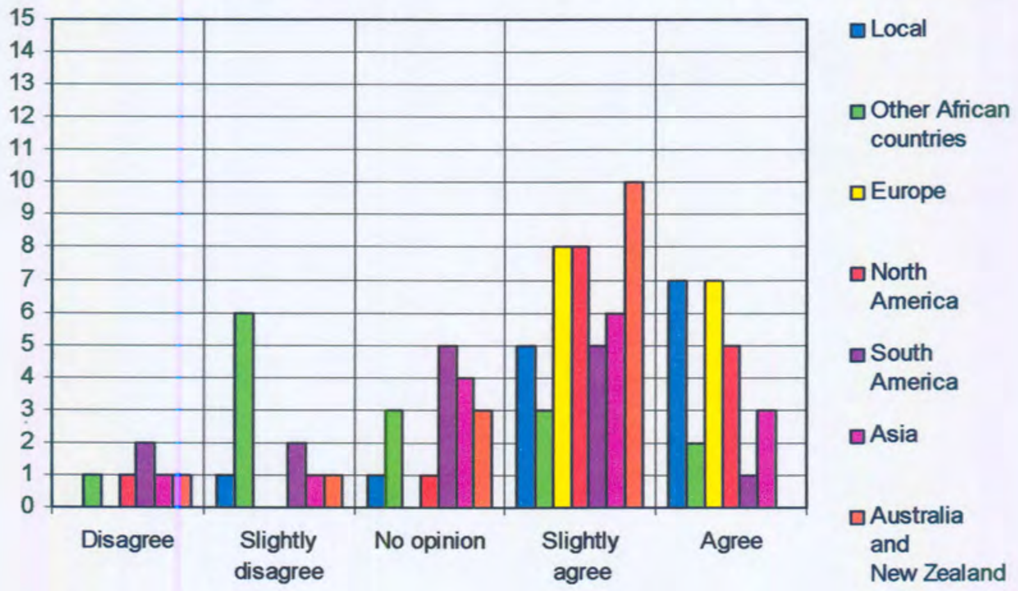



**Figure 5-9. Bar chart of the nanotechnology relationships.**

With the emphasis on building nanotechnology relationships, the most likely collaborations seem to be within South Africa, with Europe and North America (followed closely by Asia, Australia and New Zealand). Other African countries lean towards not being an important source of nanotechnology relationships.

### *5.1.5 SWOT analysis*

Initially the section was included just to get an indication of what the South African nanotechnology panel of experts felt the strengths, weaknesses, opportunities and threats are and would be. The four questions turned out to be the most thoroughly answered of the research project questionnaire. All the participants took the opportunity to mention all the aspects they felt would influence the development of nanotechnology in South Africa (refer to Appendix C.1.5).

In the initial conception of the question, it was thought that the perceived strengths, weaknesses, opportunities and threats would differ between university, industry and science council participants. The university and science council participants tend to emphasise strengths and weaknesses regarding:

- available nanotechnology equipment compared to other developed countries;
- the amount of funding available for nanotechnology R&D;
- the amount, quality and age of available researchers, and
- the existence of a nanotechnology knowledge gap.

The industry participants tend to focus more on strengths and weaknesses regarding:

- nanotechnology commercialisation and manufacturing aspects;
- technical nanotechnology support from universities and science councils;
- nanotechnology collaborations with other countries;
- nanotechnology product and process innovation leadership, and
- the availability of natural resources.

Table 5-1 and Table 5-2 illustrate the groupings, frequency and percentage of the strengths, weaknesses, opportunities and threats. There is no distinction between the opportunities and threats perceived by the university, industry and science council participants. The opportunities and threats concern:

- South Africa addressing environmental, human resource and social needs;
- South Africa exploiting natural resources;
- development of nanotechnology in developed countries, and
- unknown nanotechnology implications (social and economic).

| Key internal factors<br>Strengths (S) | Frequency | % |
|---|---|---|
| 1. South Africa possess selected nanotechnology-related knowledge, skills and experience | 6 | 0.207 |
| 2. South Africa possess cost-efficient human resource practices (research and labour) | 5 | 0.172 |
| 3. Good tertiary education standard | 3 | 0.103 |
| 4. Innovative human resources | 2 | 0.069 |
| 5. South African nanotechnology strategy in place | 2 | 0.069 |
| 6. South African nanotechnology community have strong collaborations | 2 | 0.069 |
| 7. Dedicated professional | 2 | 0.069 |
| 8. Talent, interest and vision | 1 | 0.034 |
| 9. Abundance of natural resources | 1 | 0.034 |
| 10. Good positioning in Africa | 1 | 0.034 |
| 11. Good facilitating by Manfred Scriba | 1 | 0.034 |
| 12. Developed countries developing pacing technologies creating learning opportunities | 1 | 0.034 |
| 13. Good stable financial system in place | 1 | 0.034 |
| 14. Manufacturing and logistic infrastructure | 1 | 0.034 |
| Total | 29 | 1.000 |
| **Weaknesses (W)** | **Frequency** | **%** |
| 1. Insufficient funding | 11 | 0.204 |
| 2. Insufficient amount of knowledgeable, skilled and experience human resources | 10 | 0.185 |
| 3. Insufficient equipment | 8 | 0.148 |
| 4. Limited knowledge in some nanotechnology fields – lack of access to information and . dependent on developed countries | 7 | 0.130 |
| 5. Fragmentation of nanotechnology community (geographically) | 4 | 0.074 |
| 6. Lack of nanotechnology focus areas | 3 | 0.056 |
| 7. Lack of blue sky R&D | 3 | 0.056 |
| 8. Not market driven | 2 | 0.037 |
| 9. Educational system not entrepreneurial development orientated | 1 | 0.019 |
| 10. Perception that local industry cannot compete with international competition | 1 | 0.019 |
| 11. Lack of government incentives | 1 | 0.019 |
| 12. Affirmative action | 1 | 0.019 |
| 13. Follower approach adopted by SA | 1 | 0.019 |
| 14. Lag behind developed countries in nanotechnology development | 1 | 0.019 |
| Total | 54 | 1.000 |

**Table 5-1. Strengths and weaknesses from research project questionnaire.**

| Key external factors<br>Opportunities (O) | Frequency | % |
|---|---|---|
| 1. Abundance of natural resources | 5 | 0.161 |
| 2. Increased support for social development (energy, environment and health) | 5 | 0.161 |
| 3. Increased support for centres of excellence development (innovation hub) Nanotechnology-related knowledge, skills and experience | 5 | 0.161 |
| 4. Untapped South African nanotechnology market | 4 | 0.129 |
| 5. Untapped international nanotechnology market | 3 | 0.097 |
| 6. Developed countries developing pacing technologies creating learning opportunities | 3 | 0.097 |
| 7. Increased support for skilled human resource development | 2 | 0.065 |
| 8. South Africa perceived as possessing cost-efficient human resource practices (research) | 2 | 0.065 |
| 9. South Africa possess production and manufacturing knowledge, skills and experience | 1 | 0.032 |
| 10. Increased social pressure to become industry leader | 1 | 0.032 |
| Total | 31 | 1.000 |
| **Threats (T)** | **Frequency** | **%** |
| 1. Pace of overseas nanotechnology development | 6 | 0.207 |
| 2. South African tendency to licence technologies | 5 | 0.172 |
| 3. International countries have greater resources available (human) | 5 | 0.138 |
| 4. Increased international competition | 4 | 0.138 |
| 5. Loss of knowledgeable, skilled and experience human resources (immigration, HIV/Aids) | 4 | 0.138 |
| 6. Incorrect allocation of South African funds | 2 | 0.069 |
| 7. Increase in nanotechnology social/ethical/legal implications | 2 | 0.069 |
| 8. Unawareness of increasing nanotechnology opportunities and threats | 1 | 0.034 |
| 9. South African crime rate | 1 | 0.034 |
| Total | 30 | 1.000 |

**Table 5-2. Opportunities and threats from research project questionnaire.**

## 5.2 CSIR baseline study questionnaire

The CSIR baseline study questionnaire circulated for a period of four weeks. Forty-seven participants replied to the CSIR baseline questionnaire – including 30 university departments, 13 firms and 3 science councils. The author of the research project was responsible for contacting, distributing and gathering the industry participants' questionnaires. Due to urgency in structuring the CSIR baseline questionnaire the author did not sufficiently review the final draft, before it was distributed. Alterations to the gathered information were made, to enable productive and accurate analysis.

Most of the industry participants were chosen from the SANi database; it was therefore expected that almost all the industry participants would be involved in some nanotechnology activities. Other firms in industries, which could be affected by the proliferation of nanotechnology, were contacted. Once again a 52% (9) response rate was achieved (regarding the industry participants), with 12% (2) not participating, 24% (4) unreachable and 12% (2) not returning the questionnaires. Another member of the CSIR baseline study team gathered data from mining firms. The CSIR baseline study involved almost all the South African universities, with the focus on identifying previously disadvantaged and underdeveloped universities.

### *5.2.1 Nanotechnology awareness, involvement and focus areas*

Seventy-two per cent of the participants stated their involvement in nanotechnology. The majority of nanotechnology activities are performed by universities followed by industry and science councils (refer to Figure 5-10).

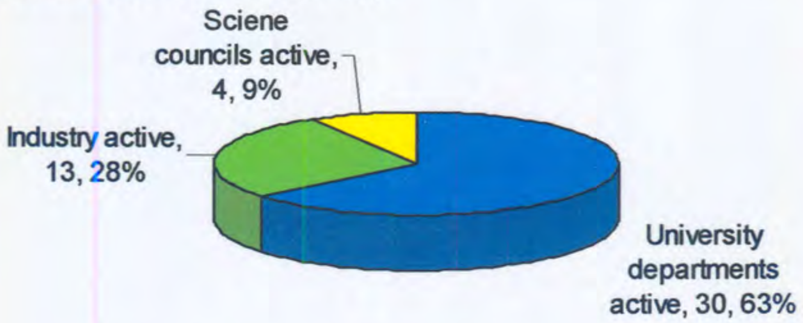



**Figure 5-10. Pie chart of the CSIR baseline-study participants.**

Participants have been active in nanotechnology-related activities for an average of 7.8 years, with a standard deviation of 2.44 years. Most participants stated that they were active in nanotechnology for 4 years. Many of the participants focus on the future and on leading some current industry or future nanotechnology field.

Figure 5-11 illustrates the decreasing trend from R&D to import. Participants are more involved in R&D development than any other nanotechnology product life cycle. Most of the institutions are involved in R&D (37%), followed closely by manufacturing technology (23%) and import (10%). Other categories (5%) are performing estimations, reading publications and just generally following the evolution of nanotechnology. Only a small number of institutions are looking at nanotechnology R&D in terms of process (10%) and product (15%) technologies. Only one participant fully commercialised a nanotechnology incorporating (or supported) product (refer to Appendix C.2.1 for statistical data).

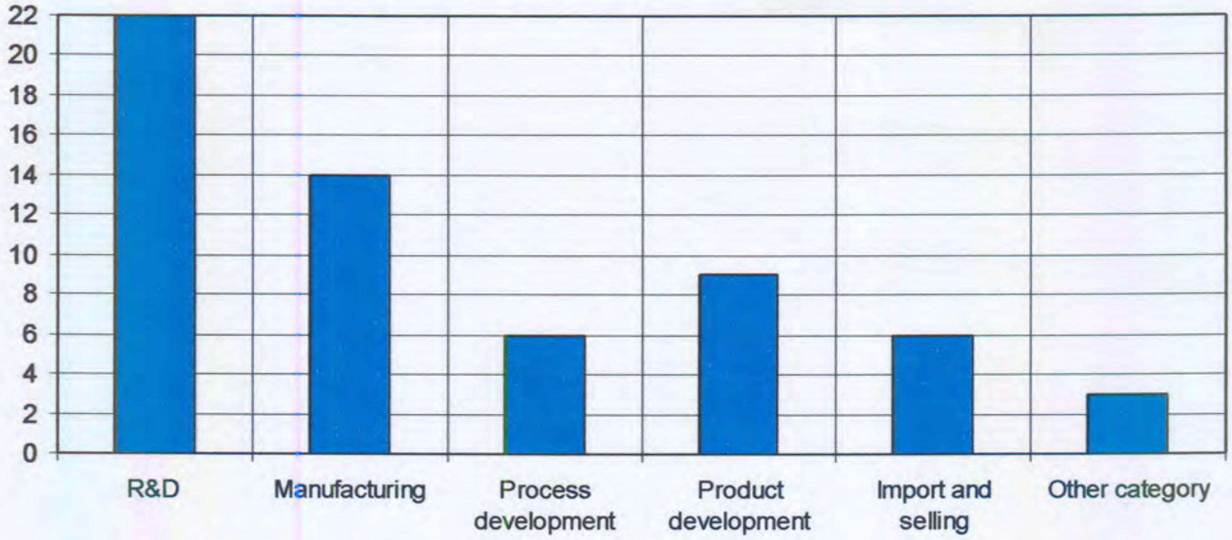



**Figure 5-11. Bar chart of South African nanotechnology involvement. Note that the number of participants, not the number of activities is plotted.**

An assumption is that the R&D and manufacturing fields consist mostly of basic (modelling and characterisation) and applied research (processing and small-scale manufacturing). According to the distribution, shown in Figure 5-11, the participants are almost equally involved through all the nanotechnology product life cycles, except that industry focus more on product development than anyone else does. Science councils did not indicate any import and selling involvement.

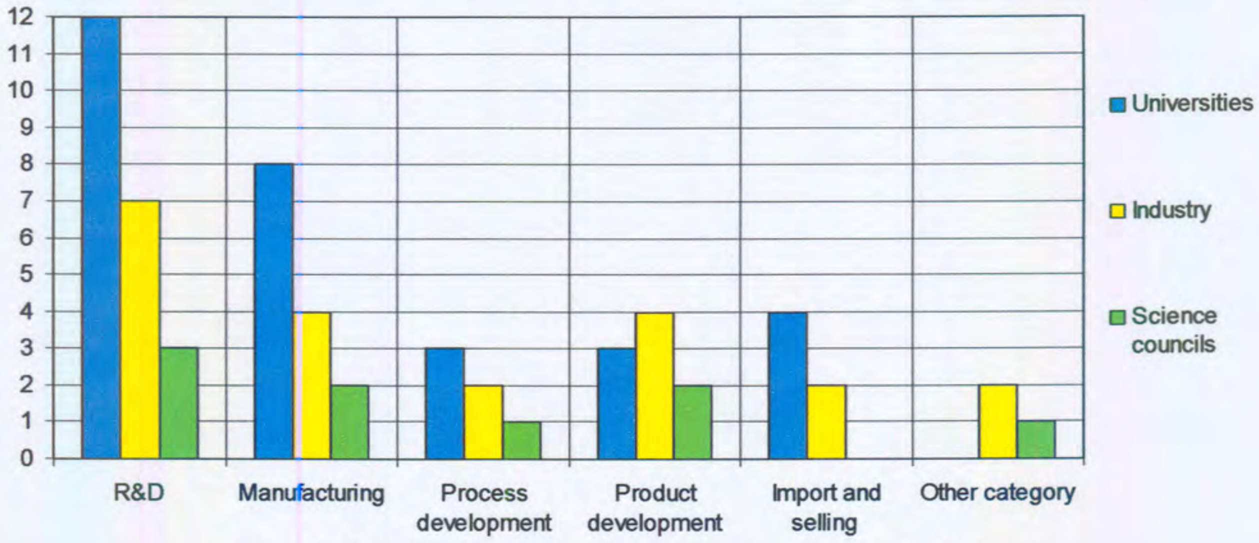



**Figure 5-12. Bar chart of nanotechnology involvement per institution.**

An estimate of R7,680,000 nanotechnology-related material was imported by four universities and two industry participants, ranging from raw materials, membranes to finished products. In the manufacturing of nanotechnology-related products, most participants merely estimated market values and referred to their work as being in the development stage.

Nanomaterials (18%), fundamental research (15%), characterisation (16%) and catalysis (10%) were identified as the primary nanotechnology focus areas (refer to Figure 5-13).

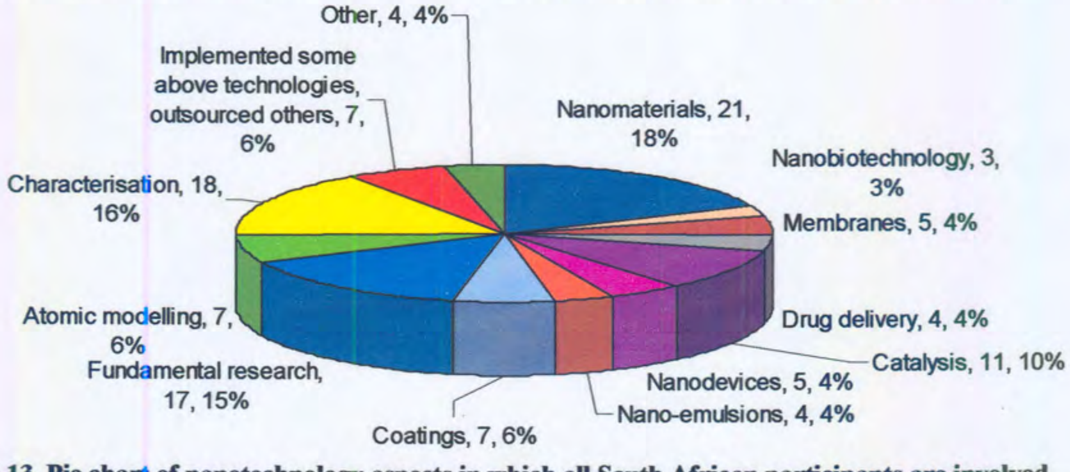



**Figure 5-13. Pie chart of nanotechnology aspects in which all South African participants are involved.**

Consequently South African nanotechnology participants are focussing on building a good basis for nanotechnology development and are exploring less complex nanotechnology segments.

Table 5-3 shows the number of South African participants patenting, publishing and implementing nanotechnology products, processes and services. Five patents have been registered and 217 nanotechnology-related articles or conference papers have been published.

| | Patentees | Publication writers | Nanotechnology implementers |
|---|---|---|---|
| Universities | 3 | 12 | 0 |
| Industry | 1 | 0 | 1 |
| Science councils | 0 | 1 | 0 |
| Total | 4 | 13 | 1 |

**Table 5-3. The number of South African nanotechnology participants producing technical outputs**

This might be an indication that participants are actively pursuing greater knowledge in nanotechnology fields, but have not yet been able to capitalise in the form of patenting or licensing.

## *5.2.2 Nanotechnology funding*

Unfortunately, the data was seen as confidential (or in some instances unknown) by most of the participants, who then only stated the sources of their funding and not the amount of funding received. Figure 5-14 illustrates the number of nanotechnology funding sources. Private, public and internal sources were the most utilised, with less emphasis on international and science councils' funding (refer to Appendix C.2.2 for statistical data).

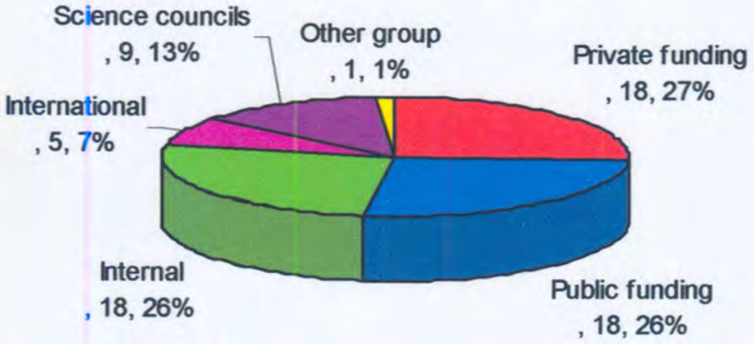



**Figure 5-14. Pie chart of South African nanotechnology funding sources.**

Universities, much more than industry and science councils, used public funding sources. Industry relied more on private and internal funding sources (refer to Figure 5-15).

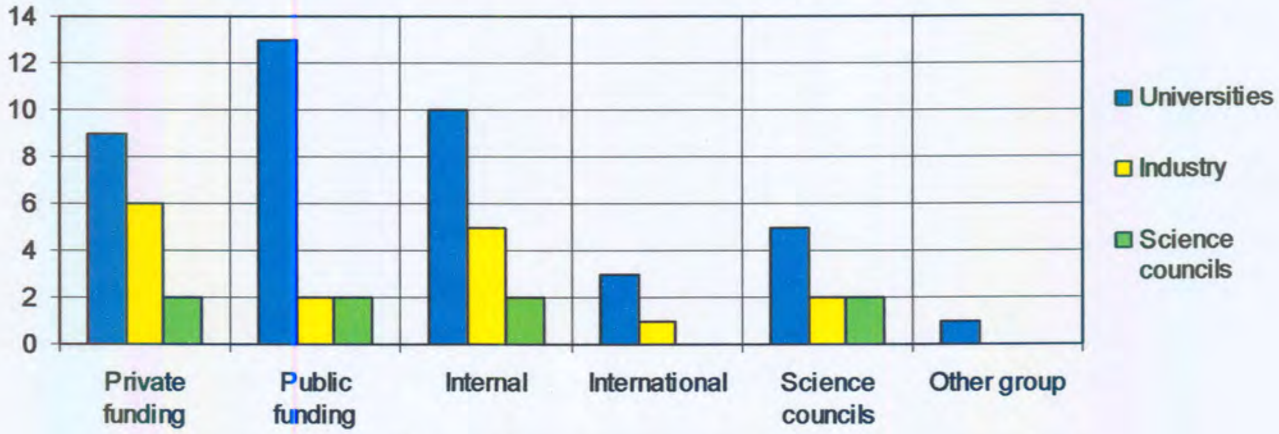



**Figure 5-15 Bar chart of South African nanotechnology funding sources per institution.**

Although only 7% of funding sources are international, the amount of funding, which could be available to South Africa, is endless. As expressed in SANi (2003:8), SANi possesses a strong link with FP6 (that could provide international funding) and government does have numerous arrangements with a number of international partners.

Many of the participants raised complaints on the role of government in nanotechnology developments and in retrospect it would have been helpful to gauge the amount of government incentives already used by the different institutions as funding mechanisms.

### *5.2.3 Nanotechnology personnel*

There are a third more male than female personnel, with almost an equal number of non-white and white, nanotechnology personnel (refer to Figure 5-16). Universities employ the most nanotechnology personnel (92), followed by science councils (30) and industry (23). The demographics per institution are similar to that in Figure 5-17 (refer to Appendix C.2.3 for statistical data).

Unfortunately, the spread of male, female, non-white and white personnel might contain some missing values – some participants merely stated the total amount of personnel. The figure does, however, provide an interesting insight into the development of nanotechnology human resources.

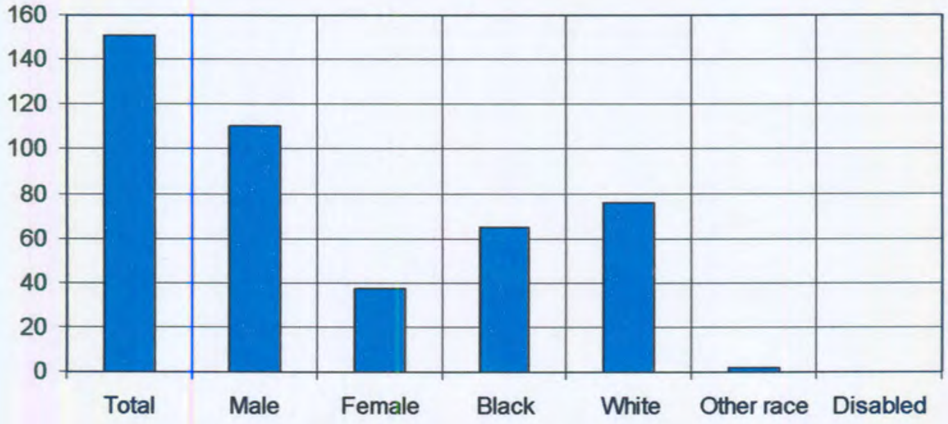



**Figure 5-16. Bar chart of the nanotechnology personnel demographics.**

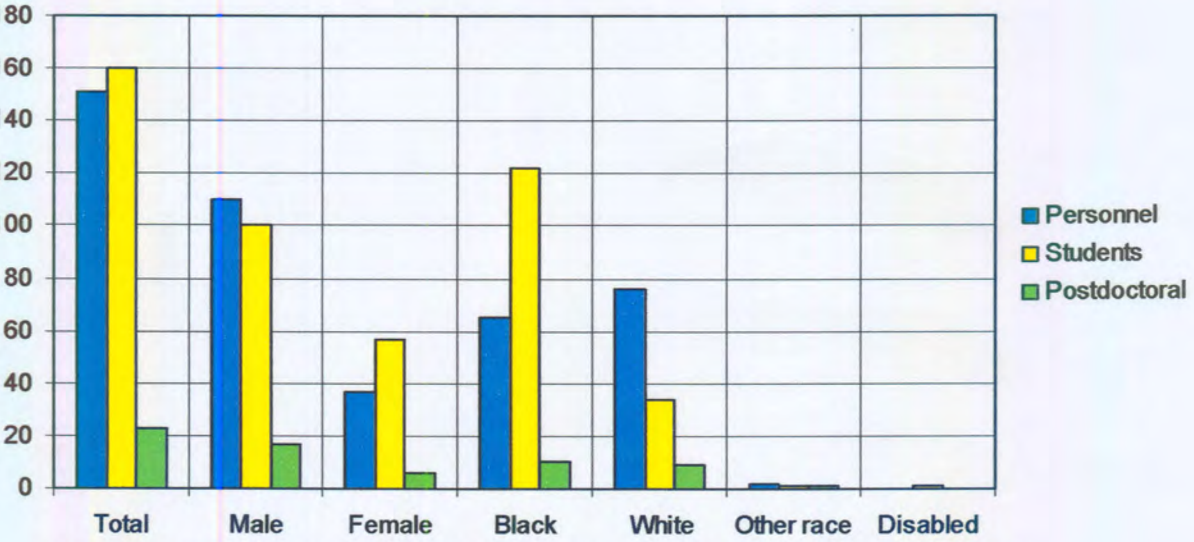



**Figure 5-17. Bar chart of the nanotechnology personnel demographics per institution.**

One of the issues brought up in the research project questionnaire is the aging nanotechnology research community – and how this could be a weakness within the South African nanotechnology community. This is clearly not the case, as shown in Figure 5-18. The majority of the personnel are between the ages of 20 and 30, with only 10% of the personnel over the age of 50.

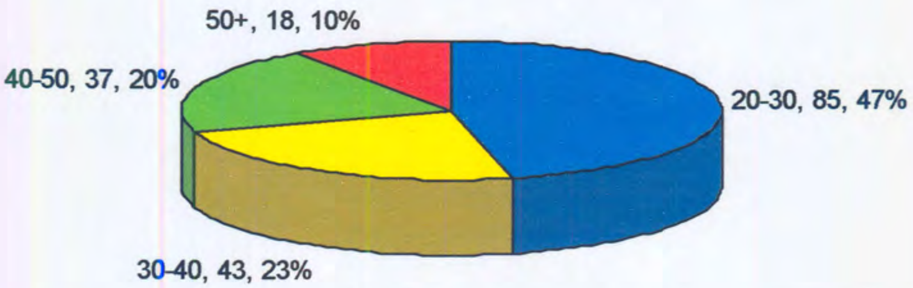



**Figure 5-18. Pie chart of South African nanotechnology personnel age.**

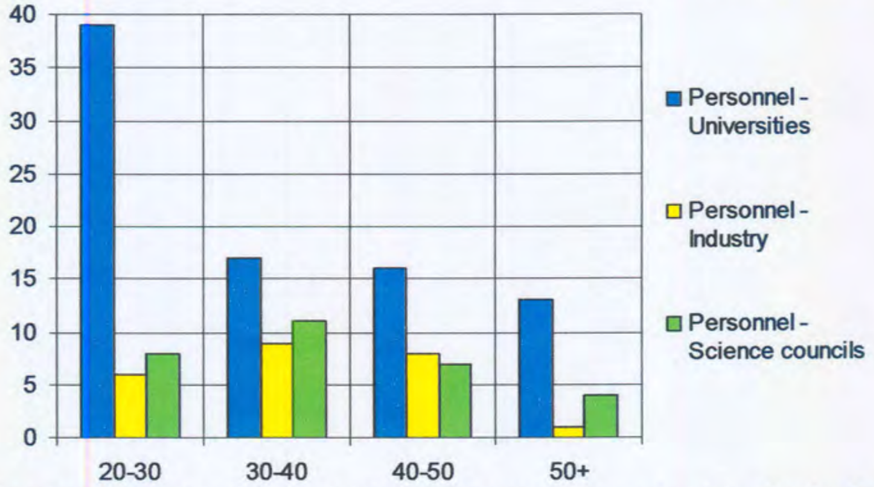



**Figure 5-19. Bar chart of South African nanotechnology personnel employed per institution per age.**

Universities employed more people between the ages of 20 and 30 (refer to Figure 5-19) than any other age, therefore it can be said that the nanotechnology community could have access to a range of young and diverse nanotechnology researchers. Industry and science councils possess a good distribution of young and old employees. Note that the total number of personnel might be slightly skewed because of the possible inclusion of students as personnel by many of the university departments. Students are able to act as junior lecturers, teaching and research assistants, while continuing their studies.

### *5.2.4 Nanotechnology education*

One of the primary drivers of technology development is building knowledge, skills and expertise. One way of evaluating this driver is through focussing on the number and level of South African nanotechnology educational curricula, and the amount and origin of the students enrolled in these curricula (refer to Appendix C.2.4 for statistical data).

One hundred-and-sixty-two students are enrolled in nanotechnology curricula (refer to Figure 5-20). Female nanotechnology students are more than female nanotechnology personnel and more than half of the male nanotechnology students. Non-white nanotechnology students are three times more than the white nanotechnology students.

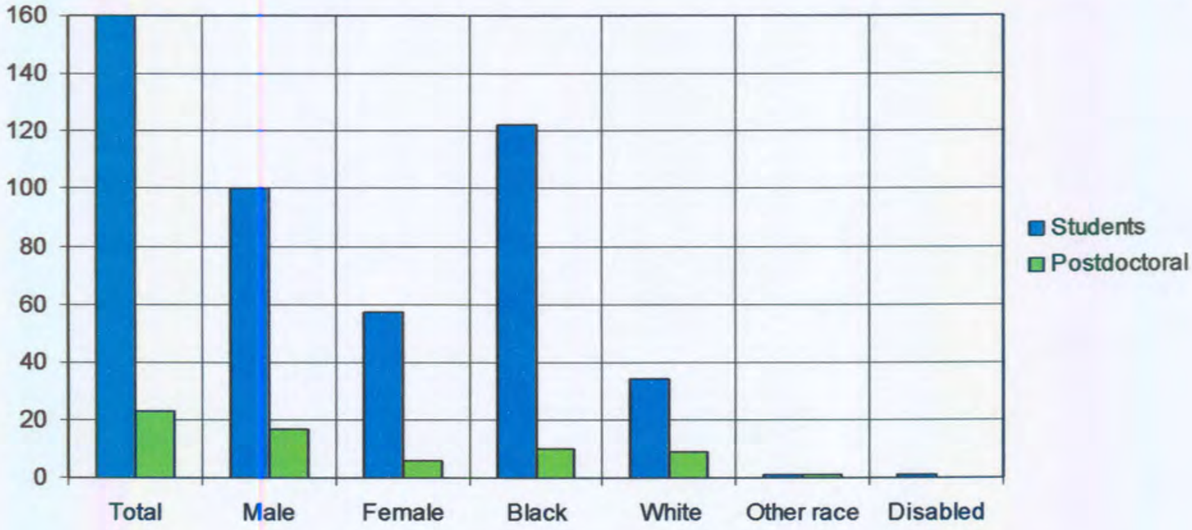



**Figure 5-20. Bar chart of South African nanotechnology students.**

Eighty per cent of the nanotechnology students are South African, with a small number of students from other African countries, Europe and Asia (refer to Table 5-4).

| Country | Number of students |
|---|---|
| Local | 132 |
| Other African countries | 13 |
| Europe | 9 |
| Asia | 8 |
| North America | 0 |
| South America | 0 |
| Australia and New Zealand | 0 |
| Total number of students | 162 |

**Table 5-4. The number of nanotechnology students studying at South African universities.**

As shown by Figure 5-21, almost 86% of all taught nanotechnology programmes are aimed at postgraduate level and an equal distribution of students (each about 30%) are enrolled in Honours, Master's and PhD programmes. Only 15% of Bachelor's students enrolled in nanotechnology subjects.

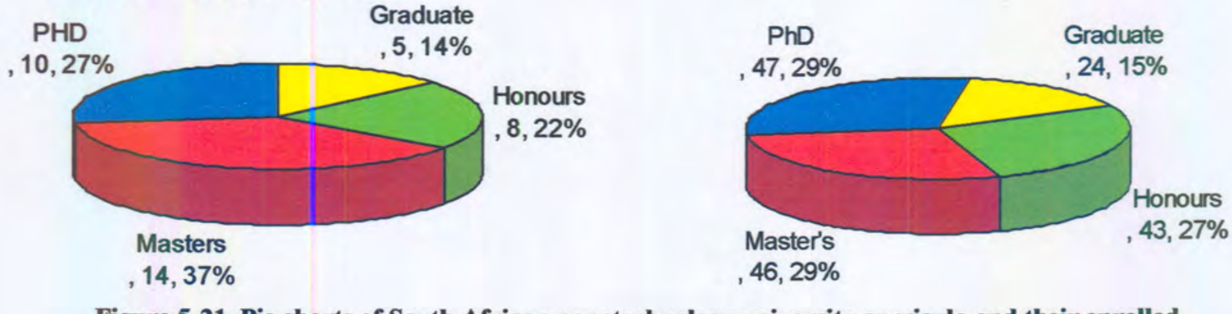



**Figure 5-21. Pie charts of South African nanotechnology university curricula and their enrolled students.**

A reason why less emphasis is placed on nanotechnology-centred curricula at Bachelor's level, might be due to the fact that universities initially rather invest in a broad field of expertise, like engineering, and then create the opportunity for specialising in nanotechnology fields at Honours, Master's and PhD level.

### *5.2.5 Nanotechnology networking and collaborations*

Collaborations are also an important aspect of knowledge, skills and expertise building. An organisation could allocate millions in developing knowledge. For many of the South African firms and universities, this might not be enough. Many might not have comparable budgets to those of European or North American industries, therefore the need exists for the organisations to collaborate with both national and international organisations (refer to Appendix C.2.5 for statistical data).

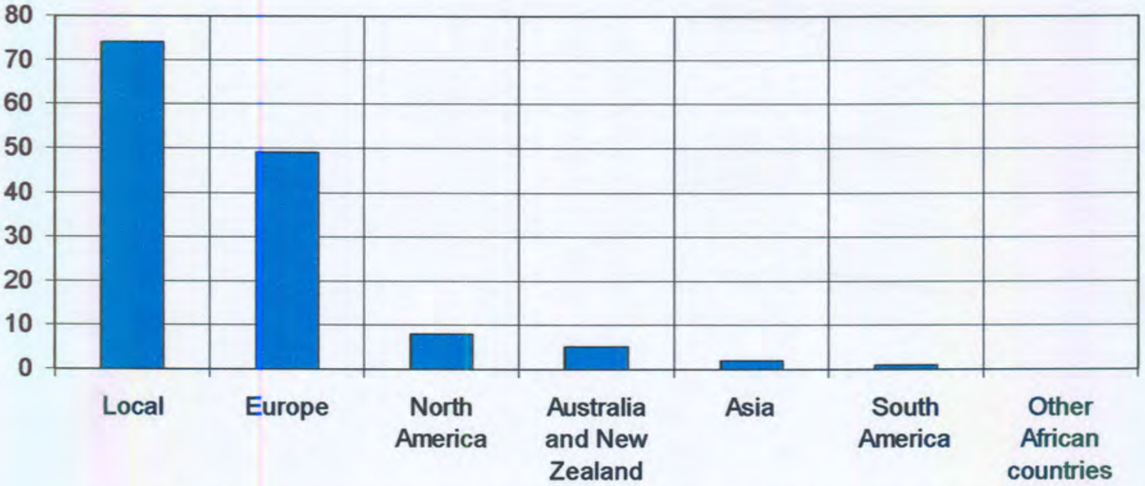



**Figure 5-22. Bar chart of the number of South African nanotechnology collaborations.**

The majority of nanotechnology collaborations are with firms and universities in Europe and with very few in North America, Australia and Asia (refer to Figure 5-22). Curiously, no collaborations were noted with other African countries, since 13 students originated from other African countries.

Figure 5-23 indicates the awareness of the nanotechnology community concerning their surroundings and their interaction with it. Participants did not engage in many government-arranged collaborations and possessed limited knowledge of other potential nanotechnology players.

Participants are aware of the existence of SANi (and most probably its activities), and do engage in national (74) and international (71) collaborations. Most of the national collaborators are groups from local universities. This might be an indication that most of the industry participants contract or fund a South African university in the development of nanotechnology knowledge and skills, and acquisition of nanotechnology equipment. Another proposition is that many of the employees of these industry participants, studied (or are still studying) at these universities.

Interestingly, the same amount of reliance on national and international collaborations was found. This contradicts the notion that international funding is not significant. Why would many South African institutions possess international collaborations, but not use these collaborations as funding mechanisms?

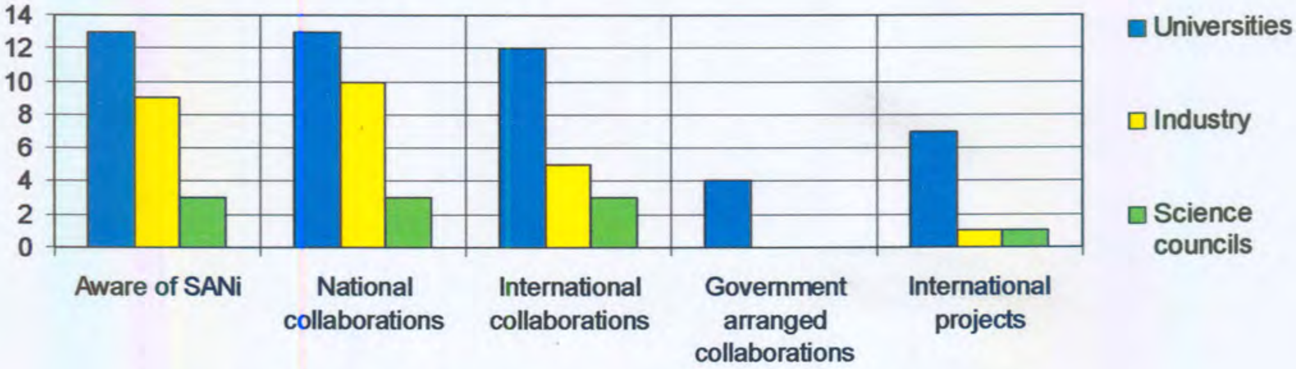



**Figure 5-23. South African nanotechnology relations and networking.**

International projects are an indication of both the willingness to learn and to build international relationships. Universities primarily support most of the international projects. Only four universities stated that the government arranged some of the collaborations.

### *5.2.6 Nanotechnology equipment information*

Figure 5-24 illustrates the condition of South African nanotechnology equipment and its comparison with modern equipment (refer to Appendix C.2.6 for statistical data). Half of the participants felt the equipment was in a good condition, with 36% and 13% feeling that their equipment was average or bad. In the comparison of the equipment, 31% felt their equipment was on the same standard as the rest of the world's, with 42% and 27% feeling that their equipment are slightly and much worse.


**Figure 5-24. Bar chart of South African nanotechnology equipment condition and comparison with modern equipment.**

Most of the equipment belonged to universities and science councils. Industry has limited access to state-of-the-art equipment. Most of the universities stated that their equipment was funded either internally or through public funding mechanisms such as THRIP and the NRF. Some of the universities stated that they did already allow the use of their equipment by other departments, universities and industry.

# 6 Data analysis

The chapter contains the analysis of the data gathered through the research project and CSIR baseline study (refer to Appendix D.

## 6.1 Research project questionnaires

### *6.1.1 Nanotechnology segments*

Figure 6-1 and Figure 6-2 illustrate the mean and standard deviation of the nanotechnology segment data (refer to Appendix D.1.1 for statistical data). The perceptions regarding future nanotechnology segments are:

- The segments increase almost linearly in time to market, from 1-5 years to 10-15 years time to market, with raw materials expected the earliest and machines expected the latest. Note that the time to market for machines (10-15 years) differs greatly from the other segments (between 1-5 years to 5-10 years), indicating that machines might still be very much a futuristic concept.
- The segments have medium to big market potential, with raw materials, devices and systems having the most and machines having the least.
- Tools, nanotubes and fullerenes are more complementary, with devices, systems and intelligent materials more replacing. The spread of answers between complementary and replacing for raw materials, structures and machines shifts the averages of these segments towards no opinion.
- The segments increase almost linearly in complexity from relatively complex to very complex, with raw materials the least complex and machines the most complex. Again note that the complexity, as with the time to market, for machines (very complex) differs greatly from the other segments (between relatively complex to complex), confirming that machines might still be a futuristic concept.

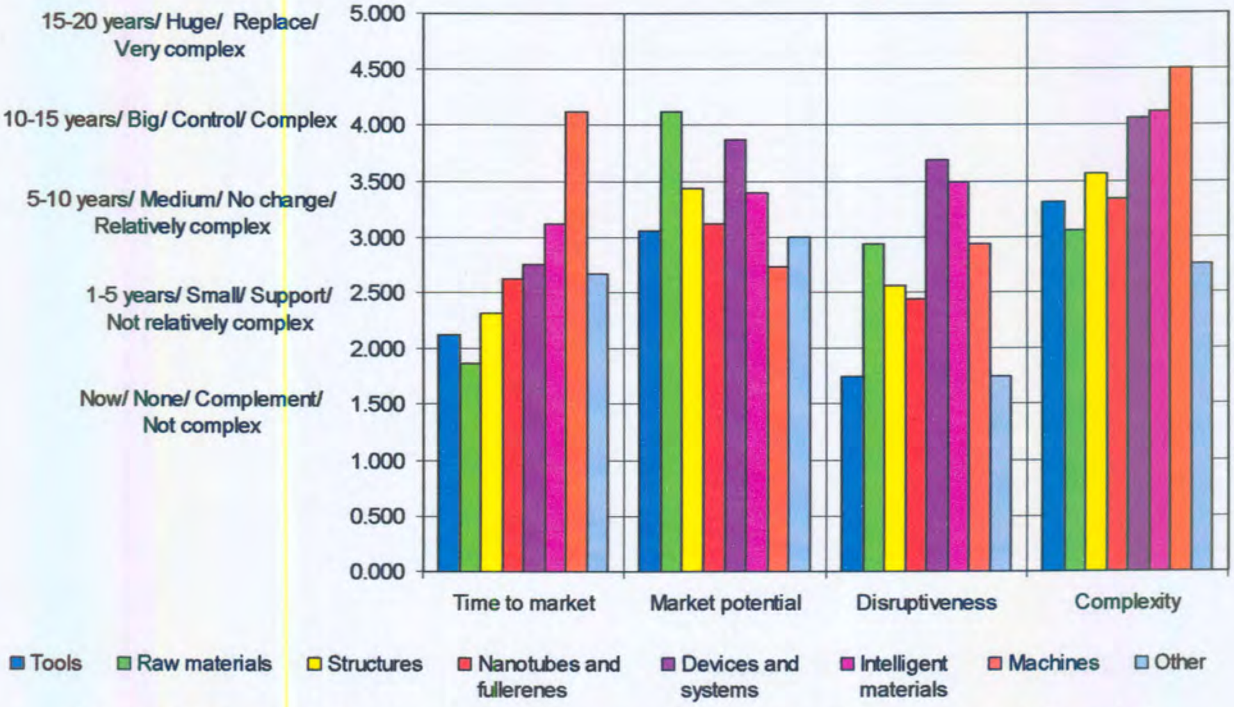



**Figure 6-1. Bar chart of the nanotechnology segments' mean regarding time to market, market potential, disruptiveness and complexity.**

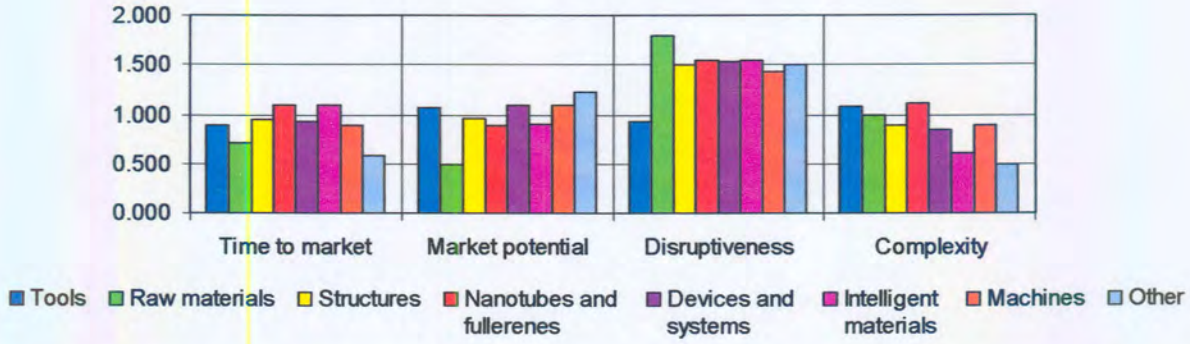



**Figure 6-2. Bar chart of the nanotechnology segments' standard deviation regarding time to market, market potential, disruptiveness and complexity.**

The change in the disruptive scale caused about a 0.400 increase in the standard deviation. The standard deviation regarding the raw materials' time to market (0.719) and market potential (0.500), the intelligent materials' complexity (0.619) and the tools' disruptiveness (0.931) indicated a relative agreement between participants in these areas. Interestingly the disruptiveness of raw materials has the highest standard deviation, thus the participants disagreed whether raw materials would fulfil a complementary or replacing role.

Referring to hypotheses listed in Table 3-3, based on empirical data, some conclusions are drawn:

- Tools, raw materials structures, nanotubes and fullerenes are most likely to emerge within the next 5 years supporting H2.4; devices, systems, intelligent materials and machines ,however, are most likely to emerge in 5 to 15 years supporting H3.4.
- All the nanotechnology segments possess a medium to big market potential supporting H2.5
- Tools, nanotubes and fullerenes will be more complementary, supporting H2.6, and devices, systems and intelligent materials will be more replacing, supporting H3.6.

Because only two participants answered the second questionnaire, the data was considered insignificant and not analysed. However, two conclusions that could be drawn from the answers are:

- Tools, raw materials, structures, nanotubes and fullerenes require a medium amount of skilled human resources to fully research, develop, manufacture, market and sell, while devices, systems, intelligent materials and machines require a huge amount of skilled human resources.
- The South African government will have to support research and development until feasible nanotechnology applications are generated, at which point venture capital would play a role in the exploitation of these nanotechnology incorporating products, processes and services.

Figure 6-1 hints at the correlation between the time to market and complexity of the nanotechnology segments. Figure 6-3 illustrates this possible positive linear correlation between time to market and complexity. Surprisingly, Figure 6-3 also shows a slight positive correlation between market potential and disruptiveness.

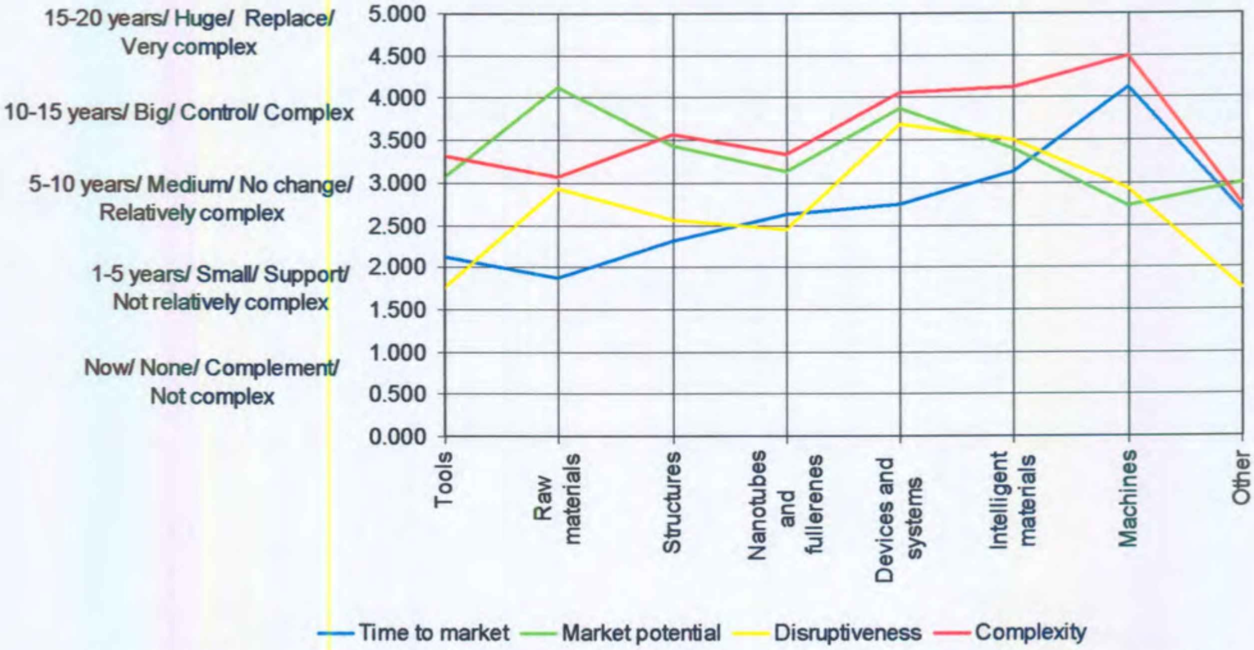



**Figure 6-3. Interaction plots for nanotechnology segments' mean regarding time-to-market, market potential, disruptiveness and complexity.**

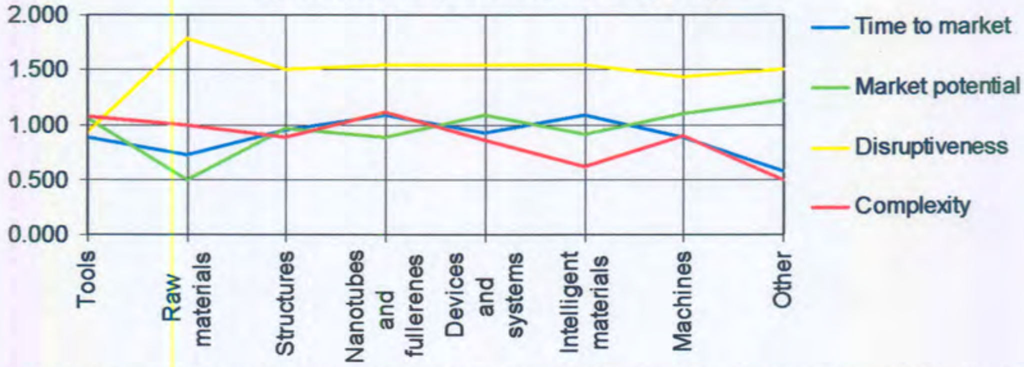



**Figure 6-4. Interaction plots for nanotechnology segments' standard deviation regarding time to market, market potential, disruptiveness and complexity.**

As stated earlier, the data is ordinal and discrete in nature, thus mathematically only cross-tabulations, instead of Spearman correlations may be implemented in investigating relationships between the variables. The summation of several ordinal variables into combined continuous ordinal variables or bigger sample sizes overcome this obstacle (Page and Meyer, 2000:146). Therefore, the time to market, market potential, disruptiveness and complexity data of each segment were summated, to construct continuous time to market, market potential, disruptiveness and complexity ordinal variables.

Table 6-1 confirms the correlation between time to market and complexity. There exists a relatively strong positive correlation between time to market and complexity (0.471) and interestingly enough a relatively strong negative correlation between time to market and market potential (-0.426).

These correlations indicate that as the complexity increases so does the time spent in the research, development, manufacturing, marketing and eventual time to market. The increase in time to market leads to a decrease in market potential. The reason for the last stated correlation might be due to a short-term perspective of when a return of investment is expected. If the time to market is too long, investors might perceive the segment as not having great short-term market potential and then would wait for the entry of dominant designs into the market before investing?

| Spearman correlation | Variable | Time to market | Market potential | Disruptiveness | Complexity |
|---|---|---|---|---|---|
| Time to market | Correlation Coefficient | 1.000 | -0.426** | 0.163 | 0.471** |
| | Sig. (2-tailed) | 0.000 | 0.000 | 0.085 | 0.000 |
| | N | 115 | 113 | 112 | 113 |
| Market potential | Correlation Coefficient | -0.426** | 1.000 | 0.147 | -0.061 |
| | Sig. (2-tailed) | 0.000 | . | 0.119 | 0.521 |
| | N | 113 | 115 | 113 | 113 |
| Disruptiveness | Correlation Coefficient | 0.163 | 0.147 | 1.000 | 0.115 |
| | Sig. (2-tailed) | 0.085 | 0.119 | . | 0.227 |
| | N | 112 | 113 | 114 | 113 |
| Complexity | Correlation Coefficient | 0.471** | -0.061 | 0.115 | 1.000 |
| | Sig. (2-tailed) | 0.000 | 0.521 | 0.227 | . |
| | N | 113 | 113 | 113 | 115 |

**Table 6-1. Spearman correlation coefficient of nanotechnology segments' time to market, market potential, disruptiveness and complexity. ** Correlation is significant at the 0.01 level (2-tailed).**

As mentioned previously, one of the objectives of the research project is to explore future nanotechnology segments and link them with current nanotechnology activities. The CSIR baseline study questionnaire includes nanotubes and fullerenes as nanomaterials, intelligent materials as structures, and nanobiotechnology as a separate nanotechnology segment.

The research project nanotechnology segments were adapted to fit these nanotechnology segments, with raw materials becoming nanomaterials (incorporating nanotubes and fullerenes) and nanostructures including intelligent materials (refer to Figure 6-5 and Appendix D.1.2 for statistical data).

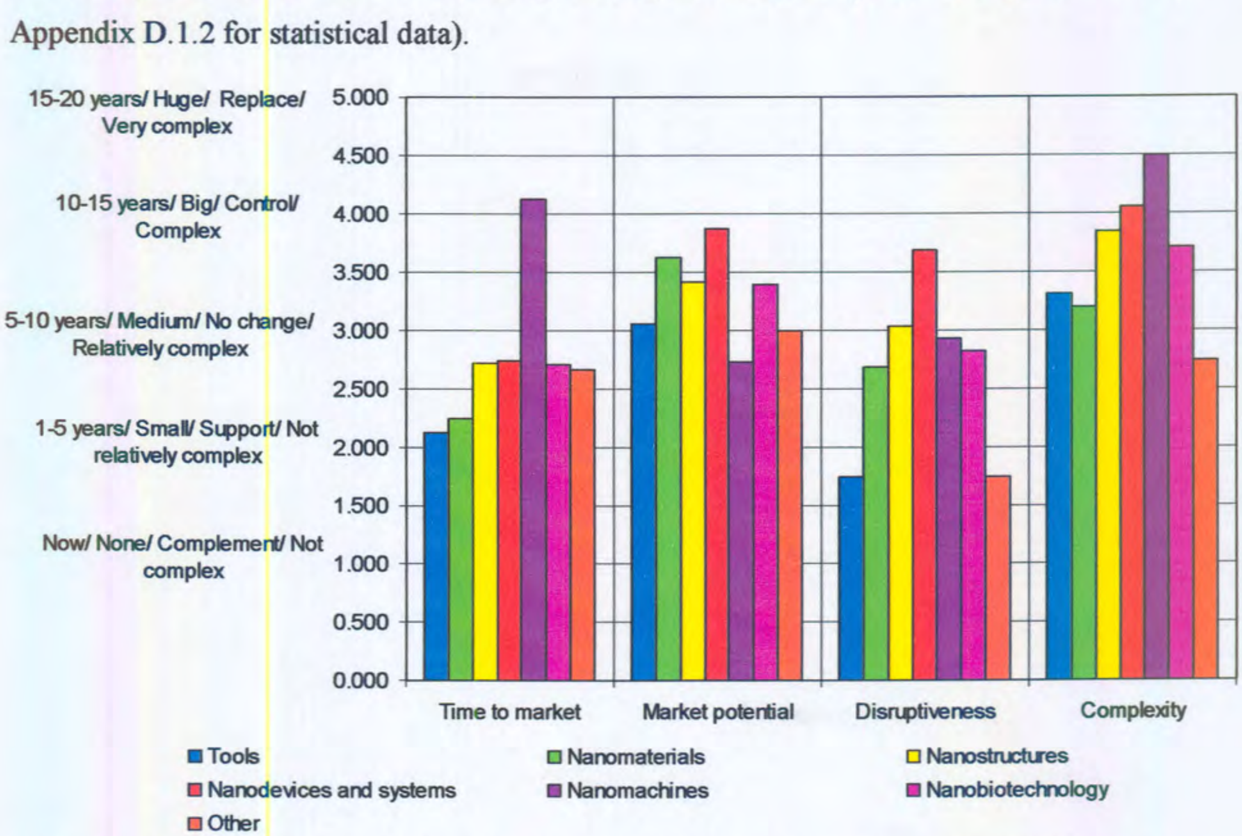



**Figure 6-5. Bar chart of grouped nanotechnology segment' mean regarding time to market, market potential, disruptiveness and complexity.**

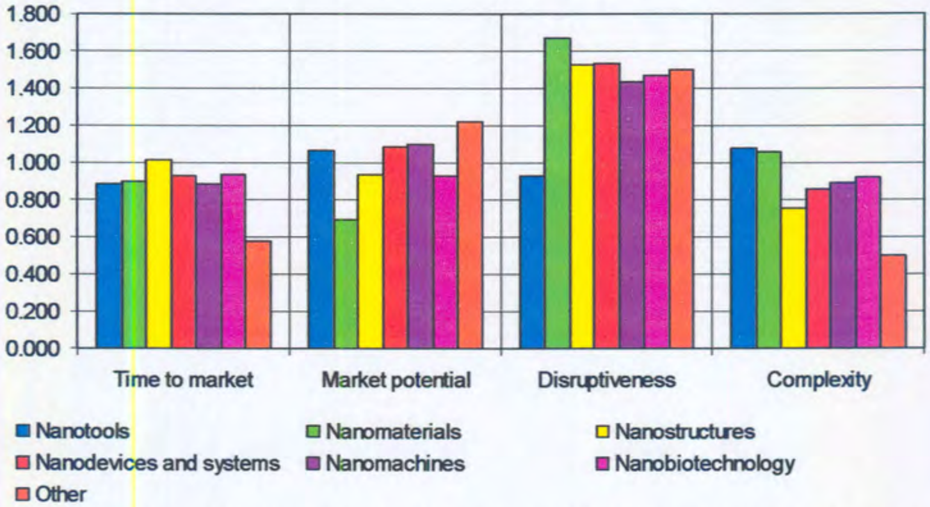



**Figure 6-6. Bar chart of grouped nanotechnology segments' standard deviation regarding time to market, market complexity, disruptiveness and complexity.**

The new nanomaterials have a longer time to market (+0.375), smaller market potential (-0.500), are more supportive (-0.248) and have the same level of complexity (+0.135). The new nanotechnology structures also have a longer time to market (+0.406), the same market potential (-0.019), greater diversity in disruptiveness and greater complexity (+0.281).

Nanobiotechnology encompasses elements of all the other nanotechnology segments, and is complex with a 5-10 years time to market and medium to big market potential. Nanobiotechnology is so diverse in its definition, that obtaining the combined average of all the nanotechnology segments seemed fair. Future studies must strive to define what constitutes nanobiotechnology, and characterise each subsegment separately.

The inclusion of nanotubes and fullerenes caused the nanomaterials' time to market and market potential standard deviation to increase with 0.185 and 0.193, and disruptiveness to decrease with 0.122. The inclusion of intelligent materials in structures decreased the complexity standard deviation with 0.136, and no significant change to other standard deviations (refer to Figure 6-6).

### *6.1.2 Innovation hampers*

Figure 6-7 illustrates the mean and standard deviation of the innovation hampers data (refer to Appendix D.1.3 for statistical data). The five most important South African nanotechnology innovation hampers are:

- Lack of tools, equipment and techniques (hardware - microscopes, software - computer simulations)
- Insufficient funding (lack of appropriate government or other external funding)
- Lack of qualified personnel (insufficient training)
- Uncertainty in the net economic effect (breadth, growth and impact of nanotechnology unsure)
- Costs involved (estimated cost too high)

These five innovation hampers create a dangerous cocktail. The proposition is that the participants perceive that nanotechnology must be sufficiently invested in (by government and venture capitalists, etc) so that:

- the necessary tools and equipment can be bought,
- the personnel can be trained and recruited, and
- operating expenses can be covered.

Due to the uncertainty of what the future of nanotechnology holds (regarding the time to market, market potential and disruptiveness) this might hamper nanotechnology innovation.

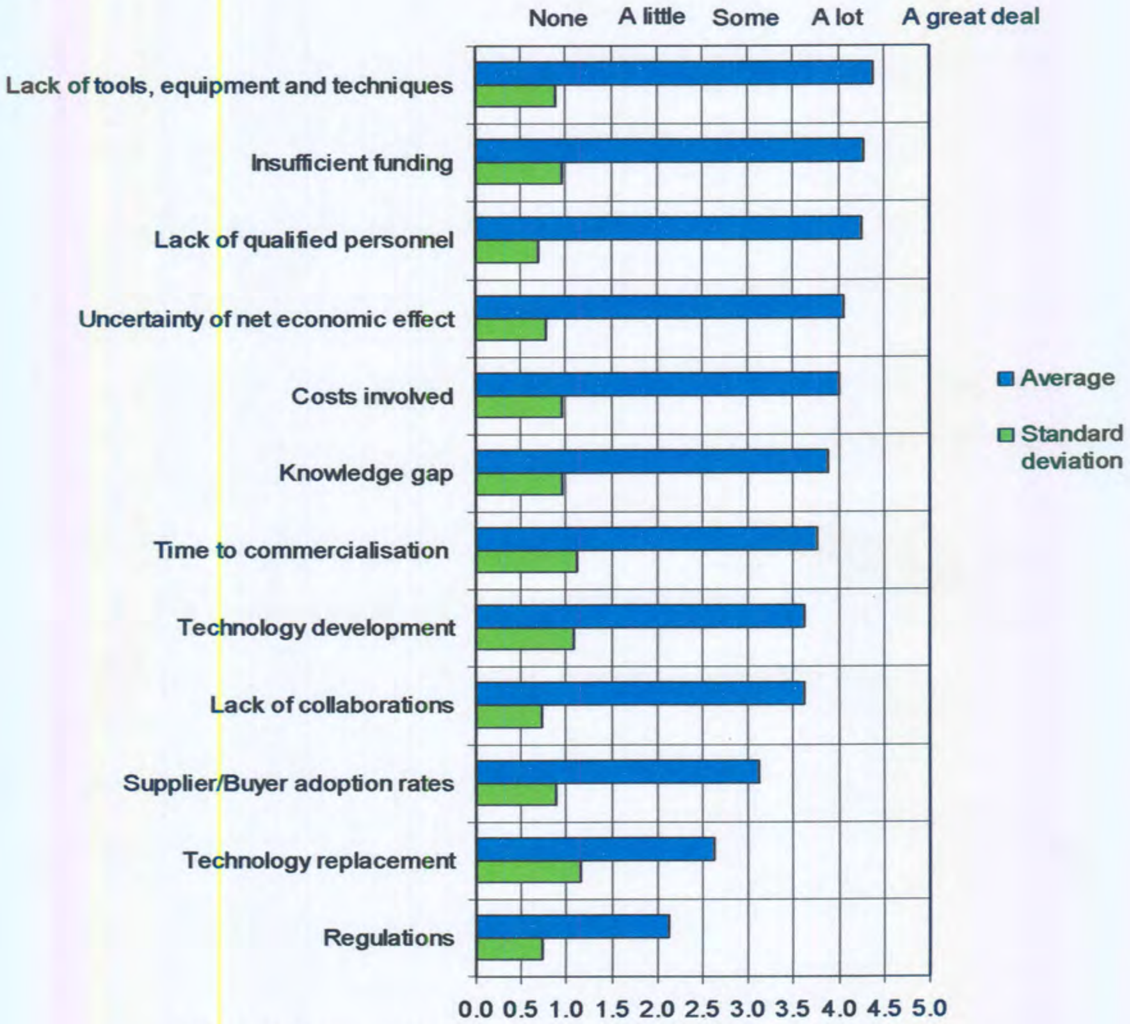



**Figure 6-7. Innovation hampers' mean and standard deviation.**

As stated in chapter 5, some innovation hampers not mentioned were corruption, the misuse or mismanagement of funds, lack of stakeholder initiatives, the support from government and the education of new scientists and researchers that would lead the development of nanotechnology.

The five least important South African nanotechnology innovation hampers are:

- Regulations (governmental and other legal restrictions)
- Technology replacement (potential for other newer nanotechnology products or processes to replace existing or up-and-coming nanotechnology products or processes)

- Supplier/Buyer adoption rates (when to switch from known product/processes to new nanotechnology product/processes)
- Lack of collaborations (relationships with other innovative organisations)
- Technology development (the disruptiveness and unfamiliarity of nanotechnology)

The proposition is that the participants perceive that:

- South African and world regulations will not hamper nanotechnology development;
- enough relationships are in place, or possible, with local and international nanotechnology firms;
- current markets will adapt fluently and quickly to new nanotechnology products and processes, and
- new nanotechnology markets will be sustainable.

Referring to hypotheses listed in Table 3-3, based on empirical data, the lack of tools, equipment, techniques and funding, together with the lack of personnel, was found as the biggest innovations hampers – supporting H0.2.

### *6.1.3 Nanotechnology actors*

Countries perceive to fulfil the following nanotechnology roles (refer to Figure 6-8 and Appendix D.1.4 for statistical data):

- The most important buyers are North America, Asia and Europe. This is understandable if you look at the current amount of R&D activities in countries like the United States, China, Singapore, Germany and France. The second most important buyers are Australia, New Zealand and South Africa, with no opinion on South America and other African countries.
- The most important suppliers and competitors are North America, Asia and Europe. The second most important suppliers are Australia and New Zealand, with no opinion on South Africa and South America, and other African countries not seen as suppliers or competitors.
- The most important sources of relationships are Europe, South Africa and North America. South Africa already has strong innovation relationships with European countries (Oerlemans, Pretorius, Buys and Rooks 2003:78). Asia, Australia and

New Zealand can be seen as the second most important source of relationships, with no opinion on South America and other African countries.

As illustrated in Figure 6-9 the greatest amount of standard deviation was with South Africa as buyers and suppliers, with other African countries as buyers and/or relationships, and with South America in almost every role.

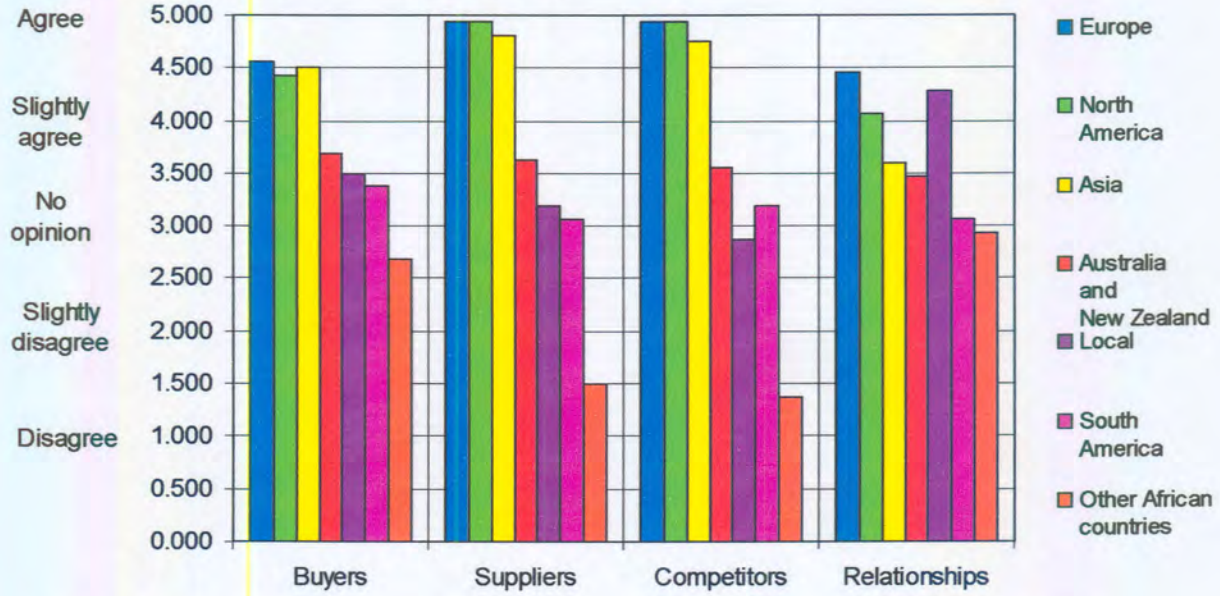



**Figure 6-8. Bar chart of the nanotechnology actors' mean regarding each of the roles fulfilled.**


**Figure 6-9. Bar chart of the nanotechnology actors' standard deviation regarding each of the roles fulfilled.**

Some propositions are that, with some certainty, Europe and North America will be the suppliers and competitors, South Africa will form relationships with European countries, and Asian countries will be the buyers and suppliers in nanotechnology products and processes.

South Africans feel a strong, but mixed, social responsibility to develop local and other African nanotechnology-related technologies and infrastructure, thus towards the formation of relationships with other African countries. South Africa might serve as the gateway of nanotechnology products and processes into the rest of Africa.

Figure 6-8 hints at the correlation between different nanotechnology roles, which are clearly illustrated by Figure 6-10. The greatest amount of standard deviation regarded the various nanotechnology roles of South Africa and South America (refer to Figure 6-11). The positive perception of South Africa as a huge supplier in certain nanotechnology segments, like raw materials, but maybe not in other areas of high technology, was the cause of the big standard deviation regarding South Africa as a supplier of nanotechnology products and processes. The least amount of standard deviation regarded Europe and Asia. The participants therefore agree on the nanotechnology roles these countries will fulfil in the future.

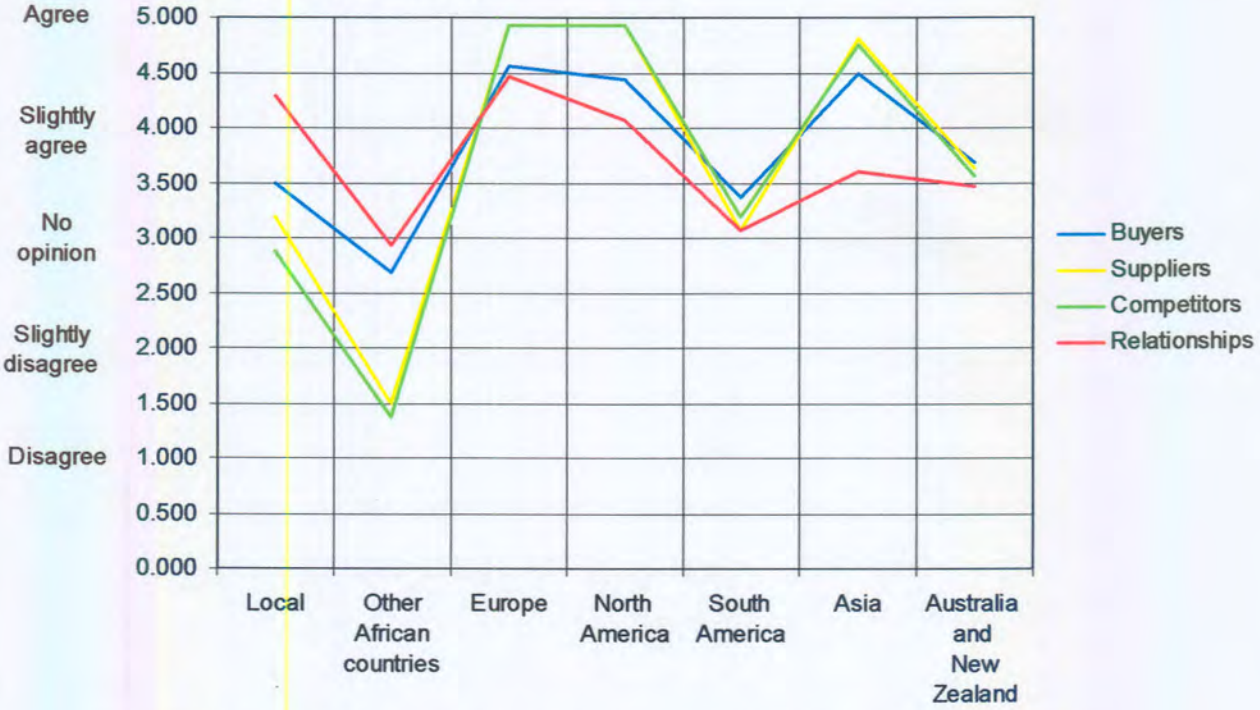



**Figure 6-10. Interactive plots for nanotechnology actors' means regarding each country.**

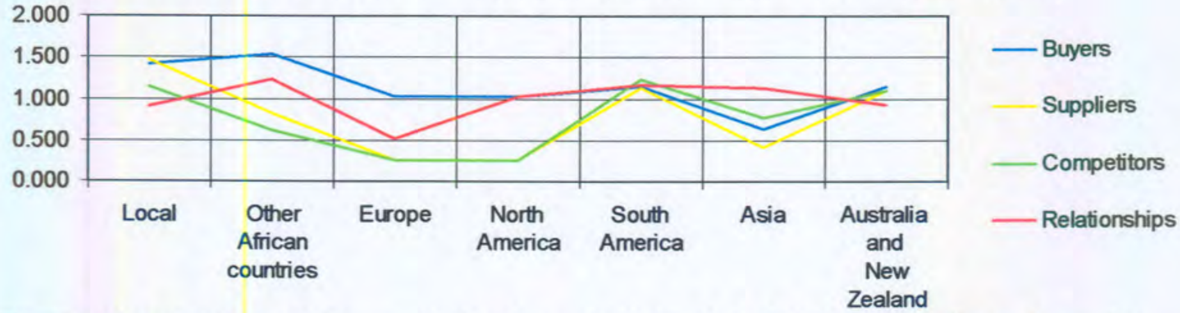



**Figure 6-11. Interactive plots for nanotechnology actors' standard deviations regarding each country.**

As illustrated in Table 6-2, there exist strong, positive correlations between all of the nanotechnology roles. The strongest correlations are between suppliers and competitors (0.922), buyers and suppliers (0.601), and buyer and competitors (0.581).

The proposition is that the buyers and suppliers of nanotechnology are also the most important competitors, with suppliers exerting the greatest competitive force. Interestingly the strongest correlation regarding relationships was with competitors (0.441). So indirectly, the most important relationships must be with suppliers.

| Spearman correlation | Variable | Buyer | Supplier | Competitor | Relationship |
|---|---|---|---|---|---|
| Buyer | Correlation Coefficient | 1.000 | 0.601** | 0.581** | 0.381** |
| | Sig. (2-tailed) | . | 0.000 | 0.000 | . 0.000 |
| | N | 112 | 112 | 112 | 104 |
| Supplier | Correlation Coefficient | 0.601** | 1.000 | 0.922** | 0.420** |
| | Sig. (2-tailed) | 0.000 | . | 0.000 | 0.000 |
| | N | 112 | 112 | 112 | 104 |
| Competitor | Correlation Coefficient | 0.581** | 0.922** | 1.000 | 0.441** |
| | Sig. (2-tailed) | 0.000 | 0.000 | . | 0.000 |
| | N | 112 | 112 | 112 | 104 |
| Relationship | Correlation Coefficient | 0.381** | 0.420** | 0.441** | 1.000 |
| | Sig. (2-tailed) | 0.000 | 0.000 | 0.000 | . |
| | N | 104 | 104 | 104 | 104 |

**Table 6-2. The Spearman correlation of questions 8 to 11. **Correlation is significant at the .01 level (2-tailed).**

Referring to hypotheses listed in Table 3-3, based on empirical data, Europe is regarded as the most important buyer, supplier, competitor and source of relationships – supporting H0.3

### *6.1.4 SWOT analysis*

The author proposes the following analogy to define strengths, weakness, opportunities and threats: "The moment time is frozen, the forces internal to a system (defined by a set of boundaries) that one have or not have is defined as a strength or weakness. The forces that only influence the system, when the time is continued (either pushing or pulling), external to the system are defined as an opportunity or threat." The information from the SANi and

AMTS SWOT analyses was reviewed and combined with the SWOT data provided by the participants. Table 6-3 illustrates the SWOT internal and external factors.

| Key internal factors |
|---|
| **Strengths (S)** |
| 1. South Africa possess selected nanotechnology-related knowledge, skills and experience |
| 2. South Africa possess cost-efficient human resource practices (research and labour) |
| 3. Good tertiary education standard |
| 4. Innovative human resources |
| 5. South African nanotechnology strategy in place |
| 6. South African nanotechnology community have strong collaborations |
| 7. Dedicated professionals |
| **Weaknesses (W)** |
| 1. Insufficient funding |
| 2. Insufficient amount of knowledgeable, skilled and experienced human resources |
| 3. Insufficient equipment |
| 4. Limited knowledge in some nanotechnology fields – lack of access to information, dependent on developed countries |
| 5. Fragmentation of nanotechnology community (geographically) |
| 6. Lack of nanotechnology focus areas |
| 7. Lack of blue sky R&D |
| **Key external factors** |
| **Opportunities (O)** |
| 1. Abundance of natural resources |
| 2. Increased support for social development (energy, environment and health) |
| 3. Increased support for centres of excellence development in nanotechnology-related knowledge, skills and experience |
| 4. Untapped South African nanotechnology market |
| 5. Untapped international nanotechnology market |
| 6. Developed countries developing pacing technologies creating learning opportunities |
| 7. Increased support for skilled human resource development supporting nanotechnology |
| **Threats (T)** |
| 1. Pace of overseas nanotechnology development |
| 2. South African tendency to licence technologies |
| 3. International countries have greater resources available (human) |
| 4. Increased international competition |
| 5. Loss of knowledgeable, skilled and experienced human resources (immigration, HIV/Aids) |
| 6. Incorrect allocation of South African funds |
| 7. Increase in nanotechnology social/ethical/legal implications |

**Table 6-3. SWOT internal and external factors.**

Table 6-4 and Table 6-5 discuss the strategies developed from the SWOT factors.

| Capitalising on strengths and maximising opportunities (offensive strategies) | |
|---|---|
| **Factors used** | **Description of strategy** |
| S1, S2, S4, O1 | Combine innovative nanotechnology knowledge, skills and experience in natural resource processing to develop cost-efficient products and processes implementing beneficiated natural resources. |
| S6, O4, O5 | Use strong collaborations with Europe to penetrate foreign niche markets, and create strong relationship with other African countries to become a supplier of nanotechnology products and processes to sub-Saharan Africa. |
| S3, S6, S7, O6 | Use strong collaboration with Europe to create more learning opportunities for dedicated South African students and personnel in European countries |
| S1, S5, S6, O2, O3, O6, O7 | Illustrate through current nanotechnology knowledge, skills and expertise, and South African nanotechnology strategy to South African government, European nanotechnology institutions and other support organisations that the South African nanotechnology community are capable of developing industry leading nanotechnology products, processes and services |
| S1, O6 | Offer South African nanotechnology knowledge, skills and expertise to international universities, investors, firms, etc. interested in nanotechnology research and development. |
| **Addressing weaknesses through maximising opportunities (developmental strategies)** | |
| **Factors used** | **Description of strategy** |
| W1, W2, W3, O2, O3, O6, O7 | Appeal to South African government, European nanotechnology institutions and other support organisations that the South African nanotechnology community need support in the form of funding, equipment and training structures. |
| W2, W7, O4 | Create awareness of the strengths, weaknesses, opportunities and threats of South African nanotechnology community and nanotechnology products, processes and services to South African public, universities, industry and science councils. |
| W4, O6 | Create strong relationships with European, North American and Asian institutions to facilitate the training in and licensing of foreign nanotechnology products, processes and services research and development. |
| W5, W6, W7, O3 | Create nanotechnology centres of excellence capable of funding, coordinating and facilitating South African nanotechnology product life cycle activities. |
| W6, O1 | Focus nanotechnology research and development on the abundance of South African natural resources. Find applications for the natural resources. |

**Table 6-4. South African offensive and developmental nanotechnology strategies.**

| Minimising threats through capitalising on strengths (competitive strategies) | |
|---|---|
| **Factors used** | **Description of strategy** |
| S1, S4, S7, T1, T3, T4 | Focus South African nanotechnology knowledge, skills and expertise on possible nanotechnology markets not identified or occupied by international nanotechnology researchers, developers and manufacturers. |
| S1, S2, S4, T2 | Negotiate short-term licensing agreements with international nanotechnology research, developers and manufacturers with the goal of innovatively and cost-efficiently imitating these licensed nanotechnologies. |
| S3, S6, T1, T3 | Use strong collaborations with European institutions to learn research, development and manufacturing practises, and negotiate separate areas of nanotechnology research, development and manufacturing. For instance, let South African researchers focus on materials beneficiation and European researchers on the implementation of the beneficiated materials. |
| S5, S6, T1, T7 | Learn through international collaborations of the social, legal and ethical implications involved in nanotechnology research, development and manufacturing. Place the knowledge gained through these learning opportunities in the South African strategy as guidelines for South African nanotechnology researchers, developers and manufacturers. |
| S5, T6 | Formulate the South African nanotechnology strategy to include funding structures, income statements, balance sheets, etc. of the South African nanotechnology community. |
| S6, T5 | Regarding the loss of nanotechnology students and personnel due to immigration, keep strong collaboration with these individuals and firms. These collaborations could provide entry points into international nanotechnology markets and create international learning opportunities. |
| **Minimising threats and avoiding weaknesses (defensive strategies)** | |
| **Factors used** | **Description of strategy** |
| W1, W2, W3, W4, T1, T3 | Negotiate collaborations with the international institutions, contract foreign human resources for the development of South African nanotechnology products, processes, services, knowledge and skills. Build relationships with the institution supporting their nanotechnology research, development and manufacturing. |
| W6, W7, T2 | Use licensing technologies to create or identify South African nanotechnology focus areas and implement backward integration nanotechnology strategies. |
| W4, T4 | Appeal to international nanotechnology institutions to support in the development of African technologies and economies. Appeal to their moral and ethical responsibility to improve the social and financial situation of developing countries. Offer competition free markets for these institutions in exchange for nanotechnology support. |
| W1, T6 | Create necessary South African accounting and funding structures. |
| W5, T5 | Do not regard immigration of nanotechnology students and personnel as negative, but rather build relationships with potential researchers, developers and manufacturers and keep these relationships even after immigration. |

**Table 6-5. South African competitive and defensive nanotechnology strategies.**

## 6.2 CSIR baseline study questionnaire

### *6.2.1 South African nanotechnology activity formulation*

The figures in Section 5.2.1 illustrated the number of participants involved in each nanotechnology product life cycle and nanotechnology segment. The purpose of the research project is, however, to estimate the number of activities in each nanotechnology product life cycle and nanotechnology segment.

The product life cycles of the CSIR baseline study questionnaire were transformed into product life cycles of the De Wet-Buys model (refer to Table 6-6). 'R&D' was cross-tabulated with 'Fundamental research', dividing 'R&D' into research and technology development.

| De Wet-Buys model product life cycles | Product life cycle involvement question used | Nanotechnology involvement question used |
|---|---|---|
| Research | R&D | Fundamental research |
| Technology development | R&D | None |
| Product and process development | Use nanotechnology in process<br>Use nanotechnology in product | None |
| Product and process improvement | Use nanotechnology in process<br>Use nanotechnology in product<br>Description written in other | None |
| Product and manufacture | Manufacture nanotechnology in process | None |
| Distribution, marketing, sales and service | Import and sell nanotechnology Nanomaterials or devices | None |
| Other | Other | None |

**Table 6-6. CSIR baseline questions used as indicators of each nanotechnology product life cycle activity.**

The comments of the participants provided a method to distinguish between process and product development and improvement.

The CSIR baseline study questionnaire nanotechnology involvement areas were grouped similarly to the nanotechnology segments used in the research project questionnaire (refer to Table 6-7). The aim was to create a relationship between the present nanotechnology segment developments and what the research project questionnaire experts perceive the future of these nanotechnology segments are. The classifications provided by Gordon (2002), confirmed through interviews with Mr. M Scriba, serve as the basis for the groupings.

Drug delivery was interpreted as drug delivery systems, thus classifying under nanodevices and systems. Membranes belong to the nanostructures segment.

A proposition is that other information regarding the nanotechnology source of funding, personnel, education, networking, collaboration and equipment serve only as background information, supporting the nanotechnology activity information. It would be fruitless, for instance, to estimate the number of personnel or student activities per nanotechnology product life cycle and nanotechnology segment – The cross-tabulation would be a carbon copy of the cross tabulation of the amount of university, industry and/or science activities per nanotechnology product life cycle and nanotechnology segment.

| Research project nanotechnology segment | CSIR baseline study nanotechnology areas |
|---|---|
| Tools | Atomic modelling and characterisation |
| Nanomaterials | Nanomaterials (Particles, tubes, composites), catalysis, Nano-emulsions and coatings |
| Nanostructures | Membranes |
| Nanodevices and systems | Drug delivery and nanodevices |
| Nanomachines | None |
| Nanobiotechnology | Nanobiotechnology |
| Other | Other |

**Table 6-7. Grouping of CSIR baseline questionnaire nanotechnology involvement areas into research project questionnaire nanotechnology segments.**

According to Page and Meyer (2000), only cross tabulations are bivariate measures of association between any discrete variables. Thus, in the analysis of the amount of nanotechnology activities, cross tabulations between the product life cycle involvement and nanotechnology segment involvement were calculated, and illustrated in terms of university, industry and science council activities.

Figure 6-12 illustrates these activities. Appendix D.2.1 and D.2.2 contain the full cross tabulation between the new nanotechnology product life cycles, the original and new groupings of nanotechnology segment involvement areas.

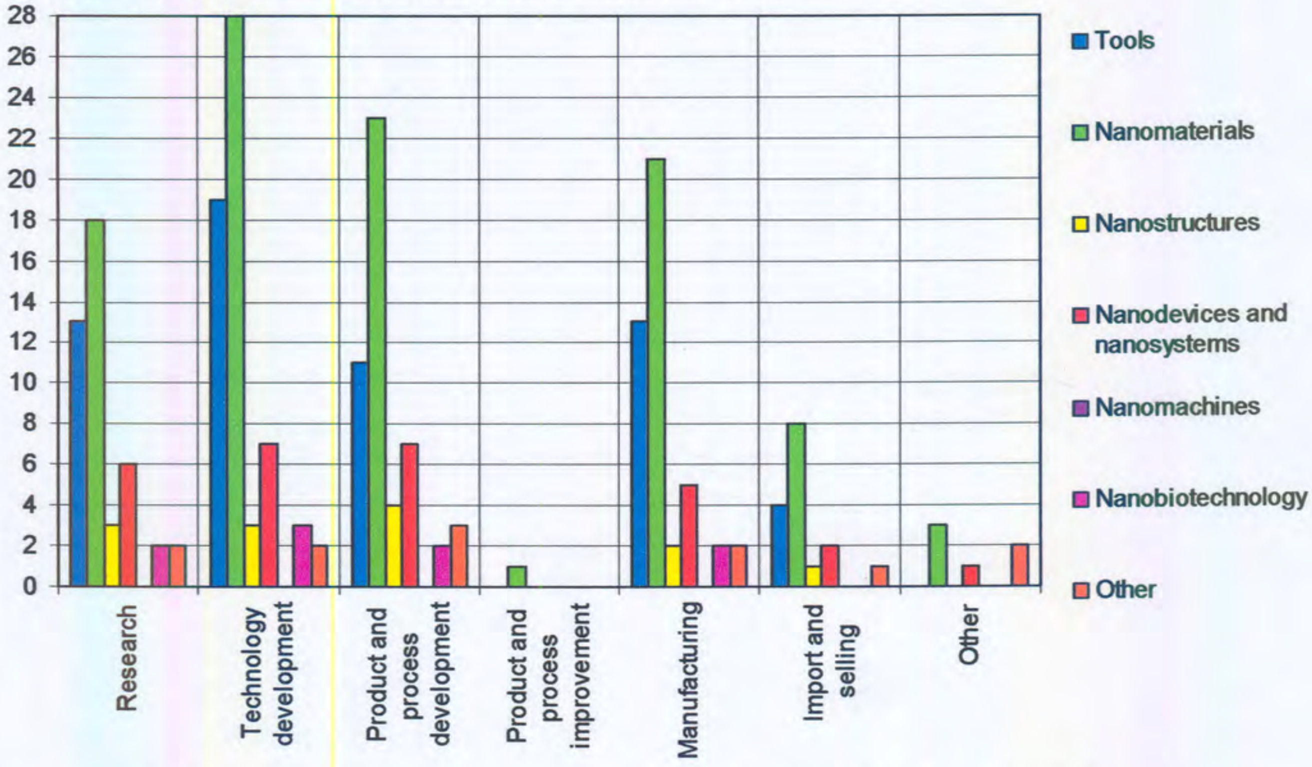



**Figure 6-12. Bar chart of cross tabulation for nanotechnology product life cycle and involvement areas.**

An extremely important assumption in performing the cross-tabulation was that the participants perform all the chosen nanotechnology product life cycles equally on all the chosen nanotechnology segments. The assumption might not be true, but in answering all the questions to gauge all the nanotechnology involvement segments and the product life cycles applicable to them would be daunting to the participants. In the original CSIR baseline questionnaire that would add up to thirteen nanotechnology segment multiple choice questions with six product life cycle options each, equalling a maximum of seventy-eight multiple choice answers. The assumption could be scratched, but would the participants even bother to look at the questions?

### *6.2.2 South African product life activities*

As postulated earlier, the level of activities should gradually increase from research to distribution, marketing, sales and services. Figure 6-13 illustrates that the activity level increases from research to technology development, but slightly decreases to product and process development and dramatically decreases to product and process improvement. The level of manufacturing activities is comparable to product and process development, but again the amount of distribution, marketing, sales and services activities of manufactured products and processes are very low. The level of activities thus tends to decrease, instead of increase, towards distribution, marketing, sales and service with almost no product and process improvement activities.

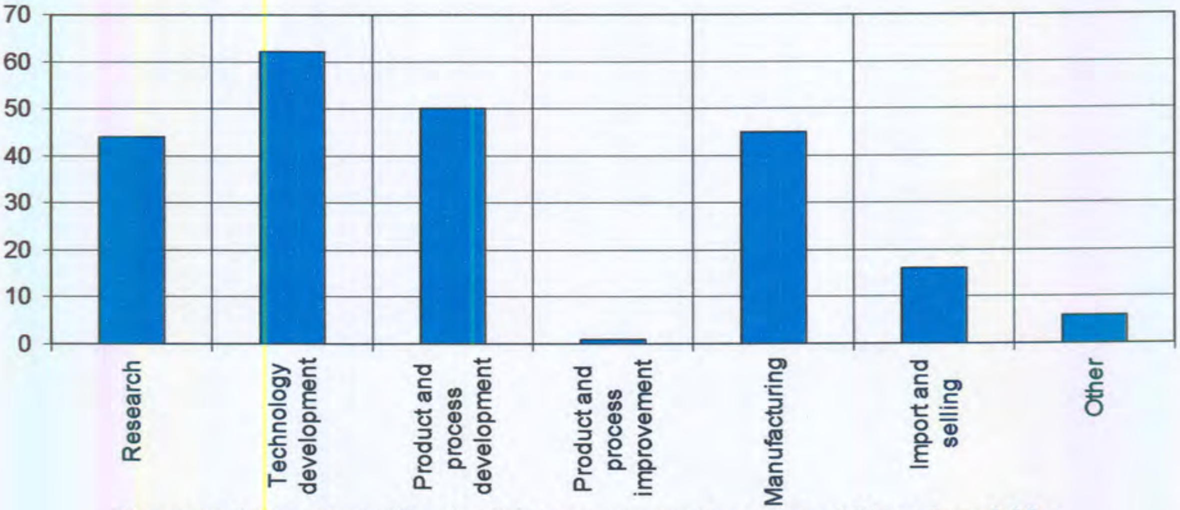



**Figure 6-13. Bar chart of South African nanotechnology product life cycle activities.**

The proposition is that most South African researchers focus on the first, second, third and fifth product life cycle. The focus is on development of fundamental knowledge, skills and human resources (the basis of technology).

Another proposition is that most of the manufacturing activities are small-scale manufacturing, with the aim of developing and testing products and processes. Interviews with Mr. M. Scriba confirmed these propositions. Possibly, only one participant (also involved in the product and process improvement) possesses large-scale manufacturing capabilities.

Other activities mentioned in the study was participants being interested in nanotechnology development and merely reading publications relating to nanotechnology developments, investments and international industry discussions.

Nanotechnology is still relatively unexplored; the majority of worldwide activities are only research, technology development, and product and process development. South Africa is currently on the right track. Internationally only a few products, featuring nanotechnology incremental improvements, have emerged. Thus, internationally the level of activity trend decreases from research to distribution, marketing, sales and services.

However, a worrying factor is that South African nanotechnology participants do not regard licensing as a source for product and process improvement (for backward integration according to Buys (2001)). This is evident in the fact that only seven participants imported some existing nanotechnology products and processes. Remember that from the research project questionnaire, many of the participants perceived that licensing as a South African weakness and felt threatened by the pace of overseas nanotechnology developments. These seven participants are also involved in other nanotechnology product life cycle activities (refer to Figure 6-14), which could be because of implemented backward integration strategies.

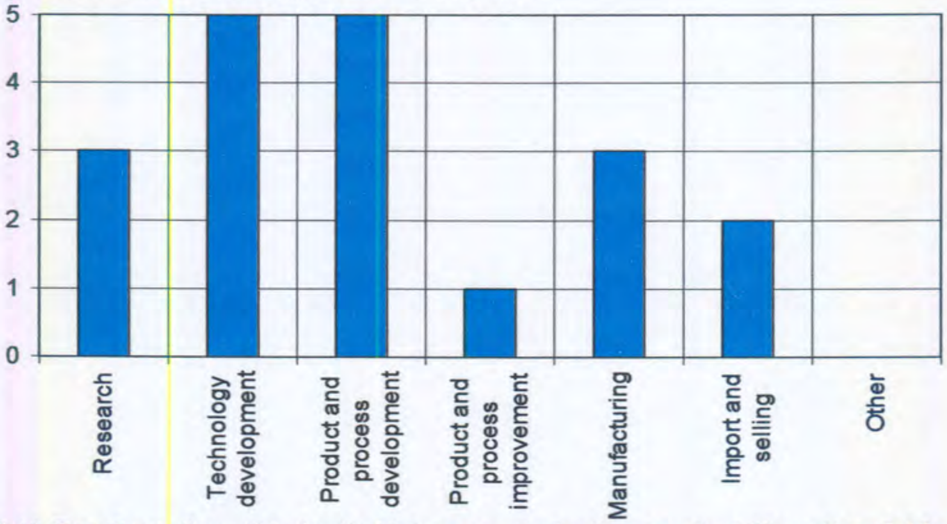



**Figure 6-14. Bar chart of possible South African nanotechnology product life cycle activities relating to the import of nanotechnology products and processes.**

Due to the amount of university participants (63% versus 28% industry and 9% science councils), it was assumed that the majority of activities would also be performed by personnel and students at these universities. The assumption proved to be true (refer to Figure 6-15).

There is, however, some interesting facts regarding the South African nanotechnology product life cycle activities:

- Universities perform twice as many research and technology development activities as industry and science councils.
- Universities and science councils perform almost the same amount of product and process development activities, and twice more than industry. This is astounding if taken into account that three times less science council participants took part in the CSIR baseline study.
- Only one participant performs known product and process improvements.
- Universities perform twice as many manufacturing activities as industry and science councils. This might also enforce the assumption that most of the manufacturing activities are small-scale manufacturing for testing and developing purposes.
- Universities perform the majority of the import and selling activities. The assumption is that the universities import nanotechnology with the goal of research and development in mind, not selling a product or process. Industries perform two import and selling activities.

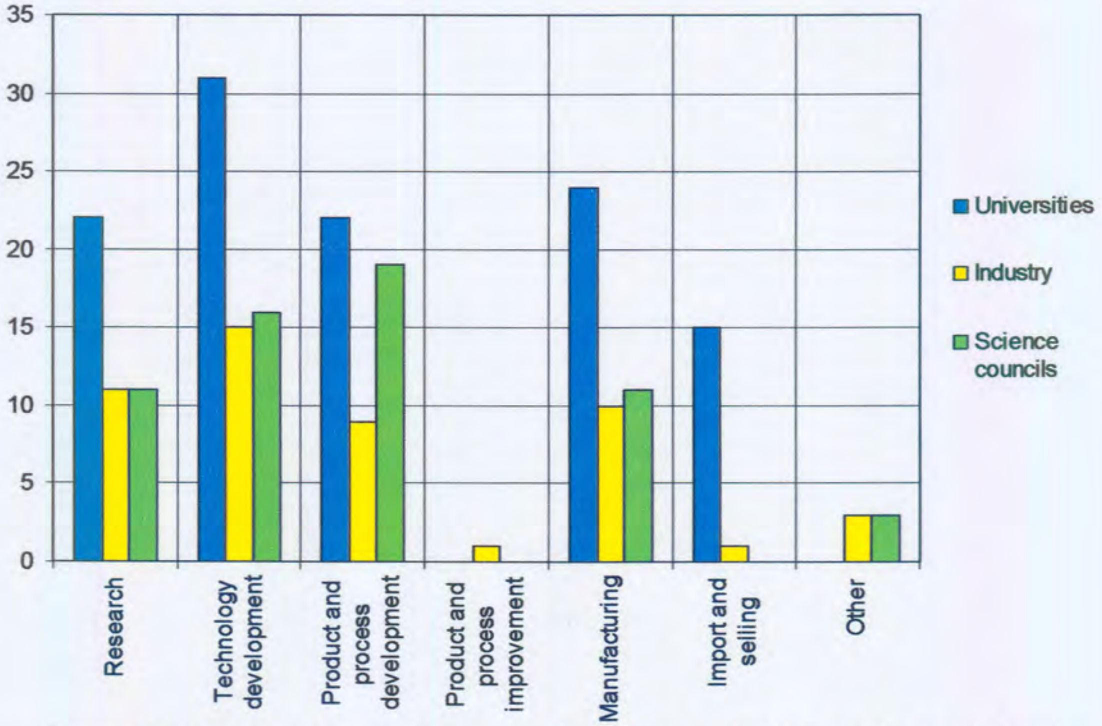



**Figure 6-15. Bar chart of South African nanotechnology product life activities according to universities, industry and science councils.**

### *6.2.3 South African nanotechnology focus area activities*

Figure 6-16 illustrates the South African nanotechnology segment activities. The bulk of the activities concerns tools (with atomic modelling 18 and characterisation 42 activities) and nanomaterials (with nanomaterials 47, catalysis 23, nano-emulsions 14 and coatings 19). To a lesser extent, some activities focus on nanostructures (with membranes 14), nanodevices and systems (with drug delivery 13 and nanodevices 15). Other activities concern nanofluids (which could also form part of nanomaterials) and other modelling techniques.

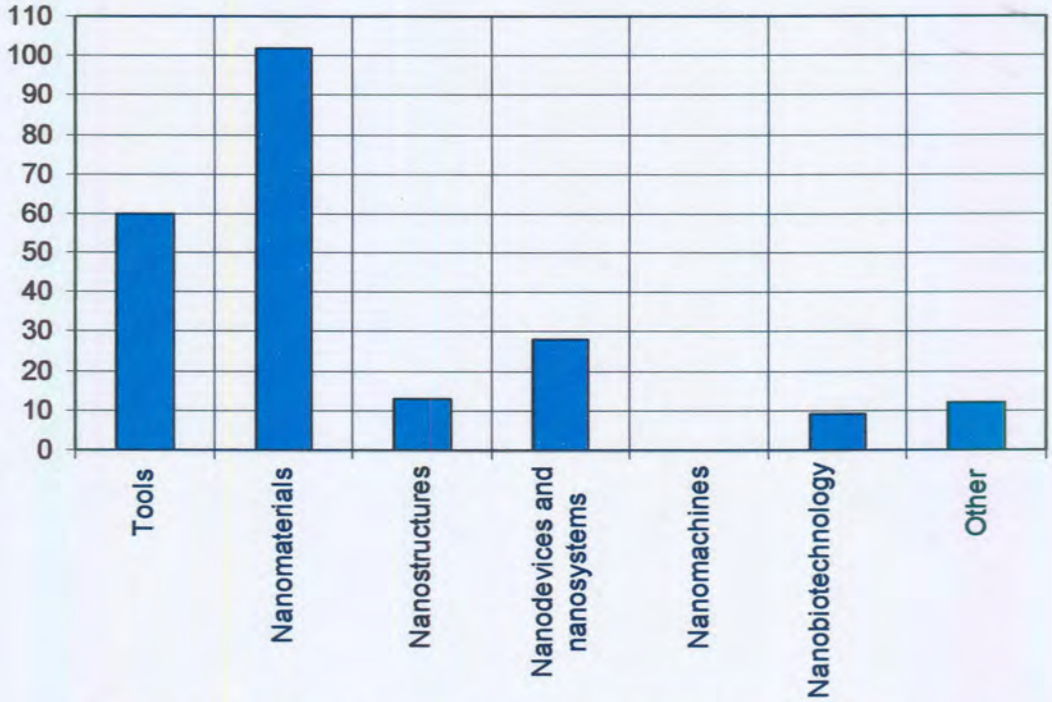



**Figure 6-16. Bar chart of current South African nanotechnology segment activities.**

When investigating the South African nanotechnology segment activities it was expected that universities would perform at least twice as much activities in multiple nanotechnology segments than industry and the science councils, due to the number of university participants. The figures proved otherwise (refer to Figure 6-17):

- Universities focus three times more on nanotechnology tools activities than industry and science councils do.
- Universities focus a third more on nanomaterials than industry, and two thirds more than science councils do.

- An almost even amount of activities are performed on nanostructures by all the institutions
- Only universities and science councils are involved in nanodevices and systems activities.
- Only industry and science councils are involved in nanobiotechnology activities.

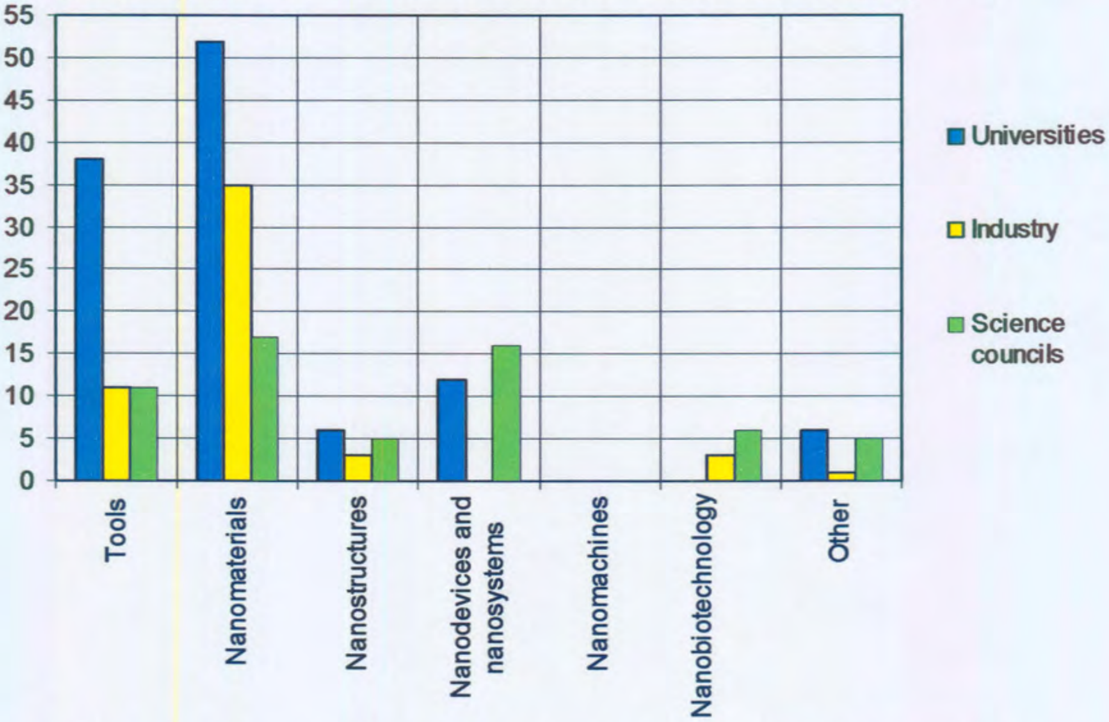



**Figure 6-17. Bar chart of current South African nanotechnology segment activities according to universities, industry and science councils.**

# 7 Conclusions and recommendations

## 7.1 Summary of research results

### *7.1.1 Background*

De Wet (2000) classified South Africa as a technology colony. Industry has never been in a position to exploit the incremental innovations and cannot create opportunities by itself due to the lack of research and development. The trend is, however, shifting. South Africa has been active in nanotechnology development for the last few years, creating nanotechnology awareness, receiving limited funding from a variety of sources, devising a national strategy and developing a new generation of researchers with new nanotechnology knowledge, skills and experiences, and building relationships with local and international institutions.

Sixteen South African nanotechnology experts with diverse backgrounds and interests took part in the research project questionnaire process. Forty-seven South African nanotechnology researchers and developers from universities (65%), industry (28%) and science councils (9%) provided information for the CSIR baseline study.

Unfortunately, the funding data was seen as confidential (or in some instances unknown) by most of the participants, who then only stated the sources of their funding and not the amount of funding received. Universities, much more than industry and science councils, used public funding sources. Industry relied more on private and internal funding sources.

Universities employ the most nanotechnology personnel, followed by science councils and industry. There is more male than female nanotechnology personnel, with almost an equal number of non-white and white nanotechnology personnel.

One of the issues brought up in the research project questionnaire is the aging nanotechnology research community – and how this could be a weakness within the South African nanotechnology community. This is clearly not the case. The majority of the personnel are between the ages of 20 and 30, with only 10% of the personnel over the age of 50.

Universities employ more people between the ages of 20 and 30 than any other age group, thus it may be said that the nanotechnology community could have access to a range of young and diverse nanotechnology researchers. Industry and science councils possess a good distribution of young and old employees. Note that the total number of personnel might be slightly skewed because of the possible inclusion of students as personnel by many of the university departments. Students are able to act as junior lecturers, teaching and research assistants, while continuing their studies.

One hundred-and-sixty-two students are enrolled in nanotechnology curricula. Female nanotechnology students are more than female nanotechnology personnel and half of the male nanotechnology students. Non-white nanotechnology students are three times more than the white nanotechnology students. Eighty per cent of the nanotechnology students are South African, with a small number of students from other African countries, Europe and Asia.

Almost 80% of all taught nanotechnology programmes are aimed at PhD level students and an equal distribution of students (each about 30%) are enrolled in Honours, Master's and PhD programmes. Only 15% of Bachelor's students are enrolled for nanotechnology subjects.

The majority of nanotechnology collaborations are with firms and universities in Europe and with very few in North America, Australia and Asia. Curiously, no collaborations were noted with other African countries, since 13 students originated from other African countries.

Participants are aware of the existence of SANi (and most probably its activities), and do engage in national and international collaborations. Most of the national collaborators are groups from local universities. This might be an indication that most industry participants contract or fund a South African university in the development of nanotechnology knowledge and skills, and acquisition of nanotechnology equipment. Another proposition is that many of the employees of these industry participants, studied (or are still studying) at these universities.

Interestingly, it was found that national and international collaborations were equally relied on. This contradicts the notion that international funding is not significant. Why would many South African institutions engage in international collaborations, but they do not use these collaborations as funding mechanisms?

International projects are an indication of both the willingness to learn and to build international relationships. Universities primarily support most of the international projects. Only four universities stated that government arranged some of the collaborations.

Half of the participants felt the nanotechnology-related equipment was in a good condition, with 36% and 13% feeling that their equipment was average or bad. In the comparison of the equipment, 31% felt their equipment was on the same standard as the rest of the world's, with 42% and 27% feeling that their equipment are slightly and much worse. Most of the equipment belonged to universities and science councils. Industry has limited access to state-of-the-art equipment. Most of the universities stated that their equipment was funded either internally or through public funding mechanisms such as THRIP and the NRF. Some of the universities stated that they did already allow the use of their equipment by other departments, universities and industry.

### *7.1.2 Nanotechnology activities, segments, innovation hampers and relationships*

Gordon (2002), amongst others, defined and plotted several nanotechnology segments as market potential versus value adding, complexity, time to market and risk. The research project took these nanotechnology segments and the nanotechnology focus areas of the CSIR baseline study, and adapted them to form six nanotechnology segments, namely:

- tools,
- nanomaterials,
- nanostructures,
- nanodevices and systems,
- nanobiotechnology, and
- nanomachines.

Figure 7-1, Figure 7-3 and Figure 7-2 plot the market potential against time to market, disruptiveness and complexity, and indicates the level of South African activities for each nanotechnology segment. The segments have medium to big market potential, with nanodevices and systems having the most and machines having the least. The segments increase almost linearly in time to market, from 1-5 years to 10-15 years time to market, with nanomaterials expected the earliest and nanomachines expected the latest. Note that the time to market for nanomachines (10-15 years) differs greatly from the other segments (between 1-5 years to 5-10 years), indicating that machines might still be very much a futuristic concept.

Tools and nanomaterials are more complementary than nanodevices and systems that are more replacing. The spread of answers between complementary and replacing for nanostructures, nanobiotechnology and nanomachines shifts the averages of these segments towards no opinion.

The segments increase almost linearly in complexity from relatively complex to very complex, with tools and nanomaterials the least complex and nanomachines the most complex. Again note that the complexity, as with the time to market, for nanomachines (very complex) differ greatly from the other segments (between relatively complex to complex), confirming that machines might still be a futuristic concept.

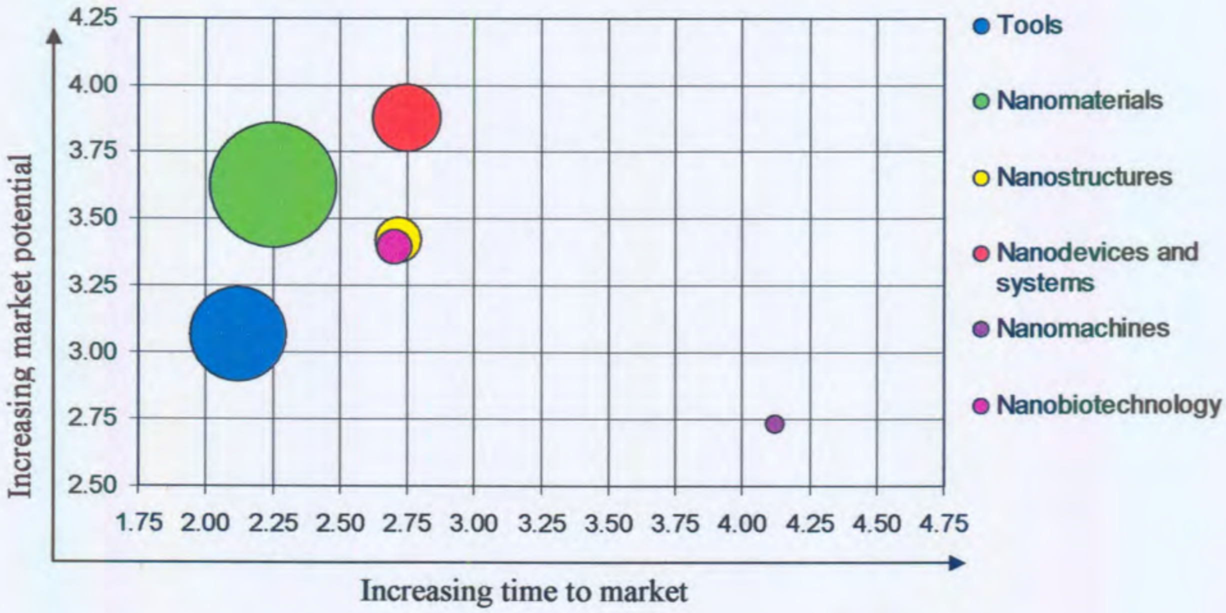



**Figure 7-1. Time to market versus market potential of nanotechnology segments. The area of each bubble is the current amount of South African activities in each nanotechnology segment.**

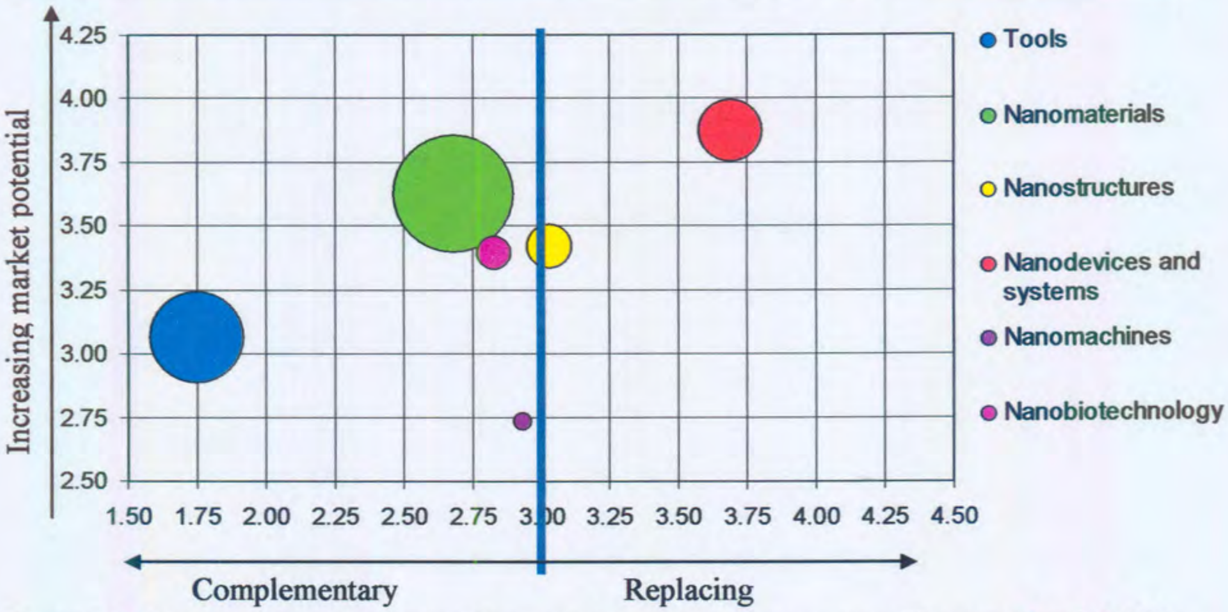



**Figure 7-2. Time to market versus disruptiveness of nanotechnology segments. The area of each bubble is the current amount of South African activities in each nanotechnology segment.**

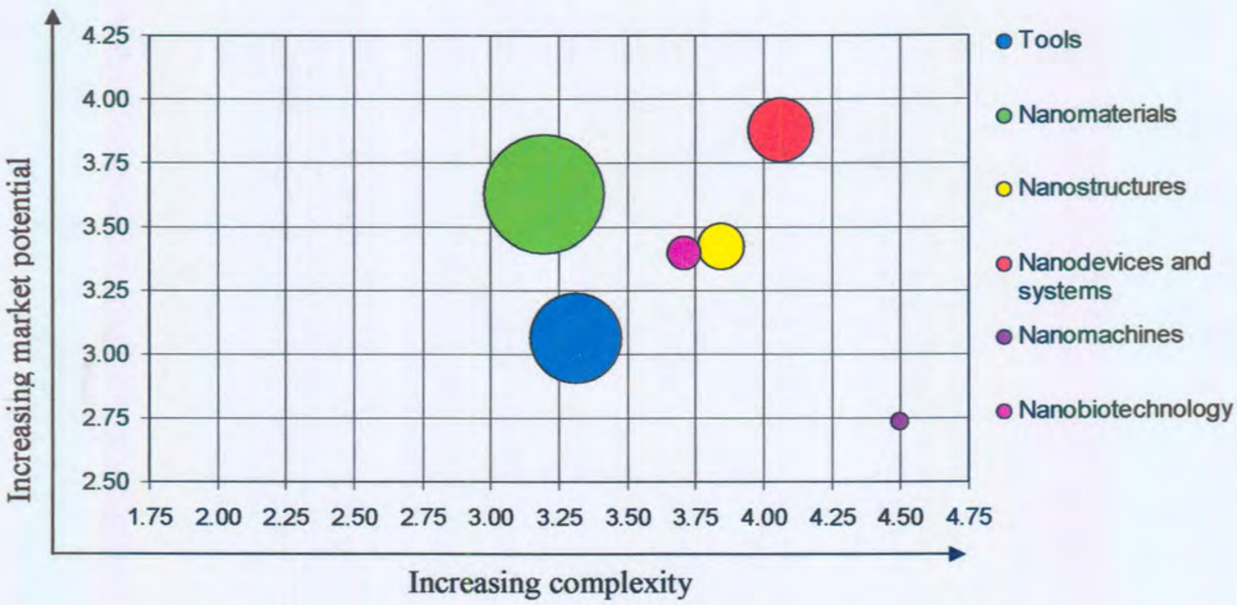



**Figure 7-3. Time to market versus market potential of nanotechnology segments. The area of each bubble is the current amount of South African activities in each nanotechnology segment.**

There exists a relatively strong positive correlation between time to market and complexity and interestingly enough, a relatively strong negative correlation between time to market and market potential. These correlations indicate that as the complexity increases so does the time spent in the research, development, manufacturing, marketing and eventual time to market. The increase in time to market leads to a decrease in market potential. The reason for the last stated correlation might be due to a short-term perspective of when a return of investment is expected. If the time to market is too long, investors might perceive the segment as not having great short-term market potential.

Because only two participants answered the second questionnaire, the data was considered insignificant and not analysed. However, two conclusions that could be drawn from the answers are:

- Tools, nanomaterials and nanostructures require a medium amount of skilled human resources to fully research, develop, manufacture, market and sell, while nanodevices, systems and nanomachines require a huge amount of skilled human resources.
- The South African government will have to support research and development until feasible nanotechnology applications are generated, at which point venture capital would play a role in the exploitation of these nanotechnology incorporating products, processes and services.

The five most important South African nanotechnology innovation hampers are and will be:

- Lack of tools, equipment and techniques (hardware – microscopes, software – computer simulations)
- Insufficient funding (lack of appropriate government or other external funding)
- Lack of qualified personnel (insufficient training)
- Uncertainty in the net economic effect (breadth, growth and impact of nanotechnology unsure)
- Costs involved (estimated cost too high)

The proposition is that the South African participants perceive that nanotechnology must be sufficiently invested in (by government and venture capitalists, etc) so that:

- the necessary tools and equipment can be bought,
- the personnel can be trained and recruited, and
- operating expenses can be covered.

Due to the uncertainty of what the future of nanotechnology holds (regarding the time to market, market potential and disruptiveness) this might hamper nanotechnology innovation.

Another proposition is that South African participants perceive that:

- the South African and world regulations will not hamper nanotechnology development;
- enough relationships are in place, or possible, with local and international nanotechnology firms;
- current markets will adapt fluently and quickly to new nanotechnology products and processes, and
- new nanotechnology markets will be sustainable.

Countries will fulfil the following nanotechnology roles regarding buyers, suppliers, competitors and relationships:

- The most important buyers are North America, Asia and Europe, followed by Australia, New Zealand and South Africa with no opinion on South America and other African countries.
- The most important suppliers and competitors are North America, Asia and Europe followed by Australia and New Zealand with no opinion on South Africa and South America, and other African countries not seen as suppliers or competitors.
- The most important sources of relationships are Europe, South Africa and North America, followed by Asia, Australia and New Zealand with no opinion on South America and other African countries.

Mixed perceptions surrounding other African countries were noticed, possibly, because South Africans feel a strong social responsibility to develop local and other African nanotechnology-related technologies and infrastructure.

The strongest correlations are between suppliers and competitors, buyers and suppliers, and buyers and competitors. The proposition is that the buyers and suppliers of nanotechnology are also the most important competitors, with suppliers exerting the greatest competitive force. Interestingly the strongest correlation regarding relationships was with competitors. Indirectly the most important relationship must be with suppliers.

The nanotechnology strategies developed in the research project, will be discussed in the sub-chapter regarding recommendations to the South African nanotechnology community. These strategies incorporated the opinions of the research project questionnaire participants, information gathered through the CSIR baseline study and other secondary data sources.

Figure 7-4 illustrates that the South African nanotechnology activity level increases from research to technology development, but slightly decreases to product and process development and dramatically decreases to product and process improvement. The level of manufacturing activities is comparable to product and process development, but again the amount of distribution, marketing, sales and services activities of manufactured products and processes are very low. Thus the level of activities tend to decrease, instead of increase, towards distribution, marketing, sales and service, with almost no product and process improvement activities.

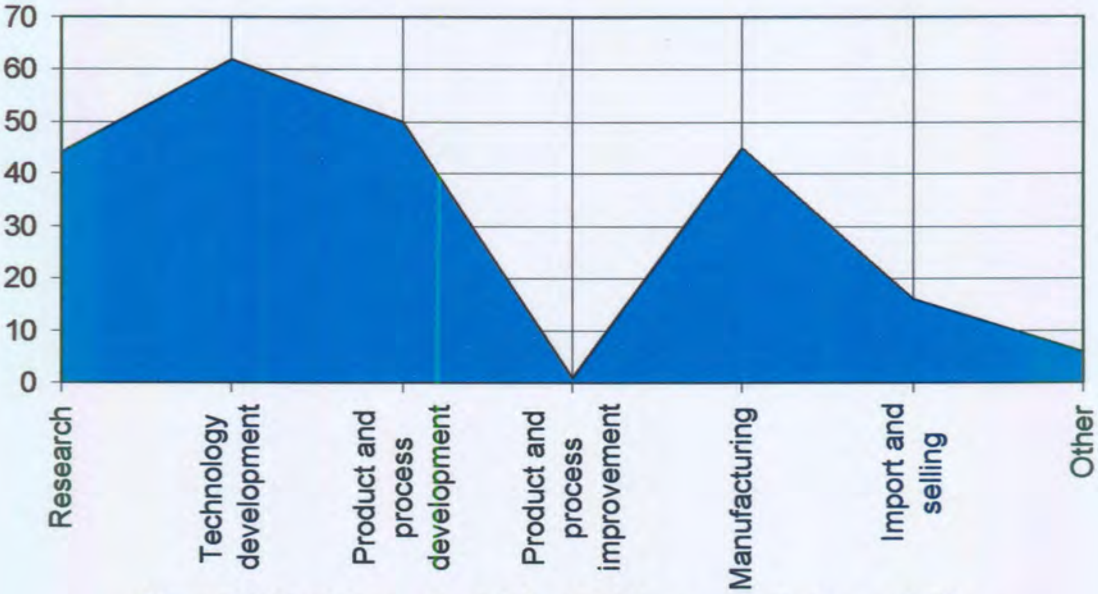



**Figure 7-4. Stacked area chart of South African nanotechnology activities.**

Nanotechnology is still relatively unexplored; the majority of worldwide activities are only research, technology development, and product and process development. Product and process improvements are only possible if extensive research, technology, product and process development have been performed. The resultant products, processes and services can then be improved, manufactured and sold (forward integration). Another product and process improvement possibility is foreign products, processes and services that are acquired with the aim of learning and improving or adapting them to local market needs (backward integration).

South Africa is currently on the right track. Internationally only a few products, featuring nanotechnology incremental improvements, have emerged. Thus, backward integration is not plausible now. The only way to develop nanotechnology products, processes and services might be to research and develop it locally, fostering entrepreneurship and through the aid of international collaborations. Internationally the level of activity trend decreases from research to distribution, marketing, sales and services.

However, a worrying factor is that South African nanotechnology participants do not regard licensing as a source for product and process improvement (for backward integration). This is evident in the fact that only seven participants imported some existing nanotechnology products and processes. Remember that from the research project questionnaire, many of the participants perceived licensing as a South African weakness and felt threatened by the pace of overseas nanotechnology developments. These seven participants are also involved in other nanotechnology product life cycle activities, which could be because of implemented backward integration strategies.

The bulk of the activities concerns tools and nanomaterials, and to a lesser extent some activities focussed on nanostructures, nanodevices and systems, and other activities concerning nanofluids and other modelling techniques (refer to Figure 7-5).

Universities focus three times more on nanotechnology tools than industry and science councils do, and a third more on nanomaterials than industry and two-thirds more than science councils. An almost even amount of activities is performed on nanostructures by all the institutions. Only universities and science councils are involved in nanodevices and systems activities. Only industry and science councils are involved in nanobiotechnology activities.

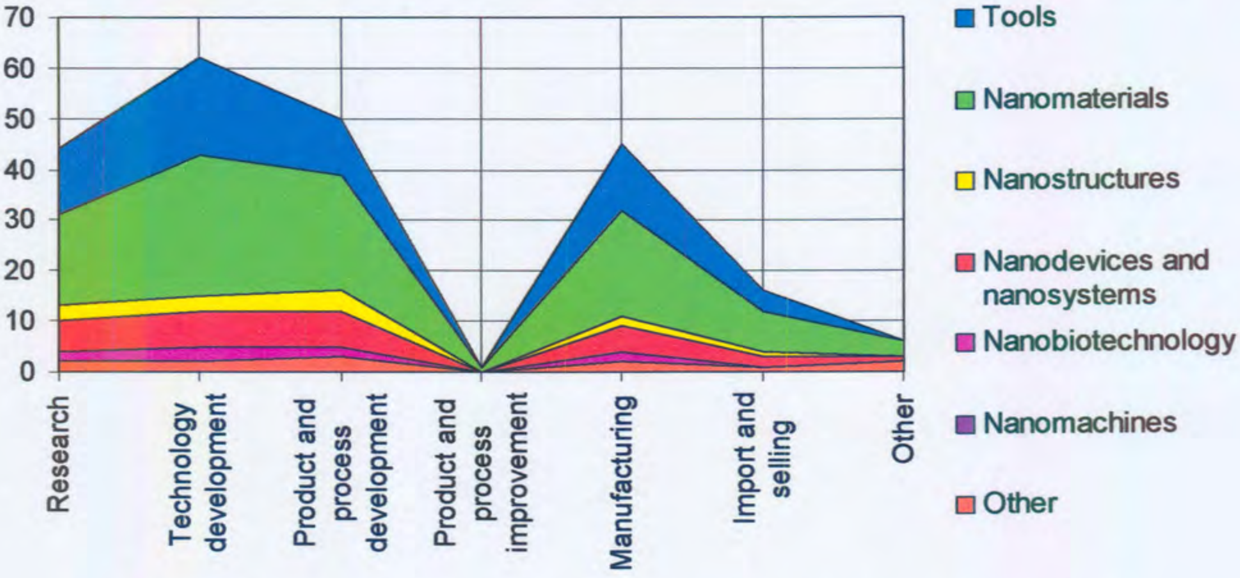



**Figure 7-5. Stacked area chart of South African nanotechnology activities per nanotechnology segment.**

Universities accounted for most of the nanotechnology product life cycle activities, with science councils focussing the most on product and process development, and industry focussing the most on technology development (refer to Figure 7-6). Only one participant performs product and process improvements.

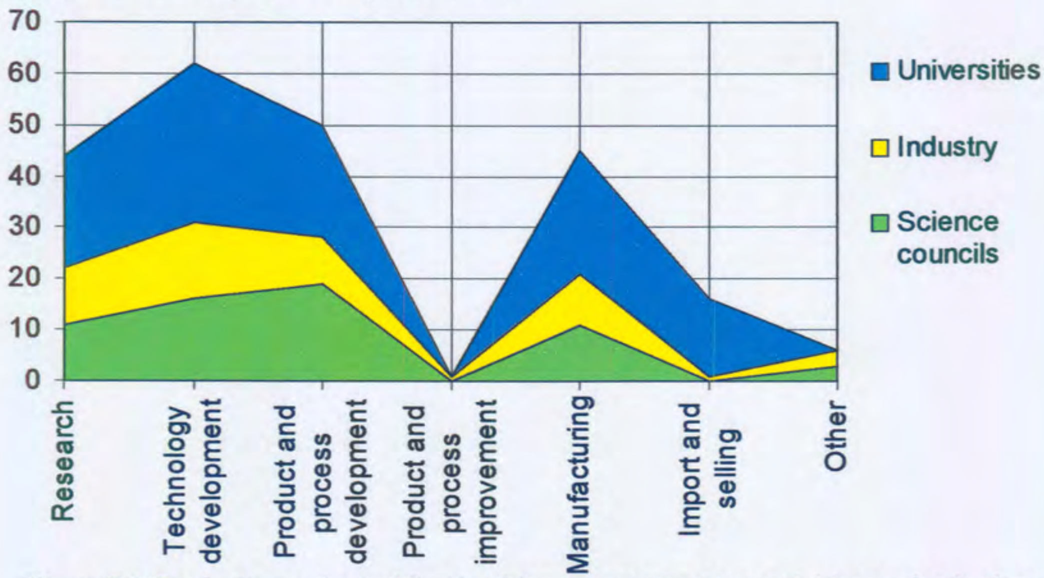



**Figure 7-6. Stacked area chart of South African nanotechnology activities per institution.**

Table 7-1 provides the conclusions drawn regarding the hypotheses, created in chapter 3.2, which guided the research project into exploring the facts of and relationships between the current and future South African nanotechnology development.

| Primary hypotheses | Description of primary hypotheses | Conclusions |
|---|---|---|
| H0 | Activities are centred on the beginning of the product life cycle, namely the research and technology development of nanotechnology knowledge | The majority of nanotechnology product life cycle activities are centred on research, technology development, product and process development and manufacturing, supporting to a greater extent H0 |
| H1 | Activities are not centred on the beginning of the product life cycle, namely the research and technology development of nanotechnology knowledge | |
| H2 | Nanotechnology already impacts current products and markets | Nanotechnology tools, nanomaterials and probably some nanostructures does already impact some product and markets supporting H2 |
| H3 | Nanotechnology does not impact current products and markets | |
| **Secondary hypotheses** | **Description of secondary hypotheses** | **Conclusions** |
| H0.1 | Universities perform the most research and technology development activities | Based on empirical data – universities do perform more research and technology development activities than any other institution supporting H0.1 |
| H1.1 | Universities do not perform the most research and technology development activities | |
| H0.2 | Funding and equipment are the biggest nanotechnology innovation hampers | Based on empirical data – the lack of tools, equipment, techniques and funding was found as the biggest innovations hampers supporting H0.2, although the lack of personnel was also found as a big innovation hamper |
| H1.2 | Funding and equipment are not the biggest nanotechnology innovation hampers | |
| H0.3 | Europe is the biggest source for international nanotechnology transfer | Based on empirical data – Europe is regarded as the most important buyer, supplier, competitor and source of relationships supporting H0.3 |
| H1.3 | Europe is not the biggest source for international nanotechnology transfer | |
| H2.4 | Nanotechnology products and processes will emerge within the next 5 years | Based on empirical data – tools, raw materials structures, nanotubes and fullerenes are most likely to emerge within the next 5 years supporting H2.4, however devices, systems, intelligent materials and machines are most likely to emerge in 5 to 15 years supporting H3.4 |
| H3.4 | Nanotechnology products and processes will not emerge within the next 5 years | |
| H2.5 | Nanotechnology does possess better than good market potential | Based on empirical data – all the nanotechnology segment posses a medium to big market potential supporting H2.5 |
| H3.5 | Nanotechnology does not possess better than good market potential | |
| H2.6 | Nanotechnology will complement current technologies | Based on empirical data – tools, nanotubes and fullerenes will be more complementary supporting H2.6 and devices, systems and intelligent materials will be more replacing supporting H3.6. |
| H3.6 | Nanotechnology will not complement current technologies | |

**Table 7-1. Conclusions to research project hypotheses.**

## 7.2 Implications for and contributions to the South African nanotechnology community

The research project was a successful collaboration between the author and the CSIR baseline study that supplements the South African strategy documentation (SANi 2003), and can act as a basis to facilitate the transformation of South Africa into an international nanotechnology competitive force.

The document contributes the following information:

- A classification of future nanotechnology industries regarding time to market, market potential, disruptiveness and complexity.
- An identification of innovation hampers for the South African nanotechnology community.
- A ranking of nanotechnology national and international nanotechnology buyers, suppliers, competitors and relationships.
- An analysis of the South African nanotechnology system of innovation.
  - Discussion of background information regarding nanotechnology awareness, involvement, funding, personnel, education, networking and equipment.
  - Calculation and illustration of figures on the level of nanotechnology activities for each product life cycle and per institution.
- Formulation of innovative strategies from information gathered on internal South African nanotechnology strengths and weaknesses, and external nanotechnology opportunities and threats.

The information extrapolates the current South African nanotechnology activities (strengths and weaknesses) with future nanotechnology industries, innovation hampers and actors (opportunities and threats).

South Africa is mainly involved in nanotechnology segments, nanotools and nanomaterials, with short time to market, and medium to big market potential, which are more complementary to current technologies. The fact suggests that South African innovation aims at short-term investment and development, which are easier to develop but still posses some market potential.

The current strategy may not be wrong; South Africa does possess knowledge, skills and expertise in selected nanotechnology fields such as modelling and the characterisation of nanomaterials. These knowledge, skills and expertise can be unique to South African researchers and development, difficult to imitate by developed countries or may even be implemented by developed countries in their nanotechnology products, processes and services. A number of institutions are involved in product and process development, which illustrates that South Africa's nanotechnology community could be able to deliver their own products, processes and services from research and development, through to the marketing and selling.

As illustrated in the study, most of the international investors (NanoInvestorNews, 2004) lean towards investment with medium to long-term investment periods, waiting for an opportunity to enter the market regarding nanotechnology-incorporating applications. This may hint that the fact most capital and support might be leveraged more towards nanodevices, systems, biotechnology and machines. These nanotechnology segments are not the primary focus of many South African researchers and developers.

Innovation hampers stand in the way of the research, development and eventual selling of the nanotechnology products, processes and services, and therefore will have to be addressed by the South African nanotechnology community itself, by industries that gain awareness of the opportunities and threats of nanotechnology or by the South African government that does support skilled human resource development.

The study illustrates that the South African nanotechnology community already possess a number of local and European relationships in the form of tertiary institution research and development collaborations or import of basic nanotechnology segments. Institutions from Europe, North America and Asia will be the most important buyers, suppliers, competitors and source of relationships. Other African countries might become a lucrative market with South Africa alleviating social, environmental and economical pressures through the implementation of nanotechnology applications. Relationships with other African countries could form through the exchange of students from these countries to South Africa (already present) and its overseas collaborators, to develop knowledge and capability bases in nanotechnology.

The nanotechnology community, with the research project information, analysis and strategies and other studies as the base, can draw and construct their own conclusions and strategies to enter competitively into the ever-growing nanotechnology markets.

## 7.3 Self assessment

The research project is the successful culmination of hundreds of hours of literature reviews, questionnaire designs, data gathering, database designs, and finally yet importantly report writing.

The author of the research project was fortunate enough to meet Mr. Manfred Scriba, the convenor and project coordinator of SANi. Without him, the research project would not have been a success. Mr. Manfred Scriba is an invaluable asset to any South African nanotechnology-related study. He possesses a great deal of knowledge of the South African nanotechnology national system of innovation, knowledge on technical knowledge nanotechnology fields and collaborations with many of the South African nanotechnology community members. The author aided in designing, distributing and gathering CSIR baseline questionnaires, and designing databases, and by plotting and analysing the gathered data. In return, the author of the research project could use the CSIR baseline study data.

The author gained a great deal of knowledge in fields such as innovation, technology management, research methodology, database design and manipulation, but also in softer skills such as business negotiations, politics and interviewing. The greatest limitation to the research project was gaining commitment from the South African nanotechnology community. Through numerous telephone conversation and interviews, and gaining the trust of many of the SANi members, this limitation was overcome.

Although initial mistakes were made, by not correlating the nanotechnology segments of the research project with those of the CSIR baseline study, and not sufficiently pre-testing the research project questionnaire, enough accurate and quality information was gathered to link both the studies and create a number of well-formulated innovation strategies.

Once again, it would have been most satisfying to have had participants stating what nanotechnology product life cycle they partake, in each nanotechnology segment, but this would have taken a tremendous amount of time and effort on the part of the participants. A decision had to be made where to draw the line on what information was really needed.

However, one aspect that the author would like to address is the change of the research design from a Delphi study to a single questionnaire, supported by feedback comments and the CSIR baseline study data. The timing of the research project and the CSIR baseline study questionnaire was not optimal, because of two reasons:

- the research project questionnaire started circulating about two weeks too late (because of a late change in the nanotechnology segments), and
- the CSIR baseline questionnaire was delayed by more than a month; this caused confusion in many of the participants.

The South African nanotechnology community are very positive about partaking in a national study, but are also particularly busy. The two questionnaires were supposed to be distributed at the same time, limiting confusion about the objectives of both questionnaires, but in the end, this was not the case. The author of the research project, after an interview with Mr. Manfred Scriba, decided to eliminate the Delphi study. A feedback form with the option of providing more information and comments on the analysed data from the first research project questionnaire was sent instead to all the participants, to which only two participants replied.

Despite all this, the author of the research project feels that the study was a huge success, an amazing learning opportunity and a great step towards further studies in the field of innovation and technology management.

## 7.4 Recommendations

### *7.4.1 Nanotechnology community*

Nanotechnology is set to change the rules by which product and process development are governed. Just type in "Nanotechnology" into any internet search engine and there are bound to be more than 1,500,000 entries returned from all ends of the earth. In essence, nanotechnology enables us through new tools and techniques, to control the basic properties of materials, such as strength, weight, purity, etc. Endless opportunities are created through exciting new materials, while pushing the limits of current technical innovations.

South Africa possesses the nanotechnology expertise, natural resources, funding sources and hunger to develop nanotechnology-related products and processes - and succeed in global niche markets. The problem is that these separate value-adding activities must be coordinated and facilitated in order to grasp the economic, social and technological growth opportunities.

The South African nanotechnology community needs to formulate concrete and practical strategies, with clear and identifiable visions, goals and objectives. Referring to the nanotechnology strategies developed in the research project, most of the strategies are concerned with:

- Developing and combining innovative nanotechnology knowledge, skills and experience with other cross-functional competencies to develop cost-efficient products and processes.
- Creating South African nanotechnology awareness and gaining support from universities, industry, science councils and government, while creating the necessary support structures (financial, educational, etc.) for nanotechnology researchers and developers.
- Collaborating with local, European, North American and Asian nanotechnology researchers and developers, with the aim of developing relations, gaining support in the form of funding, equipment, personnel, learning opportunities and negotiating trade agreements.

- Focussing on nanotechnology niche markets that are either difficult to imitate by other countries, due the lack of natural resources etc., and could provide a sustainable and competitive environment for local researchers and developers.
- Licensing technologies to create or identify South African nanotechnology focus areas and implement backward integration strategies.
- Regarding the loss of nanotechnology students and personnel due to immigration as an opportunity to keep and build local and international relationships that could provide entry points into international nanotechnology markets.

Nanotechnology is an emerging technology and the South African nanotechnology system of innovation is not a technology colony, but the nanotechnology community does need support to prevent the formation of one. Nanotechnology also entails the convergence of biotechnology and electronics, thus research and development capabilities in these technologies must also be on the agenda.

An organisation that will provide this support, by offering products and services ranging from national and international nanotechnology market analysis and forecasting, funding incentives in order to facilitate the transfer of knowledge, skills and expertise between different industries and institutions is needed. The organisation can be based on the Senter[1], an initiative started by the Dutch government to facilitate the growth of strategic technology capabilities in the Netherlands. The growth of strategic technology capabilities is made possible through the effective allocation of government and industry incentives (supporting the researchers and developers), before venture capital enters the fray. The focus is on building strong R&D capabilities, which entrepreneurs can exploit.

A third party (facilitator) would be a linkage between professional societies, investors, government departments (with their policies) and different tertiary, industrial and science council institutions (refer to Figure 7-7). This third party might be the innovation hub or any other organisation that posses, among others, some nanotechnology, innovation and technology management, legal and project management expertise.

1 www.senter.nl

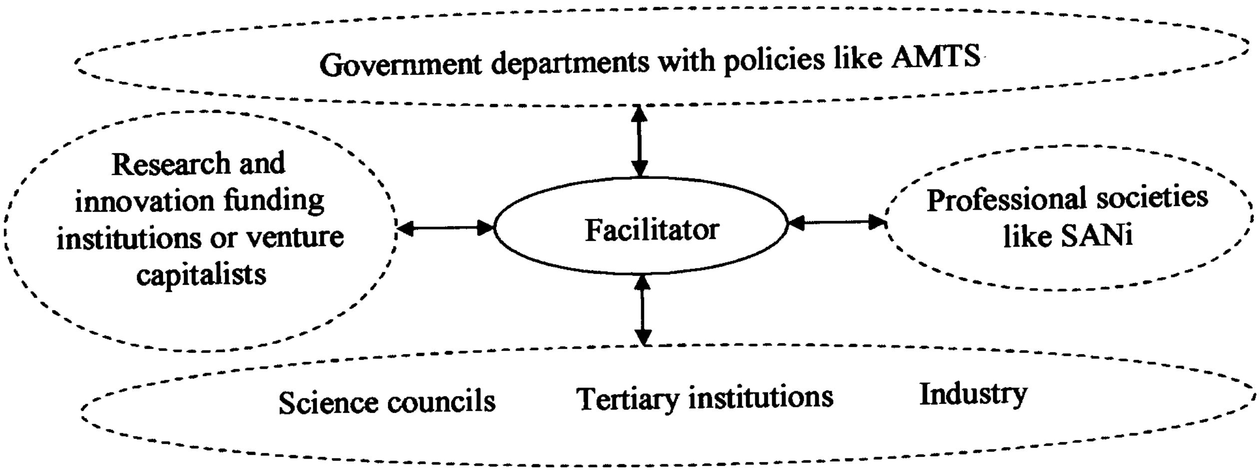



**Figure 7-7. Logical illustration of supposed placement of a technology facilitator.**

The organisation would offer all South African institutions and industries the opportunity to develop national and international nanotechnology relationships, build necessary capabilities to capitalise on nanotechnology innovative applications, empower formerly less privileged communities, encourage entrepreneurship and take full advantage of the funding sources offered by government and venture capitalists. The result will be that South Africa would gain possible footholds in nanotechnology niche markets, not dictated by developed countries – this would create an opportunity for job creation, sustainable energy development and active involvement of students from a wide range of disciplines.

With the breadth of nanotechnology development, anyone is a potential customer or collaborator, but the primary market will be South African nanotechnology actors. The secondary markets will range from South African firms and entrepreneurs (realising the opportunities and threats of nanotechnology) to international nanotechnology actors. Critical success factors would be creating South African awareness of the impact of nanotechnology on all institutions and industries, and safe, effective and efficient transfer of needed knowledge, funding, skills and expertise.

Facilitating directly connects a number of possible researchers, developers and manufacturers with each other through the generation, gathering and distribution of tenders to a wide range of nanotechnology requests for proposals. Key processes in delivering the service could be; gathering request for proposals from local and international nanotechnology actors (which would state the need for, or availability of, basic research, applied research, design, development and/or manufacturing technology of a specific product, process and/or service). Other local and international nanotechnology actors could tender to complete some of the product life cycles. The project could be awarded to a capable nanotechnology actor, negotiating and facilitating the agreement between the two parties. Once the collaboration has been set up, consultation services provided by the organisation could coordinate and help with the overall research, development, manufacturing and/or selling of the nanotechnology products, processes and services.

### *7.4.2 Future studies*

The research project focussed on the softer sciences behind nanotechnology innovation. Many research areas are still unexplored on the technical aspects of nanotechnology.

A number of theoretical issues regarding nanotechnology innovation and technology management also remains (In Realis 2002), some of which are:

- How fast will buyers and intermediaries switch from current technologies and products to nanotechnology-related applications?
- How will the exploitation of nanotechnology influence productivity, the growth of current and new markets?
- How many products, organisations, markets and industries will nanotechnology influence?
- What are the consequences of nanotechnology on national and international economies?

The research project does provide a superb overview of South African nanotechnology current and future activities, but these issues will remain for many years to come. Although nobody can provide the absolute correct answer to any of these questions – forecasts, scenarios and strategies will help countries prepare for the nanotechnology age.

*"Nanotechnology is an important and exciting emerging technology, and one that has the capacity to improve daily life for us all."*

*Nigel Griffiths, Minister of the United Kingdom's Department of Trade and Industry*

# 8 References

Abernathy, W.J. and Utterback W.J., *Patterns of Industrial Innovation*, Technology Review, MIT Alumni Association, 1978.

Advanced Materials Technology Core Team, *Advanced Materials Technology*, Facilitated by Dr. P Truter and Mr. W Merhold, Advanced Manufacturing Strategy (Volume 2): A National Manufacturing Technology Strategy (AMTS) for South Africa, 2002.

Burgelman, R.A., *Intraorganisational Ecology of Strategy Making Organisational Adaption: Theory and Field Research*, Organisational Science 2/3, The Institute of Management Services, 1991.

Burgelman, R.A. and Grove, A.S., *Strategic Dissonance*, California Management Review 38/2, 1996.

Burgelman, R.A, Maidique, M.A. and Wheelwright, S.C., *Strategic Management of Technology and Innovation*, Third edition, McGraw-Hill, New York, 2001

Buys, A.J., *Technological Decolonisation of South Africa by Backwards Integration of National System of Innovation*, Institute for Technological Innovation, University of Pretoria, 2001.

Buys, A.J., *Industrial development in South Africa by Backward Integration of the National System of Innovation.* Institute for Technological Innovation, University of Pretoria, 2002.

Buys, A.J, *Characterisation of the South African National System of Innovation*, Department of Engineering and Technology Management, University of Pretoria, 2003.

Canton, J., *The Strategic Impacts of Nanotechnology on the Future of Business and Economics*, Institute for Global Futures, Published in the Societal Implications of Nanoscience and Nanotechnology, National Science Foundation, United States, 2001

Carlsson, B., Jacobsson, S.,Holménb, M. and Rickne, A., *Innovation systems: analytical and methodological issues*, Elsevier Science B.V., 2002.

Christensen, C.M., *Exploring the limits of Technology S-Curve. Part 1: Component Technologies*, Production and Operations Management 1, no. 4 Production and Operations Management Society, 1992a.

Christensen, C.M., *Exploring the limits of Technology S-Curve. Part 2: Architectural Technologies*, Production and Operations Management 1, no. 4 Production and Operations Management Society, 1992b.

Cohen, W.M. and Levinthal, D.A., *Adsorptive Capacity: Perspective on Learning and Innovation*, Administrative Science Quarterly 35, pp. 128-52, 1990.

Cooper, C. and Schendel, D., *Strategic Responses to Technological Threats*, Business Horisons, Krannert Graduate School of Business Administration, Purdue University, 1976.

David, F.R., *Strategic management concepts*, Eighth edition, Prentice Hall, Upper Saddle River, New Jersey, 2001.

De Wet, G., *Corporate Strategy and Technology Management: Creating the Interface*, CSIR, Pretoria, 1992

De Wet, G., *Emerging from the Technology Colony: A View from the South*, Working Paper ITB2001/1, Department of Engineering and Technology Management, University of Pretoria, South Africa, 2000.

De Wet, G., *Technology Space Maps for Technology Management and Audits*, Faculty of Engineering, University of Pretoria, Pretoria, unknown.

Drejer, A., *The discipline of management of technology, based in considerations related to technology*, Technovation 17(5) 253-265, Elsevier Science Ltd., Great Britain, 1996.

Forbes/Wolfe Nanotech Report, *Nano 101: An Insider Guide to the World of Nanotechnology*, Forbes Inc. & Angstrom Publishing LLC. ,www.forbesnanotech.com, 2002.

Ford, D., *Develop your Technology Strategy*, Long range planning, vol.21 no.5, pp.85-94, 1988.

Gann, D., *The Emperor's New Coating - New Dimensions for the Built Environment: The Nanotechnology Revolution*, University of Sussex, February 2003

Gerybadze, A., *Technology forecasting as a process of organisational intelligence*, R&D Management 24/2, Blackwell Publishers, Cambridge, UK,1994

Gingrich, N., *The Age of Transition*, American Enterprise Institute, Published in the Societal Implications of Nanoscience and Nanotechnology, National Science Foundation, United States, 2001.

Gordon, N., *Brief Investment overview of where Nanotech & Biotech will Converge*, Turtlesnap Convergence of Nanotech and Biotech Investment Symposium, Sygertech Consulting Group Inc., 2002.

Hamel, G., Doz, Y.L. and Prahalad, C.K., *Collaborate with Your Competitors – and Win*. Harvard Business Review, President and Fellows of Harvard Business College, 1989.

Helmer, O., Linstone, H.A. and Turoff, M., *The Delphi Method: Techniques and Applications,* Murray Turoff and Harold A. Linstone Publications, Portland, 2002.

Henderson, R.M. and Clark, K.B., *Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms*, Administrative Science Quarterly, Cornell University, pp 9-30, 1990.

In Realis, *A Critical Investor's guide to Nanotechnology*, www.inrealis.com , 2002.

International Technology Research Institute, *Nanotechnology Research Directions: IWGN Workshop Report, Vision for Nanotechnology R&D in the Next Decade*, World Technology (WTEC) Division, Maryland, 1999.

Khalil, T.M., *Management of Technology: The key to Competitiveness and Wealth Creation*, First Edition, McGraw-Hill International Editions, Singapore, 2000.

Kostoff, R.N. and Schaller, R.R., *Science and Technology Roadmaps*, IEEE Transactions on Engineering Management, 2000.

Leedy, P.D. and Ormrod, J.E., *Practical Research: Planning and Design*, Seventh Edition, Prentice-Hall Inc., Upper Saddle River, New Jersey, 2001.

Lieberman, M.B. and Montgomery D.B., *First-mover advantages*, Graduate School of Business, Stanford University, Stanford, California, U.S.A. 1988

Linton, J.D. and Walsh, S.T., *A Theory of Innovation for Nanotechnologies and other Process-Based Innovations*, IEEE Publications, 2003.

LuxCapital, *The Nanotech Report: Investment overview and market research for nanotechnology, Volume 2*, Lux Capital Group, LLC, New York, 2003

LuxCapital, *The Nanotech Report 2004: Investment overview and market research for nanotechnology (Third Edition)*, Lux Capital Group, LLC, New York, 2004.

Moore, G.A., *Crossing the chasm – and Beyond*, HarperBusiness, New York, 1999.

Moore, G.A. Predator and Prey: *A New Ecology of Competition*, The President and Fellows of Harvard College, 1993.

NanoInvestorNews, www.nanoinvestornews.com, 23 July, 2003

National Science and Technology Council, *Nanotechnology: Shaping the world atom for atom*, The Interagency Working group on NanoScience, Engineering and Technology, Washington D.C., 1999.

Narayanan, V.K., *Managing Technology and Innovation for Competitive Advantage*, Prentice-Hall Inc., Upper Saddle River, New Jersey, 2001.

Nieto, M., Lopez, F. and Cruz, F., *Performance analysis of technology using the S-Curve model: the case of digital signal processing (DSP) technologies*, Technovation, 18(6/7), Elsevier Science Ltd., Great Britain, 1998.

Nolte, F.W. and Pretorius, M.W., *Implementing first world technology systems in third world industrial systems*, Siemens Telecommunications (Pty) Ltd, Pretoria, South Afirca and University of Pretoria, Pretoria, South-Africa, 2002.

Oerlemans, L.A.G, Pretorius, M.W., Buys, A.J. and Rooks, G., *South African Innovation Survey 2001: Industrial innovation in South Africa*, Department of Engineering and Technology Management and Eindhoven University of Technology, Pretoria, 2003.

Page, C. and Meyer D., *Applied Research Design for Business and Management*, First Edition, McGraw-Hill Companies Inc., Australia, 2000.

Pavitt, K., *What we know about the Strategic Management of Technology*, Annual Meeting of the Bristish Academy of Management, published in R. Mansfields, Ed., Frontiers of Management, London, Routledge, 1989.

Porter M. E., *How competitive forces shape strategy*. Harvard Business Review, 57 (2), March - April, 1979.

Porter, M.E, *Technological dimensions of competitive strategy, Research on Technological Innovation, Management, and Policy*, Vol. 1, JAI Press, Inc., London, England 1988.

Prahalad, C.K. and Hamel, G., *The Core Competency of the Corporation*, The President and Fellows of Harvard College, Harvard, 1990.

Roberts, E. and Berry, C., *Entering new businesses: Selecting strategies for success*, Sloan Management Review, 1985.

South African Nanotechnology Initiative (SANi), *South African Nanotechnology Strategy: Nanowonders – Endless possibilities, Volume 1*, Pretoria, 2003a.

South African Nanotechnology Initiative (SANi), *South African Nanotechnology Strategy: Nanowonders – Endless possibilities, Volume 2*, Pretoria, 2003b.

Thomke, S. and Nimgabe, A., *Note on Lead User Research*, Article adapted from Von Hippel, E., Churchill, J. and Sonnack, M., Breakthrough Products and Services with Lead User Research, Cambridge, Minneapolis: Lead User Concepts, Oxford University Press, 1998.

Twiss, B.C., *Technological forecasting for decision-making: Managing Technological Innovation*, Second Ed, Longman, New York, 1980.

Willyard, C.H. and McClees, C.W., *Motorola's Technology Roadmap Process*, Motorola Inc., 1987.

Zikmund, W.G. and d'Amico, M., *Effective Marketing*, 3rd ed., South-Western Publications, Cincinnnati, Ohio, 2002.

# 9 Personal Information

| | |
|---|---|
| First names | Derrick Louis |
| Surname | Van der Merwe |
| Student number | 99159032 |
| Postal address | P.O. Box 49906<br>South Africa<br>Gauteng<br>Hercules<br>0030 |
| E-mail address | dlvdm@tuks.co.za |
| Home telephone number | +2712 379 7939 |
| Mobile number | +2782 629 8807 |
| University | University of Pretoria |
| Degree | MEng (Technology Management) |

# Appendix A. Research project questionnaires

## A.1 First research project questionnaire

**STUDY OF THE NANOTECHNOLOGY SYSTEM IN SOUTH AFRICA**
by

**DERRICK VAN DER MERWE**

# QUESTIONNAIRE

Part of a research project submitted in partial fulfilment of the requirements for the degree of

**MASTER OF TECHNOLOGY MANAGEMENT**

in the

FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY

UNIVERSITY OF PRETORIA

May 2004

Contact details
Name: Derrick van der Merwe
E-mail address: dlvdm@tuks.co.za
Mobile number: 082 629 8807
Fax number: (012) 362 5307

Please fill in the following information

Name of Participant ______________________

Field of Nanotechnology interest ______________________

Employer ______________________

## Introduction

The purpose of the questionnaire is to identify possible opportunities for and threats to South African nanotechnology initiatives, through the identification of future nanotechnology actors, products, services, industries and factors hampering innovation. The aim is to gain information on the South African nanotechnology system and devise a possible innovation strategy for South Africa to consider.

Results from the first questionnaire will be analysed and returned to the panel of experts. Interesting and abnormal answers can then be discussed further (via E-mail or telephone) and elaborated upon in the second (and possible third) iteration. The questionnaire will take a maximum of 15 minutes to complete. Results will be readily available to the panel of experts.

No questions are asked in this questionnaire concerning the current state of nanotechnology in South Africa – this will be the goal of future baseline questionnaires by the South African Nanotechnology Initiative (SANi). Selective information from these questionnaires and other secondary data sources will be used in the Master's research project.

Seven nanotechnology segments and their applications were considered for the questionnaire. These segments were accumulated through a number of literature reviews and by no means incorporate the full breadth of nanotechnology in the future:

1. Tools (microscopy, techniques, tools, techniques, etc.)
2. Raw materials (catalysis, biocompatible materials, coatings and protective creams, etc.)
3. Structures (nanocapsules, nanofilters, quantum dots, branched polymers, etc.)
4. Nanotubes and fullerenes (Buckeyballs)
5. Devices and Systems (bio-sensors, detectors, drug delivery systems, electro-mechanical systems, etc.)
6. Intelligent materials (sense external stimuli and altering properties)
7. Machines (molecular machines, assemblers, nanobots etc.

Please tick the best answer – the grey area may be edited in Microsoft Word

| | 5 | 6 | 7 | 8 |
|---|---|---|---|---|
| For example – How many segments have been identified? | ☐ | ☐ | ☒ | ☐ |

Now try to answer this first question by choosing the best answer

| | Yes | No |
|---|---|---|
| Do you agree with the nanotechnology segments chosen? | ☐ | ☐ |

## Nanotechnology segments

1. How long before these nanotechnology segments start replacing the majority of other technologies in current applications, or create completely new technology applications?

| | Now | 1-5 years | 5-10 years | 10-15 years | 15-20 years |
|---|---|---|---|---|---|
| a. Tools | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. Raw materials | ☐ | ☐ | ☐ | ☐ | ☐ |
| c. Structures | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. Nanotubes and Fullerenes | ☐ | ☐ | ☐ | ☐ | ☐ |
| e. Devices and Systems | ☐ | ☐ | ☐ | ☐ | ☐ |
| f. Intelligent materials | ☐ | ☐ | ☐ | ☐ | ☐ |
| g. Machines | ☐ | ☐ | ☐ | ☐ | ☐ |
| h. Other: | ☐ | ☐ | ☐ | ☐ | ☐ |

2. What is the market potential during the next 15 years for these nanotechnology segments – in terms of size and timing on return of investment, sustainable market growth, etc.?

| | None | Small | Medium | Big | Huge |
|---|---|---|---|---|---|
| a. Tools | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. Raw materials | ☐ | ☐ | ☐ | ☐ | ☐ |
| c. Structures | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. Nanotubes and Fullerenes | ☐ | ☐ | ☐ | ☐ | ☐ |
| e. Devices and Systems | ☐ | ☐ | ☐ | ☐ | ☐ |
| f. Intelligent materials | ☐ | ☐ | ☐ | ☐ | ☐ |
| g. Machines | ☐ | ☐ | ☐ | ☐ | ☐ |
| h. Other: | ☐ | ☐ | ☐ | ☐ | ☐ |

3. How disruptive are these nanotechnology segments the next 15 years to other known and familiar technologies? (What role will nanotechnology assume in relation to the technology it ultimately replaces or complements?)

| | No change | Support | Complement | Control | Replace |
|---|---|---|---|---|---|
| a. Tools | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. Raw materials | ☐ | ☐ | ☐ | ☐ | ☐ |
| c. Structures | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. Nanotubes and Fullerenes | ☐ | ☐ | ☐ | ☐ | ☐ |
| e. Devices and Systems | ☐ | ☐ | ☐ | ☐ | ☐ |
| f. Intelligent materials | ☐ | ☐ | ☐ | ☐ | ☐ |
| g. Machines | ☐ | ☐ | ☐ | ☐ | ☐ |
| h. Other: | ☐ | ☐ | ☐ | ☐ | ☐ |

4. How complex are these nanotechnology segments to perform basic and applied research on, design, manufacture and market to a potential market? (Keep in mind the nanotechnology segments in relation to each other in terms of knowledge, time, skills, general public's perceptions, etc. needed)

| | Not complex | Not relatively complex | Relatively complex | Complex | Very complex |
|---|---|---|---|---|---|
| a. Tools | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. Raw materials | ☐ | ☐ | ☐ | ☐ | ☐ |
| c. Structures | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. Nanotubes and Fullerenes | ☐ | ☐ | ☐ | ☐ | ☐ |
| e. Devices and Systems | ☐ | ☐ | ☐ | ☐ | ☐ |
| f. Intelligent materials | ☐ | ☐ | ☐ | ☐ | ☐ |
| g. Machines | ☐ | ☐ | ☐ | ☐ | ☐ |
| h. Other: | ☐ | ☐ | ☐ | ☐ | ☐ |

5. Do you have any comments on the above questions?

## Innovation hampers

6. How much does each of the following factors hamper nanotechnology innovation in South Africa – by creating for instance uncertainty in investors?

| | None | A little | Some | A lot | A great deal |
|---|---|---|---|---|---|
| a. Knowledge gap (Lack of information) | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. Technology development (Disruptiveness and unfamiliarity) | ☐ | ☐ | ☐ | ☐ | ☐ |
| c. Lack of tools, equipment and techniques (Microscopes, simulation, etc.) | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. Lack of qualified personnel (Insufficient training) | ☐ | ☐ | ☐ | ☐ | ☐ |
| f. Costs involved (Estimated costs too high) | ☐ | ☐ | ☐ | ☐ | ☐ |
| g. Uncertainty of net economic effect (Breadth, growth and impact of nanotechnology unsure) | ☐ | ☐ | ☐ | ☐ | ☐ |
| h. Insufficient funding (Lack of appropriate government or other external funding) | ☐ | ☐ | ☐ | ☐ | ☐ |
| i. Time to commercialisation (Too long estimated investment return periods) | ☐ | ☐ | ☐ | ☐ | ☐ |
| j. Regulations (Governmental or other legal restrictions) | ☐ | ☐ | ☐ | ☐ | ☐ |
| k. Supplier/Buyer adoption rates (When to switch from known products to new Nanoproducts) | ☐ | ☐ | ☐ | ☐ | ☐ |
| l. Technology replacement (Potential for other newer Nanoproducts to replace existing Nanoproducts) | ☐ | ☐ | ☐ | ☐ | ☐ |
| m. Lack of collaborations (Relationships between innovative organisations and other institutions) | ☐ | ☐ | ☐ | ☐ | ☐ |
| n. Other factors…… | ☐<br>☐<br>☐ | ☐<br>☐<br>☐ | ☐<br>☐<br>☐ | ☐<br>☐<br>☐ | ☐<br>☐<br>☐ |

7. Do you have any comments on the above questions?

| |
|---|
| |

## Nanotechnology actors

In the future, local and international nanotechnology buyers, suppliers, competitors, investors and research partners will emerge.

8. Do you agree that markets in these locations will be important **buyers** of nanotechnology for the next 15 years? (Consider buying power, size of the market, etc.)

| | Disagree | Slightly disagree | No opinion | Slightly agree | Agree |
|---|---|---|---|---|---|
| a. Local | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. Other African countries | ☐ | ☐ | ☐ | ☐ | ☐ |
| c. Europe | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. North America | ☐ | ☐ | ☐ | ☐ | ☐ |
| e. South America | ☐ | ☐ | ☐ | ☐ | ☐ |
| f. Asia | ☐ | ☐ | ☐ | ☐ | ☐ |
| g. Australia and New Zealand | ☐ | ☐ | ☐ | ☐ | ☐ |

9. Do you agree that manufacturers in these locations will be important **suppliers** of nanotechnology for the next 15 years? (Consider current national strategies, breadth of potential industries, availability of resources, etc.)

| | Disagree | Slightly disagree | No opinion | Slightly agree | Agree |
|---|---|---|---|---|---|
| a. Local | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. Other African countries | ☐ | ☐ | ☐ | ☐ | ☐ |
| c. Europe | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. North America | ☐ | ☐ | ☐ | ☐ | ☐ |
| e. South America | ☐ | ☐ | ☐ | ☐ | ☐ |
| f. Asia | ☐ | ☐ | ☐ | ☐ | ☐ |
| g. Australia and New Zealand | ☐ | ☐ | ☐ | ☐ | ☐ |

10. Do you agree that institutes in these locations will be important **competitors** in the nanotechnology global economy for next 15 years? (Consider the size and amount of potential competitive organisations and industries, etc.)

| | Disagree | Slightly disagree | No opinion | Slightly agree | Agree |
|---|---|---|---|---|---|
| a. Local | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. Other African countries | ☐ | ☐ | ☐ | ☐ | ☐ |
| c. Europe | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. North America | ☐ | ☐ | ☐ | ☐ | ☐ |
| e. South America | ☐ | ☐ | ☐ | ☐ | ☐ |
| f. Asia | ☐ | ☐ | ☐ | ☐ | ☐ |
| g. Australia and New Zealand | ☐ | ☐ | ☐ | ☐ | ☐ |

11. Do you agree that South Africa will have strong **relationships** with partners (private or public institutes) located in these areas in the nanotechnology global society for the next 15 years? (Consider countries with similar interests than South Africa or current good bonds with South Africa)

| | Disagree | Slightly disagree | No opinion | Slightly agree | Agree |
|---|---|---|---|---|---|
| a. Local | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. Other African countries | ☐ | ☐ | ☐ | ☐ | ☐ |
| c. Europe | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. North America | ☐ | ☐ | ☐ | ☐ | ☐ |
| e. South America | ☐ | ☐ | ☐ | ☐ | ☐ |
| f. Asia | ☐ | ☐ | ☐ | ☐ | ☐ |
| g. Australia and New Zealand | ☐ | ☐ | ☐ | ☐ | ☐ |

12. Do you have any comments concerning any of these relationships – for instance do you feel that the importance of a location could change significantly as time progresses or radically between nanotechnology segments?

## Nanotechnology strengths, weaknesses, opportunities and threats

13. What do you perceive as the most important strengths and weaknesses of South African nanotechnology industries and tertiary institutions focussing on nanotechnology research activities?

a. Strengths

b. Weaknesses

14. What do you perceive as the biggest opportunities and threats for South African nanotechnology industries and tertiary institutions focussing on nanotechnology research activities?

a. Opportunities

b. Threats

15. Please, feel free to comment on this research project (maybe some questions regarding the research objectives or sources) or questionnaire (maybe some questions were not clear)

| |
|---|
| |

# PLEASE REMEMBER

Please make sure that you **SAVE** the answers you entered and E-mail the Word document to dlvdm@tuks.co.za or print the document and fax it to (012) 362 5307. Address any faxes to Derrick van der Merwe.

If you have you any questions you can contact me via E-mail at dlvdm@tuks.co.za or cell phone at +2782 629 8807

## A.2 Second research project questionnaire (feedback form)

**STUDY OF THE NANOTECHNOLOGY SYSTEM IN SOUTH AFRICA**
**by**

**DERRICK VAN DER MERWE**

# QUESTIONNAIRE

Part of a research project submitted in partial fulfilment of the requirements for the degree of

**MASTER OF TECHNOLOGY MANAGEMENT**

in the

FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY

UNIVERSITY OF PRETORIA

July 2004

Contact details
Name: Derrick van der Merwe
E-mail address: dlvdm@tuks.co.za
Mobile number: 082 629 8807
Fax number: (012) 362 5307

Please fill in the following information
Name of Participant ______________________________

Thank you for all your time and effort. Note that all the graphs are based on the averages of the answers provided, and they are by no means faultless…but do provide the general trends and indicate the majority perception of the expert panel. The standard deviation and frequency tables of the data have not been included.

# 1 Feedback from previous questionnaire

## 1.1 Nanotechnology segments

As you may remember the time to market (from now = 1 to 20 years = 5), the market potential (from no potential = 1 to huge potential = 5), disruptiveness (from no change = 1 to total replacement = 5) and complexity (from not complex = 1 to very complex = 5) for seven different nanotechnology segment were asked. The graph below illustrates these results.

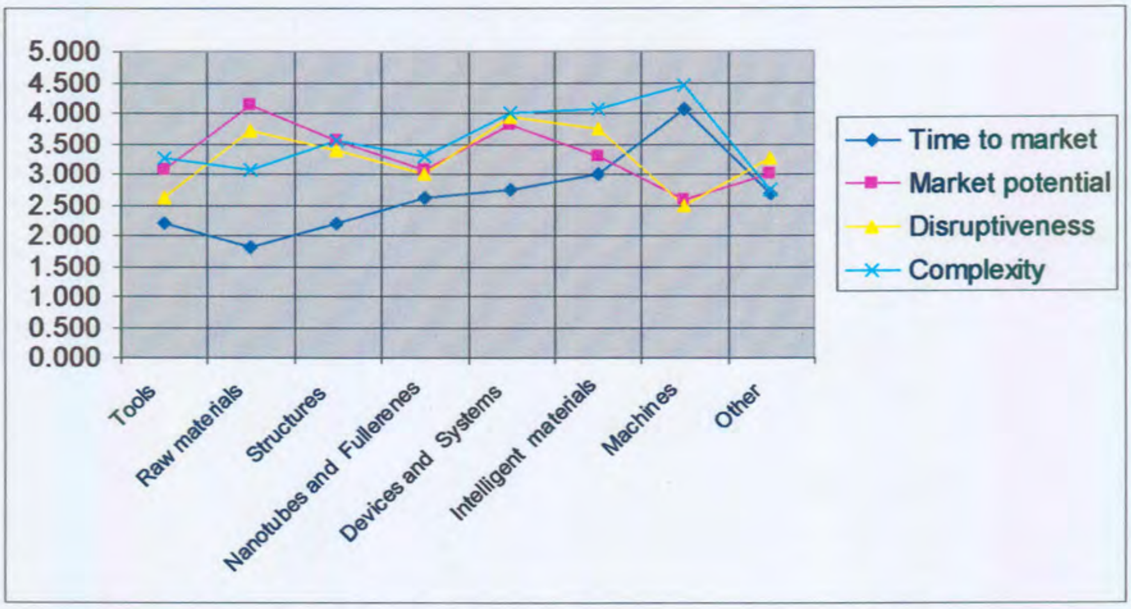



**Figure 1-1. The time to market, market potential, disruptiveness and complexity of seven identified nanotechnology segment.**

Nanotechnology is extremely diverse with many different definitions, segmentations, groupings and perspectives. The goal is to try and establish some relationship between and estimations of the time to market, market potential, disruptiveness and complexity. Already some evidence suggests that time-to-market and complexity is linearly related. Below are 3 questions, which are optional, but could be helpful to my study.

How much skilled **human** resources are needed to fully research, develop, manufacture, market and sell each of these nanotechnology segments?

| | Nothing | Small | Medium | Large | Huge |
|---|---|---|---|---|---|
| a. Tools | ☐ | ☐ | ☐ | ☐ | ☐ |
| b. Raw materials | ☐ | ☐ | ☐ | ☐ | ☐ |
| c. Structures | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. Nanotubes and Fullerenes | ☐ | ☐ | ☐ | ☐ | ☐ |
| e. Devices and Systems | ☐ | ☐ | ☐ | ☐ | ☐ |
| f. Intelligent materials | ☐ | ☐ | ☐ | ☐ | ☐ |
| d. Machines | ☐ | ☐ | ☐ | ☐ | ☐ |
| e. Other: | ☐ | ☐ | ☐ | ☐ | ☐ |

What is the current and future role (influence) of venture capital and government incentives in the research, development, manufacturing, marketing and selling of each of these nanotechnology segments?

Do have any comments on the results of this first section or recommend any grouping, dividing or inclusion of other nanotechnology segments?

## 1.2 Innovation hampers

The graph below illustrates the innovation hampers standing in the path of nanotechnology development in South Africa (the scale is from none =1 to great deal = 5).

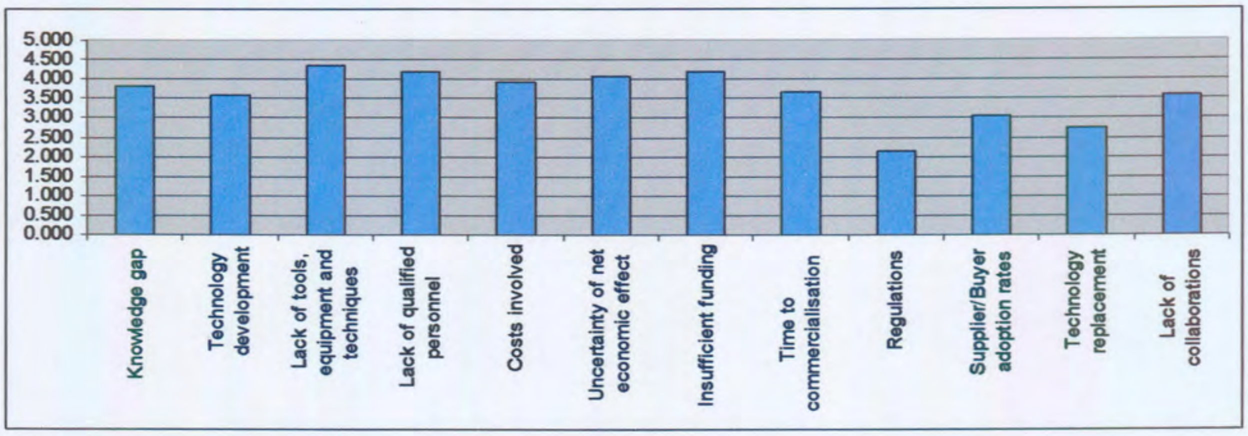



**Figure 1-2. The innovation hampers**

The lack of equipment, funding and qualified personnel was rated as the top three innovation hampers. Note that the first eight factors together with the lack of collaboration with other institutions was seen hampering nanotechnology innovation in South Africa a lot.

Do have any comments on the results of this second section

## 1.3 Nanotechnology actors

The graph below illustrates the national actors in nanotechnology worldwide (the scale is disagree = 1, slightly disagree = 2, no opinion = 3, slightly agree = 4 and agree = 5)

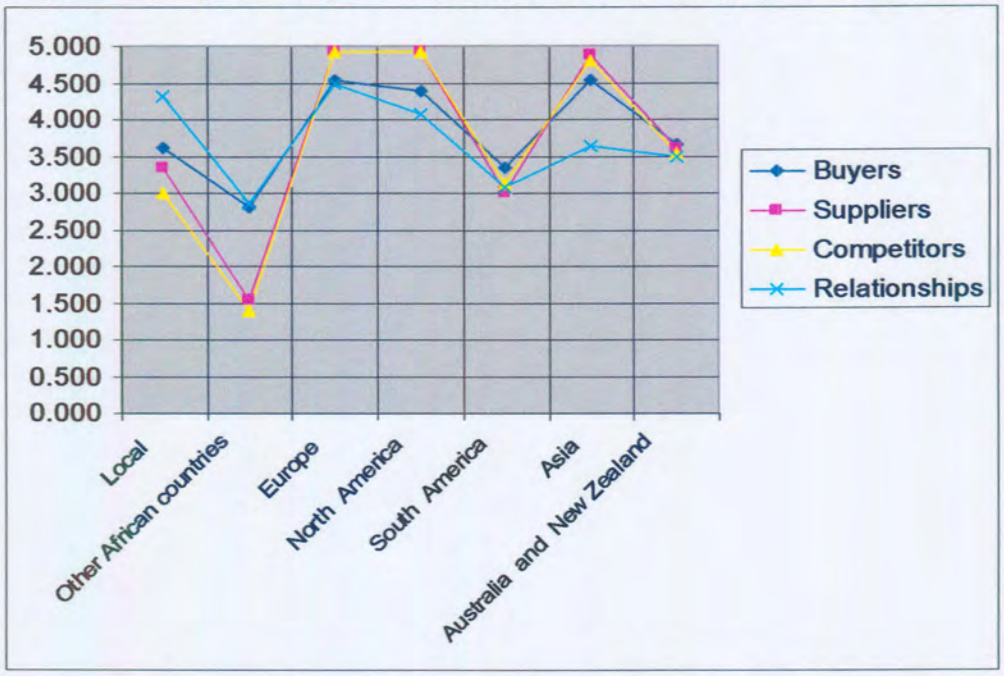



**Figure 1-3. Nanotechnology actors in terms of buyers, suppliers, competitors and collaborations.**

Europe was rated as the most important geographical area in all the groups and together with North America and Asia rated as the biggest buyers and competitors. Local actors was seen the second most important source of relationships or collaborations, strangely enough Asia was not seen as source of relationships and the greatest uncertainty as buyers existed concerning local, other African countries and South America.

Do have any comments on the results of this third section

# Please Remember

Please make sure that you SAVE the answers you entered and E-mail the Word document to dlvdm@tuks.co.za or print the document and fax it to (012) 362 5307. Address any faxes to Derrick van der Merwe.

If you have you any questions you can contact me via E-mail at dlvdm@tuks.co.za or cell phone at +2782 629 8807

## Appendix B. CSIR baseline study questionnaire

**Baseline Study on Nanotechnology**
**Activities in South Africa - May/June 2004**

**Section 1**

| | |
|---|---|
| Date: | |
| Information collected by: | |

**Section 2**

| | | |
|---|---|---|
| 1 | Surname | |
| 2 | Name | |
| 3 | Title | |
| 4 | Position | |
| 5 | Organisation | |
| 6 | Department | |
| 7 | Tel. | |
| 8 | e-mail | |
| 9 | Fax. | |

**Section 3**

| | |
|---|---|
| Main focus of your company/group? (Physics, Chemistry, Pharmaceutical, Plastic manuf. etc.) | |

**Section 4a**

Do you know what Nanotechnology/Nanoscience is?

| Yes | | No | |
|---|---|---|---|

If not, please do section 19 and 20 only.

**Section 4b**
In which broad Nanotechnology / Nanoscience areas is your group active?

| Processing/Manufacturing | Characterisation | Modelling | Other |
|---|---|---|---|
| | | | |

**Section 5**

Are you involved in Nanotechnology R&D or are you Manufacturing Nanomaterials or devices or use Nanotechnology in a Product or Process?

| R&D | Manufacture Nanomaterials or devices | Use Nanotechnology in Process | Use Nanomaterials in a Product | Import and sell Nanomaterials or devices directly | Other |
|---|---|---|---|---|---|
| | | | | | |

**Section 6**

What aspect of Nanotechnology are you involved in?
(Mark more than one if required)

| | |
|---|---|
| Nanomaterials (Particles, Tubes, Composites etc.) | |
| Nano Biotechnology | |
| Membranes | |
| Drug Delivery | |
| Catalysis | |
| Nano Devices | |
| Nano emulsions | |
| Coatings | |
| Fundamental Research | |
| Atomic Modelling | |
| Characterisation | |
| Use some of the above in a product or process but buy inn from other source (specify) | |
| Other | |

Please give more details on the involvement and projects of your group. (Max 2 sentence per area)

| |
|---|
| |
| |
| |
| |
| |
| |
| |
| |

**Section 7**

Who is funding your groups Nanotechnology research?

| | Estimate amount |
|---|---|
| Private (Industry) | |
| Public (NRF, Government etc.) | |
| Internal (Own funds) | |
| International | |
| Science Councils | |
| Other | |
| | |

**Section 8**

In the case of you importing Nanomaterials or Devices

| What are you importing | Estimate amount in Rand |
|---|---|
| | |
| | |
| | |
| | |
| | |
| | |
| | |

**Section 9a**

In the case of you commercially manufacturing Nanomaterials or Devices

| What are you manufacturing? | Estimate amount in Rand |
|---|---|
| | |
| | |
| | |
| | |
| | |
| | |
| | |

**Section 9b**

Estimate the % effort (time and cost) spent between R&D and Production?

| R&D | Production | |
|---|---|---|
| % | % | (Total must be 100%) |

**Section 10a**

If you licence Nanotechnology from overseas, roughly what are the costs of the Licence?

| R |
|---|

**Section 10a**

Do you have international collaborators in Nanotechnology?
Please name countries and organisations if possible.

| Country | Organisation |
|---|---|
| | |
| | |
| | |
| | |
| | |

**Section 11**

Personnel Information (all questions applicable to Nanotechnology group only)

| Total number of Personnel | |
|---|---|

| Gender | Male | Female |
|---|---|---|
| | | |

| Race | Black | White |
|---|---|---|
| | | |

| People with disability/ies | |
|---|---|

| Number in Age group | 20-30 | 30-40 | 40-50 | 50+ |
|---|---|---|---|---|
| | | | | |

| Do you have programmes for staff to further their education? |
|---|
| |

**Section 12 (Academia Only)**

At what level is Nanotechnology being taught?

| Graduate | Honours | Masters | PhD |
|---|---|---|---|
| | | | |

Roughly how much financial support for students do you get from Industry? (Bursaries etc.)

| kR |
|---|

Nanotechnology Education Training and Curriculum
(Industry, Funding Agencies and Science Councils – please record your actual students that you support here. Academia, record actual students enlisted in your group)

| Total number of students | |
|---|---|

| Gender | Male | Female |
|---|---|---|
| | | |

| Race | Black | White |
|---|---|---|
| | | |

| Disabled | |
|---|---|
| | |

Level of education

| | Number of students |
|---|---|
| Honours | |
| Masters | |
| PhD | |

Post Doctoral Students

| | |
|---|---|
| Total number of Post Docs | |

| Gender | Male | Female |
|---|---|---|
| | | |

| Race | Black | White |
|---|---|---|
| | | |

| | |
|---|---|
| People with disability/ies | |

**Section 13 (Academia Only)**

From which countries do these students come? (Include all students)

| Country | Number of students |
|---|---|
| South Africa | |
| | |
| | |
| | |
| | |
| | |

**Section 14**

Technical Outputs of the group

| | |
|---|---|
| Number of Nanotechnology PATENTS | |
| Number of Publications in Nanotechnology | |
| Income from Industry for Nanotechnology R&D. (Total industry support) | |
| Participation in international projects | |
| Your thoughts on how you can improve the output? | |
| Details of Nanotechnology already commercialised by your group to date | |

| | | | | |
|---|---|---|---|---|
| Does your organisation encourage spin-off companies? | Yes | | No | |
| Have there been any Nanotechnology related spin-off companies formed to date? | Yes | | No | |
| Do you have a BEE programme or initiative? | Yes | | No | |

**Section 15**

Your major need at the moment

| | |
|---|---|
| Equipment | |
| Personnel | |
| R&D Funding | |

**Section 16**

Networking

| | | | | | |
|---|---|---|---|---|---|
| Are you aware of, or a member of the South African Nanotechnology initiative (SANi)? | | | | | |
| How many national collaborators do you have? (Groups and persons) | | | | | |
| How many International collaborators do you have? (Groups and People) | | | | | |
| How many of these International Collaborators came about through government arranged international interaction? | | | | | |
| Do you know what the FP6 funding mechanism is and have you been involved in a proposal? | | | | | |
| If there were workshops and educational programmes to learn more about Nanotechnology, would you commit people to attend? | Never | Think not | Possibly | Think so | Definitely |
| | | | | | |
| Do you know organisations, companies or groups that should participate in Nanotechnology in SA but are not aware of the activities? | | | | | |

**Section 17**

Time frame:

| | |
|---|---|
| For how long have you been involved in Nanotechnology? | |
| Where do you see yourselves in future? | |
| When do you think Nanotechnology will make its impact felt internationally? | |

**Section 18**

General

| | |
|---|---|
| Where are the opportunities and gaps in Nanotechnology in SA? | |
| What should be done to address the gap? | |
| Do you see opportunities or threats for SA from Nanotechnology? | |
| Do you feel there should be investment in Nanotechnology R&D and on which areas should the focus be? | |
| What role should government play in the implementation of new sciences and technologies like Nanotechnology? | |

**Section 19**

In the case where you do not know what Nanotechnology is:

**Please read the short overview of Nanotechnology and answer the following questions.**

Do you feel your group/company should look at the benefits Nanotechnology can offer?

| | | | |
|---|---|---|---|
| Yes | | No | |

Does your group/company do research and development?

| | | | |
|---|---|---|---|
| Yes | | No | |

**Section 20**

Do you have any of the following activities in the group/company that might involve Nanotechnology without your knowledge?

| | |
|---|---|
| Catalysis | |
| Thin Films | |
| Macromolecules | |
| Dendrites | |
| Protein synthesis | |
| Fine powder manufacture | |
| Macromolecules | |
| Chemistry | |
| Composites | |
| Ceramics | |
| | |
| | |
| | |
| | |
| | |

**Section 21**

Equipment and Facilities

| | Equipment/ Facility Description | Condition (1 – Good, 2 – average, 3 – bad) | Compared to state of the art (1 - same, 2- slightly worse, 3- much worse) | Comment on requirements regarding this particular instrument (upgrade required, repairs needed, higher resolution essential etc.) |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

How are the facilities funded and managed?

Contact details of Facility manager:

Who shares/uses the facilities/equipment with you? (other universities etc.)

Equipment needs?

# Appendix C. Data gathered

## C.1 Research project questionnaire

### *C.1.1 Background information*

| Name | Surname | Title | Field of nanotechnology interest | Employer |
|---|---|---|---|---|
| Willie | Augustyn | Mr | Application of catalysis | The University of Technology – Dept. of Chemistry and Physics |
| Martin | Beyers | Mr. | Manufacturing | Groupline Technical Ceramics |
| Daven | Compton | Dr | Nanotechnology applications using precious metals | Mintek |
| Humphrey | Dlamini | Dr | Catalysis | SASOL |
| Marius | Du Plessis | Mr | Polymers, filler, coatings, binding, bio-sensors | Mondi Paper SA |
| Gerhard | Gericke | Mr | Energy, catalysis and water treatment | ESKOM |
| Andre | Germishuizen | Mr | The use of self-assembly and bio-molecules (in particular DNA) in the construction of nanoscale devices (molecular electronics MEMS, biosensors, etc) | CSIR |
| Corinne | Greyling | Ms | Polymeric nanofibres and nanoparticles, for application in catalysis, absorbents, tissue scaffolds and controlled release applications. Fundamental research and industrial product development. | Department of Chemistry and Polymer Science – University of Stellenbosch |
| Bongani | Nkosi | Dr | Zeolites and Molecular sives. Materials Characterization. | SASOL |
| Leslie | Petrik | Ms | Advanced Nanomaterials: - composite nanophase electrodes, nanocatalysts and electro catalysts, characterization of nanomaterials, applications of nanomaterials for hydrogen production, fuel cells, environmental cleanup | University of Western Cape |
| Frans | Prinsloo | Dr | Tools; Raw Materials; Nanotubes | SASOL |
| Neerish | Revaprasadu | Dr | Synthesis of Nanoparticles | University of Zululand |
| Manfred | Scriba | Mr | Implementation in SA.<br>International cooperation<br>Network management<br>Synthesis of nanoparticles<br>Nanodevices | CSIR |
| Eugene | Smit | Mr | Electro spinning as a top-down technique of manufacturing of Polymer and Inorganic nanofibres | University of Stellenbosch - Polymer Science |
| Kokkie | Swanepoel | Dr | Particles | Thermtron group of Companies |
| Hannes | Vorster | Mr | Nano particle synthesis - metals and metal oxides<br>Surface modification<br>Cosmetic applications of nano materials<br>Carbon nanotubes | Prime Product Manufacturing (Pty.) Ltd. |

**Table C-1. Background information on the nanotechnology panel of experts.**

## *C.1.2 Nanotechnology segments*

| Participant | Comment |
|---|---|
| Beyers | Although it is good that the questions are application driven, much more should be invested in manufacturing technology. Being able to make useful parts with the materials |
| Dlamini | The segmentation of nanotechnology that you have chosen is somewhat confusing. Tools such as EM are not a result of development in nanotechnology. These are general tools that are used daily in science and nanotechnology has the potential to benefit from them. An additional segment that I think could be added is nano - synthesis, to support the various segments in the questionnaire. |
| Du Plessis | Petro-chemicals, Agricultural products, nano-medicine (incl. veterinary), power generation/nuclear safety/efficiency, aircraft/transport performance, certainly must fall into place as well |
| Gericke | It is assumed that the respondent has a thorough understanding of the economics of technology – makes it difficult to give an accurate answer |
| Germishuizen | I think "intelligent materials" fit into the "structures" category, because you look to modify macroscopic effects by changing properties at molecular level, such as optical switches etc, metallic/semi conducting behaviour etc. Furthermore, it is not possible to answer in one question the difference between basic and applied research on your 7 nanotech topics: basic research is relatively easy on all but machines, but applied research on all the topics requires huge investment, large research groups (for critical mass) and equipment. Thus, it is ok in US and EU, but very difficult in S.A. Also consider these groups have worked on a topic for 10 years+ (in most cases not even calling their research "nanotechnology"), while here it will take considerable effort to compete with that. |
| Greyling | Q1 make never an option |
| Petrik | Your categories don't relate to what is happening or is possible in SA |
| Scriba | Nanotechnology is very broad in its definition. It is difficult to grasp accurately what we are talking about in each sector indicated |
| Smit | The fact that I do not agree with the division of nanotechnology in South Africa into these segments makes giving sensible answers rather difficult. The segmentation leads to certain very important fields of study being grouped with other fields that do not necessarily have as much promise. The result is that answers will either be too conservative or too liberal. |

**Table C-2. Comments from the expert panel to the nanotechnology segments.**

| Participant | Comment |
|---|---|
| Petrik | Government has a role to play to provide incentives for the basic, fundamental research needed to bring new materials to a stage where prototyping and commercialization can become feasible at which point venture capital may take the prototype forward to a product |
| Scriba | Venture capital has a huge role to play in nanotechnology but the sequence has to be well understood:<br>Initially Government will have to play a strong role mainly in establishing the HR component and development of the basic science.<br>Then Industry and Government together must fund and support R&D projects more focussed on delivery of benefits to industry.<br>Now VC can come in with commercialisation support.<br>In SA I believe the sequence above will take 3-6 years |

**Table C-3. Answers provided on the role of venture capital and government incentives in future nanotechnology research, development, manufacturing, marketing and selling.**

### *C.1.3 Innovation hampers*

| Surname | Comment |
|---|---|
| Germishuizen | Be careful in your definition of nanotech: many everyday products aren't classified as nanotech but is, in fact, such as semiconductor devices. These have been around for a few years and we are completely dependent on them. Others are now classified as nanotech (like nanotubes) but have no market. |
| Greyling | Mismanagement of funding or corruption |
| Petrik | Stakeholder initiatives NB and are needing urgent support by government to prevent SA from being left behind. We are currently losing any market niche opportunity unless we support what is already taking place in SA |
| Vorster | I think South Africa needs to train more scientists and engineers in the nanotechnology field. We also need to invest in good research infrastructure and equipment to facilitate nanotechnology development. |

**Table C-4. Comments from the expert panel to the innovation hampers.**

### *C.1.4 Nanotechnology actors*

| Surname | Comments |
|---|---|
| Beyers | Whether Asia is going to be a buyer or competitor is going to depend on how much they spend on developing nanotechnology themselves.<br>That they are going to be one of the biggest USERS of nano-technology, is beyond any doubt |
| Du Plessis | It is probably now the time to make our intentions known with respects to the technology so that we can associate ourselves with the best nanotechnology partners elsewhere in the world. I will look at Europe first then Asia then N-America but not Southern Hemisphere. South Africa needs a STRONG alliance with a known/peer reviewed partner and not a mate of the state. |
| Germishuizen | I think the world leaders (US, EU and Japan) will keep their ranking because of the long delay of other, like Africa and South America, to start fundamental work. This gap will ultimately not be bridged. |
| Petrik | Yes the location could change but once a market is established it is very difficult to break in.<br>SA has an opportunity in certain niche areas of nanotechnology and these should immediately be strengthened |
| Scriba | There is a strong link with the European FE6 system.<br>SA Government has Agreements are in place with Japan, Brazil, Russia, India and Iran.<br>These could become strong nanotechnology partners. |
| Smit | Many of the European countries and the USA have very strict regulations in terms of health and environmental safety; schooled labour and research are typically more expensive that in South Africa and other developing countries. There is also a higher degree of resistance towards disruptive technologies in the public opinion of first world countries, which is not as strong in South Africa. The importance of location becomes apparent when, as an example, American companies start using South African research groups for developing products that require animal testing and/or other controversial methods, or if the development can be done at a significantly lower price by local 'cheaper' research groups. |
| Vorster | I think as more countries becomes involved in nanotechnology the will be a definite shift and some regions of the world might develop a more advanced or niche in a specific field in nanotechnology. |

**Table C-5. Comments from the expert panel to the nanotechnology actors.**

## *C.1.5 Strength, weaknesses, opportunities and threats*

| Surname | Strengths | Weaknesses |
|---|---|---|
| Augustyn | Talent and interest (S8) | No strategy (focus areas) (W6)<br>Funds (W2)<br>Equipment (W3)<br>Qualified researchers (W1) |
| Beyers | Sufficient academic support for the second tier level of research (S1)<br>Good manufacturing and logistics infrastructure (S14)<br>Relatively well positioned currency both for<br>buying in Materials and selling value added products (NOT USED) | Lack of cooperation between different academic institutions and industry. (W5)<br>Focus too much on primary development of nano-technology. We should stay out of expensive primary research, get raw materials supplied and invest in making value added products. The development required to successfully manufacture these materials is more important that duplicating technology that is being done world-wide. (We will be re-inventing the wheel) (W8) |
| Compton | Geographical isolation forces innovation (S4)<br>Can follow prior research - follower status rather than leading, can choose best practices immediately (USED IN O6)<br>SA researchers are more innovative than international researchers (what we can do on such limited budgets.) (S2) | Funding (W2)<br>Equipment (funding) (W3)<br>Limited knowledge in some fields - too expensive to attend workshops overseas (funding) (W4)<br>Fragmentation of nanotechnology community - no critical mass in some areas (W5) |
| Dlamini | What are the nanotechnology industries in South Africa? The strength of our industries in general is cheap labour (S2),<br>natural resources (S9), and<br>good positioning in Africa (S10) | Lack of suitable infrastructure to perform nanotechnology research. (W1,2,3)<br>Poorly structured education system that does not result in the development of entrepreneurs. (W9)<br>Strong reliance on North America and Europe for good technical skills. (W4) |
| Du Plessis | Ground principles seems to have been agreed on CSIR footprints in SA and abroad is recognised (S5) | Application value largely unclear<br>At the very small scale it is impossible to visualise - nothing as exciting as the Big5. (USED IN T8) |
| Gericke | Raw material readily available (USED IN O1)<br>Research relatively cheap (S2) | Perception from industry that local institutions cannot compete with overseas counterparts (W10)<br>Lack of research funding (W2)<br>Lack of teaching programmes in this technology (W4)<br>Lack of skilled manpower to "kick start" industries (W1)<br>Lack of government incentives (W11) |

**Table C-6. Strengths and weaknesses provided by the panel of experts (Part A).**

| Surname | Strengths | Weaknesses |
|---|---|---|
| Germishuizen | Strong collaboration between institutions can result in multidisciplinary research groups, essential for nanotech research. (S6)<br>The identification of focus areas, like energy, water health, etc, can help channel funding into a flagship type project. (S5) | Lack of funding and critical mass and skilled people. (W1,2)<br>Another major weakness is the reluctance to<br>work on "blue sky" research. (W7)<br>Nanotechnology will yield products only a few years down the line, while most people expect returns much sooner, therefore a whole attitude change or paradigm shift is required. |
| Greyling | RSA has good education standard and good scientists (S3)(S1)<br>People tend to be innovative (S4)<br>People have confidence in Manfred Scriba (S11) | Funding (W2)<br>Too few young scientists (W1)<br>Ageing publishing population<br>Affirmative action (W12)<br>Insufficient industrial training (scientists become managers too fast) (NOT USED)<br>Lack of a firm direction for RSA to compete in Nanotech internationally (W6) |
| Nkosi | Labour costs for researchers lower than in the developed economies. (S2)<br>As a follower able to spend less money on R&D costs. (S12) | There are not researchers in this area, critical mass. Also the R&D funding is low. (W1,2) |
| Petrik | Small but Sophisticated R&D at some universities (S1) | Industry lack of knowledge of threat to their products and processes (W4)<br>Far too few resources allocated to developing our own skills and capabilities (W1,2,3) |
| Prinsloo | Natural resources (USED IN O1) | Follower approach usually adopted by SA (W13)<br>Limited resources (W1,2,3)<br>Too distant from leading innovators (W5)<br>Not enough R&D on nanotechnology (W7)<br>SA is already lacking on the field of nanotechnology (W14)<br>In a 3rd world Country like SA it will take a long time to convert to opportunities offered by nanotechnology<br>SA already lacks on all fronts of nanotechnology (R&D, technology, commercialisation, etc)<br>Restrictions on import tariffs |
| Revaprasadu | We have dedicated researchers who are motivated to achieve results with low funding. (S2)<br>There is now sufficient networking in this area to work on bigger projects. (S6) | There is a lack on adequate equipment such as microscopes. (W3)<br>The level of funding from Govt and industry<br>is inadequate. (W2) |

**Table C- 7. Strengths and weaknesses provided by the panel of experts (Part B).**

| Surname | Strengths | Weaknesses |
|---|---|---|
| Scriba | Have natural resources here. (USED IN O1)<br>Good expertise in certain fields, including mineral extraction and catalysis. (S1)<br>SA has been multidisciplinary for years - we could thus pick up on some nanotechnology aspect quickly. (S1) | Lack of equipment, expertise and funding. (W1,2,3)<br>The science base in SA is far from what it should be. (NOT USED)<br>This will take time to correct.<br>The SA industry in general is not high tech and there is in general very little R&D at these companies. (W7) |
| Smit | High degree of competence in some fields. (S1) | By not giving a clear definition of what 'Nanotech' really is, we are allowing every<br>researcher with his eyes on the money to describe his/her work as 'Nano'.<br>This will lead to a dilution of the available funds for nanotech, with 'nano' money being spent on non-nano research. (W4)<br>A lack of a co-ordinated focus locally could also lead to research funding being diluted among too many fields leading to unfocused, sub-relevant local expertise. (W6) |
| Swanepoel | High technology knowledge in Nuclear, Space, Lasers, Plasma, minerals beneficiation, mining, design and engineering, Petrochemical, biological sciences, medical research (S1)<br>Good banking system (S13)<br>Good scientists and technologists (S3) | Fragmented research, no collaborations (W5)<br>Not market driven (W8)<br>Old generation of scientists (W1) |
| Vorster | I think we have the tenacity as South Africans to tackle quite difficult high tech problems<br>and follow it through until we have success. (NOT USED)<br>We have a pool of people from many different backgrounds with diverse abilities and talents that can generate a critical mass of people in nanotechnology. (S7) | We are not very well equipped, far from the major research centres such as Europe, USA and Asia. (W3)<br>We are lacking in technicians and technical people and need to train much more scientists and engineers. (W1) |

**Table C- 8. Strengths and weaknesses provided by the panel of experts (Part C).**

| Name | Opportunities | Threats |
|---|---|---|
| Augustyn | Same as for the rest of the world - innumerable (NOT USED) | Because of lack of personnel, funds, strategy, etc. we may fall behind in R&D and applications (industry) (T3) |
| Beyers | Become manufacturing partners to developed countries, who will take on them the role of marketing, positioning and do the primary technology research. (O6) | Over investment on research not leading to the ability to manufacture value added products (T6) |
| Compton | Critical mass of research focussed on SA natural resources (O1)<br>Initiatives for HR capital development - strong government support (O7)<br>Can learn from other countries (best practices) without making their mistakes and re-inventing the wheel. (O6) | Expensive and difficult to control intellectual property, lack of knowledge on IP issues (T7)<br>Uncoordinated actions in some areas (NOT USED)<br>International researchers are better resourced in equipment and HR capital (T3) |
| Dlamini | As a third world country there are a number of opportunities to provide solutions to a number of social problems i.e. water purification etc. (O2) | Unemployment, social instability, strong competition from the Europe, East and West (T4,7) |
| Du Plessis | New, basically unknown technology to majority of industries in South Africa (O4)<br>SA developing more and more into a recognised producing country than an exploiting country and should use the image to enhance/sell the concepts (O9) | Barrier to entry, affordability? (T4)<br>Poor contribution record from government, commitment doubtful. (T6) |
| Gericke | Beneficiation of local raw materials - add value (O1)<br>Development of high quality/high value products for niche applications (O4,5)<br>To develop centres of excellence (O3)<br>To be a leader instead of a follower (O10) | Good researchers might be lost to overseas industries/institutions due to the lack of incentives (T5)<br>SA to become dumping ground for technology from overseas competitiveness (T2,4) |
| Germishuizen | Health is a good one.<br>Bionanotechnology is relatively not too difficult to get into, and can yield biosensors and nano-scale drug delivery systems etc. much sooner. (O2) | Biggest threat is of course EU/US. (T4)<br>Products , devices, techniques (according to your idea of nanotech, like carbon nanotubes) will become much cheaper as time/research progress overseas, that we will spend money on buying the products rather than doing our won research. (T2)<br>Once again the threat from uninformed people in government (and local researchers) that don't understand the significance of nanotech research will hamper progress significantly (T8) |

**Table C-9. Opportunities and threats provided by the panel of experts (Part A).**

| Name | Opportunities | Threats |
|---|---|---|
| Greyling | None | None |
| Nkosi | No huge investments as the country is a follower in this area. (O6) | May lag and never be able to catch up. (T1) |
| Petrik | Catalysis, electro catalysis, renewable energy, clean water, health (O2) | Huge budgets and significant leads in R&D in other countries (T3) |
| Prinsloo | Weak Rand (NOT USED)<br>Natural resources (O1)<br>Capitalisation on human potential, with centres of nanotechnology (O3)<br>Fuel cell vehicles (should we manufacture methanol). Paint industry, now is the time to take up the opportunities. Energy industry (O2,4,5) | Crime (T9)<br>HIV/AIDS (T5)<br>Collapsing of US stock market (NOT USED) |
| Revaprasadu | There are areas of research which SA has distinct expertise e.g. catalysis. (O3)<br>There are niche areas which also could be exploited. (O4,5) | If SA does not act quickly we could be very far behind the developing countries in this field. (T1)<br>We would lose momentum in research and active researchers would be forced to look elsewhere. (T5) |
| Scriba | We must focus on local needs: nanotechnology for health, energy and water. These areas are not always international priority. (O2)<br>Our wealth in minerals and PGM materials is a great opportunity and we are also leaders in diamond synthesis. (O1) | Falling into the old trap of importing technology and developing our selves. (T2)<br>Not reaching fast enough with adequate funding.<br>Having started to late in the first place (T1)<br>Brain drain. (T5) |
| Smit | Local legislation and lower cost of research could be seen by first-world companies as an incentive to utilise local expertise for development, but only if expertise and infrastructure are in place. (O8) | South Africa started late in the nano race and it might already be too late to catch up with the first world countries in many fields of research. (T1)<br>One of the biggest threats we face is being the runner-up in the development of many crytical technologies and being forced, through patents and other IP protecting structures, to licence or buy essential technologies from the first world countries like we currently do with many pre-nano technologies. (T2) |

**Table C- 10. Opportunities and threats provided by the panel of experts (Part B).**

| Name | Opportunities | Threats |
|---|---|---|
| Swanepoel | One focussed body to lead group (NOT USED)<br>Cheaper labour than USA and Europe (O8) | Dumping of old nanotechnology products on local market (T2)<br>Start to late with focussed program (T1) |
| Vorster | Biggest opportunities we have is the support of the SA Government in the DST and DTI. (O7)<br>We have a wealth of experience in other high tech fields e.g. Nuclear technology and armaments industries that can be pooled and redirected into nanotechnology. (O3)<br>We have a wealth of raw materials and base metals that is the basis of nanotechnology. (O1) | If we don't start actively pursuing nanotechnology as a national priority we can completely miss the nanotechnology wave and be pushed to the backwaters of nanotechnology in the 21st Century. (T1)<br>We don't have sufficient funding to really stimulate these industries. (T3) |

**Table C- 11. Opportunities and threats provided by the panel of experts (Part C).**

## *C.1.6 General comments*

| Surname | Comment |
|---|---|
| Du Plessis | Thanks for the opportunity. |
| Gericke | I am not sure as to how far this questionnaire will go to assist in establishing a nanotechnology strategy for South Africa. I abuse my comment on the type of questions being asked.<br>Questions such as niche market/products applications in developing countries, incentives requirements, priorities etc. are lacking. |
| Germishuizen | Define nanotechnology carefully. As I say many products around us have existed even before the phrase "nanotechnology" was coined. They completely took over our world (semiconductor devices, polymers, etc) and have nanometre dimensions, but are often not classified into "nanotech". This often leads to a lot of confusion because nanotech as you use it here has yielded very view marketable products (last year a BBC editor said that the only people who make money out of nanotechnology is conference organisers). So these two are fundamentally different, and by defining it well you can make your work much easier. |
| Petrik | Not clear what this info is for and how it relates to SANi and baseline study.<br>You ask questions that have already been addressed in the SANi strategy document to government i.e. SWOT analysis |
| Scriba | Good structure of questions<br>Some are difficult to judge. |
| Vorster | I think it is a great idea to do research on the whole status of nanotechnology in South Africa. We need urgently to benchmark our present position in the world and see how we can find niches and international collaboration to develop and stay in the development of nanotechnology. |

**Table C-12. General comments from the panel of experts to the research project questionnaire.**

## C.2 CSIR baseline study questionnaire

### *C.2.1 Nanotechnology awareness, involvement and focus areas*

| | R&D | Manufacture | Process development | Product development | Import and sell | Other category |
|---|---|---|---|---|---|---|
| Universities | 12 | 8 | 3 | 3 | 4 | 0 |
| Industry | 7 | 4 | 2 | 4 | 2 | 2 |
| Science councils | 3 | 2 | 1 | 2 | 0 | 1 |
| Total number of participants | 22 | 14 | 6 | 9 | 6 | 3 |

**Table C-13. Statistics of nanotechnology life-cycle involvement per institution.**

| Nanotechnology focus area | Number of participants |
|---|---|
| Nanomaterials | 21 |
| Nanobiotechnology | 3 |
| Membranes | 5 |
| Drug delivery | 4 |
| Catalysis | 11 |
| Nano Devices | 5 |
| Nano emulsions | 4 |
| Coatings | 7 |
| Fundamental Research | 17 |
| Atomic modelling | 7 |
| Characterisation | 18 |
| Implemented some above technologies, outsourced others | 7 |
| Other | 4 |

**Table C-14. Statistics of nanotechnology areas South African participants are involved in.**

### *C.2.2 Nanotechnology funding*

| | Private Funding | Public Funding | Internal | International | Science Council | Other group |
|---|---|---|---|---|---|---|
| Universities | 9 | 13 | 10 | 3 | 5 | 1 |
| Industry | 6 | 2 | 5 | 1 | 2 | 0 |
| Science councils | 2 | 2 | 2 | 0 | 2 | 0 |
| Total | 17 | 17 | 17 | 4 | 9 | 1 |

**Table C-15. Statistics of South African nanotechnology funding sources per institution.**

### *C.2.3 Nanotechnology personnel*

| | Total | Male | Female | Black | White | Other race | Disabled |
|---|---|---|---|---|---|---|---|
| Personnel | 151 | 110 | 37 | 65 | 76 | 2 | 0 |

**Table C-16. Statistics of the South African nanotechnology personnel demographics per institution.**

| Personnel | 20-30 | 30-40 | 40-50 | 50+ |
|---|---|---|---|---|
| Universities | 39 | 17 | 16 | 13 |
| Industry | 6 | 9 | 8 | 1 |
| Science councils | 8 | 11 | 7 | 4 |
| Total | 53 | 37 | 31 | 18 |

**Table C-17. Statistics of South African nanotechnology personnel employed per institution per age.**

## *C.2.4 Nanotechnology education*

| | Total | Male | Female | Black | White | Other race | Disabled |
|---|---|---|---|---|---|---|---|
| Students | 160 | 100 | 57 | 122 | 34 | 1 | 1 |
| Post doctoral | 23 | 17 | 6 | 10 | 9 | 1 | 0 |
| Total | 183 | 117 | 63 | 132 | 43 | 2 | 1 |

**Table C-18. Statistics of South African nanotechnology students.**

## *C.2.5 Nanotechnology networking and collaborations*

| Country | Number of collaborations |
|---|---|
| Local | 74 |
| Europe | 49 |
| North America | 8 |
| Australia and New Zealand | 5 |
| Asia | 2 |
| South America | 1 |
| Other African countries | 0 |
| Total | 139 |

**Table C-19. Statistics of the number of South African nanotechnology collaborations.**

| | Aware of SANi | National Collaborators | International Collaborators | Government arranged collaborations | International projects |
|---|---|---|---|---|---|
| Universities | 13 | 13 | 12 | 4 | 7 |
| Industry | 9 | 10 | 5 | 0 | 1 |
| Science councils | 3 | 3 | 3 | 0 | 1 |
| Total | 25 | 26 | 20 | 4 | 9 |

**Table C-20. Statistics of South African nanotechnology relations and networking.**

## *C.2.6 Nanotechnology equipment information*

| | Condition of the equipment | Compared to the state of the art equipment |
|---|---|---|
| 1 (Good or the same) | 44 | 26 |
| 2 (Average or slightly worse) | 31 | 36 |
| 3 (Bad or much worse) | 11 | 23 |

**Table C-21. Statistics of South African nanotechnology equipment.**

# Appendix D. Data analysis

## D.1 Research project questionnaire

### *D.1.1 Nanotechnology segments*

| | Tools | Raw materials | Structures | Nanotubes and fullerenes | Devices and systems | Intelligent materials | Machines | Other |
|---|---|---|---|---|---|---|---|---|
| Valid | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 3 |
| Missing | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13 |
| Mean | 2.12500 | 1.87500 | 2.31250 | 2.62500 | 2.75000 | 3.12500 | 4.12500 | 2.66667 |
| Std. Error of Mean | .221265 | .179699 | .236621 | .271953 | .232737 | .271953 | .221265 | .333333 |
| Median | 2.00000 | 2.00000 | 2.00000 | 2.50000 | 3.00000 | 3.00000 | 4.00000 | 3.00000 |
| Mode | 3.000 | 2.000 | 2.000 | 2.000 | 2.000 | 3.000 | 4.000 | 3.000 |
| Std. Deviation | .885061 | .718795 | .946485 | 1.087811 | .930949 | 1.087811 | .885061 | .577350 |
| Variance | .783333 | .516667 | .895833 | 1.183333 | .866667 | 1.183333 | .783333 | .333333 |
| Skewness | -.268 | .192 | .352 | .522 | .000 | .078 | -.927 | -1.732 |
| Std. Error of Skewness | .564 | .564 | .564 | .564 | .564 | .564 | .564 | 1.225 |
| Range | 2.000 | 2.000 | 3.000 | 4.000 | 3.000 | 4.000 | 3.000 | 1.000 |
| Minimum | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 2.000 | 2.000 |
| Maximum | 3.000 | 3.000 | 4.000 | 5.000 | 4.000 | 5.000 | 5.000 | 3.000 |
| Sum | 34.000 | 30.000 | 37.000 | 42.000 | 44.000 | 50.000 | 66.000 | 8.000 |

**Table D-1. Statistics of the nanotechnology segments' time to market.**

| | Tools | Raw materials | Structures | Nanotubes and fullerenes | Devices and systems | Intelligent materials | Machines | Other |
|---|---|---|---|---|---|---|---|---|
| Valid | 16 | 16 | 16 | 16 | 16 | 15 | 15 | 5 |
| Missing | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 11 |
| Mean | 3.06250 | 4.12500 | 3.43750 | 3.12500 | 3.87500 | 3.40000 | 2.73333 | 3.00000 |
| Std. Error of Mean | .265656 | .125000 | .240983 | .221265 | .271953 | .235028 | .283963 | .547723 |
| Median | 3.00000 | 4.00000 | 3.50000 | 3.00000 | 4.00000 | 3.00000 | 3.00000 | 3.00000 |
| Mode | 3.000 | 4.000 | 4.000 | 3.000 | 5.000 | 3.000 | 3.000 | 2.000 |
| Std. Deviation | 1.062623 | .500000 | .963933 | .885061 | 1.087811 | .910259 | 1.099784 | 1.224745 |
| Variance | 1.129167 | .250000 | .929167 | .783333 | 1.183333 | .828571 | 1.209524 | 1.500000 |
| Skewness | .243 | .343 | -.054 | .392 | -.433 | .341 | .237 | 1.361 |
| Std. Error of Skewness | .564 | .564 | .564 | .564 | .564 | .580 | .580 | .913 |
| Range | 4.000 | 2.000 | 3.000 | 3.000 | 3.000 | 3.000 | 4.000 | 3.000 |
| Minimum | 1.000 | 3.000 | 2.000 | 2.000 | 2.000 | 2.000 | 1.000 | 2.000 |
| Maximum | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 |
| Sum | 49.000 | 66.000 | 55.000 | 50.000 | 62.000 | 51.000 | 41.000 | 15.000 |

**Table D-2. Statistics of the nanotechnology segments' market potential.**

| | Tools | Raw materials | Structures | Nanotubes and fullerenes | Devices and systems | Intelligent materials | Machines | Other |
|---|---|---|---|---|---|---|---|---|
| Valid | 16 | 15 | 16 | 16 | 16 | 16 | 15 | 4 |
| Missing | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 12 |
| Mean | 1.75000 | 2.93333 | 2.56250 | 2.43750 | 3.68750 | 3.50000 | 2.93333 | 1.75000 |
| Std. Error of Mean | .232737 | .462567 | .376040 | .386962 | .384261 | .387298 | .371184 | .750000 |
| Median | 1.50000 | 2.00000 | 2.00000 | 2.00000 | 4.00000 | 4.00000 | 3.00000 | 1.00000 |
| Mode | 1.000 | 1.000 | 1.000 | 1.000 | 5.000 | 5.000 | 2.000 | 1.000 |
| Std. Deviation | .930949 | 1.791514 | 1.504161 | 1.547848 | 1.537043 | 1.549193 | 1.437591 | 1.500000 |
| Variance | .866667 | 3.209524 | 2.262500 | 2.395833 | 2.362500 | 2.400000 | 2.066667 | 2.250000 |
| Skewness | 1.133 | .115 | .199 | .750 | -.782 | -.492 | .466 | 2.000 |
| Std. Error of Skewness | .564 | .580 | .564 | .564 | .564 | .564 | .580 | 1.014 |
| Range | 3.000 | 4.000 | 4.000 | 4.000 | 4.000 | 4.000 | 4.000 | 3.000 |
| Minimum | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| Maximum | 4.000 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 | 4.000 |
| Sum | 28.000 | 44.000 | 41.000 | 39.000 | 59.000 | 56.000 | 44.000 | 7.000 |

**Table D-3. Statistics of the nanotechnology segments' disruptiveness.**

| | Tools | Raw materials | Structures | Nanotubes and fullerenes | Devices and systems | Intelligent materials | Machines | Other |
|---|---|---|---|---|---|---|---|---|
| Valid | 16 | 16 | 16 | 15 | 16 | 16 | 16 | 4 |
| Missing | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 12 |
| Mean | 3.31250 | 3.06250 | 3.56250 | 3.33333 | 4.06250 | 4.12500 | 4.50000 | 2.75000 |
| Std. Error of Mean | .269548 | .249479 | .223024 | .287297 | .213478 | .154785 | .223607 | .250000 |
| Median | 3.00000 | 3.00000 | 4.00000 | 4.00000 | 4.00000 | 4.00000 | 5.00000 | 3.00000 |
| Mode | 3.000 | 3.000 | 4.000 | 4.000 | 5.000 | 4.000 | 5.000 | 3.000 |
| Std. Deviation | 1.078193 | .997914 | .892095 | 1.112697 | .853913 | .619139 | .894427 | .500000 |
| Variance | 1.162500 | .995833 | .795833 | 1.238095 | .729167 | .383333 | .800000 | .250000 |
| Skewness | -.355 | -.138 | -1.502 | -.771 | -.129 | -.060 | -1.917 | -2.000 |
| Std. Error of Skewness | .564 | .564 | .564 | .580 | .564 | .564 | .564 | 1.014 |
| Range | 4.000 | 4.000 | 4.000 | 4.000 | 2.000 | 2.000 | 3.000 | 1.000 |
| Minimum | 1.000 | 1.000 | 1.000 | 1.000 | 3.000 | 3.000 | 2.000 | 2.000 |
| Maximum | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 | 3.000 |
| Sum | 53.000 | 49.000 | 57.000 | 50.000 | 65.000 | 66.000 | 72.000 | 11.000 |

**Table D-4. Statistics of the nanotechnology segments' complexity.**

## *D.1.2 Grouped nanotechnology segment according to CSIR baseline study*

| | Tools | Nanomaterials | Nanostructures | Nanodevices and systems | Nanomachines | NanoBiotechnology |
|---|---|---|---|---|---|---|
| Valid | 16 | 32 | 32 | 16 | 16 | 112 |
| Missing | 96 | 80 | 80 | 96 | 96 | 0 |
| Mean | 2.12500 | 2.25000 | 2.71875 | 2.75000 | 4.12500 | 2.70536 |
| Std. Error of Mean | .221265 | .173902 | .191736 | .232737 | .221265 | .108842 |
| Median | 2.00000 | 2.00000 | 3.00000 | 3.00000 | 4.00000 | 3.00000 |
| Mode | 3.000 | 2.000 | 3.000 | 2.000 | 4.000 | 2.000 |
| Std. Deviation | .885061 | .983739 | 1.084625 | .930949 | .885061 | 1.151876 |
| Variance | .783333 | .967742 | 1.176411 | .866667 | .783333 | 1.326818 |
| Skewness | -.268 | .759 | .283 | .000 | -.927 | .312 |
| Std. Error of Skewness | .564 | .414 | .414 | .564 | .564 | .228 |
| Range | 2.000 | 4.000 | 4.000 | 3.000 | 3.000 | 4.000 |
| Minimum | 1.000 | 1.000 | 1.000 | 1.000 | 2.000 | 1.000 |
| Maximum | 3.000 | 5.000 | 5.000 | 4.000 | 5.000 | 5.000 |
| Sum | 34.000 | 72.000 | 87.000 | 44.000 | 66.000 | 303.000 |

**Table D-5. Statistics of the grouped nanotechnology segments' time to market.**

| | Tools | Nanomaterials | Nanostructures | Nanodevices and systems | Nanomachines | NanoBiotechnology |
|---|---|---|---|---|---|---|
| Valid | 16 | 32 | 31 | 16 | 15 | 110 |
| Missing | 96 | 80 | 81 | 96 | 97 | 2 |
| Mean | 3.06250 | 3.62500 | 3.41935 | 3.87500 | 2.73333 | 3.40000 |
| Std. Error of Mean | .265656 | .153914 | .165745 | .271953 | .283963 | .097679 |
| Median | 3.00000 | 4.00000 | 3.00000 | 4.00000 | 3.00000 | 3.00000 |
| Mode | 3.000 | 4.000 | 3.000 | 5.000 | 3.000 | 3.000 |
| Std. Deviation | 1.062623 | .870669 | .922829 | 1.087811 | 1.099784 | 1.024471 |
| Variance | 1.129167 | .758065 | .851613 | 1.183333 | 1.209524 | 1.049541 |
| Skewness | .243 | -.411 | .117 | -.433 | .237 | -.142 |
| Std. Error of Skewness | .564 | .414 | .421 | .564 | .580 | .230 |
| Range | 4.000 | 3.000 | 3.000 | 3.000 | 4.000 | 4.000 |
| Minimum | 1.000 | 2.000 | 2.000 | 2.000 | 1.000 | 1.000 |
| Maximum | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 |
| Sum | 49.000 | 116.000 | 106.000 | 62.000 | 41.000 | 374.000 |

**Table D-6. Statistics of the grouped nanotechnology segments' market potential.**

| | Tools | Nanomaterials | Nanostructures | Nanodevices and systems | Nanomachines | NanoBiotechnology |
|---|---|---|---|---|---|---|
| Valid | 16 | 31 | 32 | 16 | 15 | 110 |
| Missing | 96 | 81 | 80 | 96 | 97 | 2 |
| Mean | 1.75000 | 2.67742 | 3.03125 | 3.68750 | 2.93333 | 2.82727 |
| Std. Error of Mean | .232737 | .298336 | .278549 | .384261 | .371184 | .149984 |
| Median | 1.50000 | 2.00000 | 4.00000 | 4.00000 | 3.00000 | 2.00000 |
| Mode | 1.000 | 1.000 | 4.000 | 5.000 | 2.000 | 1.000 |
| Std. Deviation | .930949 | 1.661066 | 1.575710 | 1.537043 | 1.437591 | 1.573048 |
| Variance | .866667 | 2.759140 | 2.482863 | 2.362500 | 2.066667 | 2.474479 |
| Skewness | 1.133 | .413 | -.107 | -.782 | .466 | .219 |
| Std. Error of Skewness | .564 | .421 | .414 | .564 | .580 | .230 |
| Range | 3.000 | 4.000 | 4.000 | 4.000 | 4.000 | 4.000 |
| Minimum | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| Maximum | 4.000 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 |
| Sum | 28.000 | 83.000 | 97.000 | 59.000 | 44.000 | 311.000 |

**Table D-7. Statistics of the grouped nanotechnology segments' disruptiveness.**

| | Tools | Nanomaterials | Nanostructures | Nanodevices and systems | Nanomachines | NanoBiotechnology |
|---|---|---|---|---|---|---|
| Valid | 16 | 31 | 32 | 16 | 16 | 111 |
| Missing | 96 | 81 | 80 | 96 | 96 | 1 |
| Mean | 3.31250 | 3.19355 | 3.84375 | 4.06250 | 4.50000 | 3.71171 |
| Std. Error of Mean | .269548 | .187911 | .142765 | .213478 | .223607 | .097795 |
| Median | 3.00000 | 3.00000 | 4.00000 | 4.00000 | 5.00000 | 4.00000 |
| Mode | 3.000 | 4.000 | 4.000 | 5.000 | 5.000 | 4.000 |
| Std. Deviation | 1.078193 | 1.046243 | .807600 | .853913 | .894427 | 1.030334 |
| Variance | 1.162500 | 1.094624 | .652218 | .729167 | .800000 | 1.061589 |
| Skewness | -.355 | -.414 | -1.267 | -.129 | -1.917 | -.663 |
| Std. Error of Skewness | .564 | .421 | .414 | .564 | .564 | .229 |
| Range | 4.000 | 4.000 | 4.000 | 2.000 | 3.000 | 4.000 |
| Minimum | 1.000 | 1.000 | 1.000 | 3.000 | 2.000 | 1.000 |
| Maximum | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 |
| Sum | 53.000 | 99.000 | 123.000 | 65.000 | 72.000 | 412.000 |

**Table D-8. Statistics of the grouped nanotechnology segments' complexity.**

## *D.1.3 Innovation hampers*

| | Knowledge gap | Technology development | Lack of tools, equipment and techniques | Lack of qualified personnel | Costs involved | Uncertainty of net economic effect |
|---|---|---|---|---|---|---|
| Valid | 16 | 16 | 16 | 16 | 16 | 16 |
| Missing | 0 | 0 | 0 | 0 | 0 | 0 |
| Mean | 3.87500 | 3.62500 | 4.37500 | 4.25000 | 4.00000 | 4.06250 |
| Std. Error of Mean | .239357 | .271953 | .221265 | .170783 | .241523 | .192976 |
| Median | 4.00000 | 4.00000 | 5.00000 | 4.00000 | 4.00000 | 4.00000 |
| Mode | 4.000 | 4.000 | 5.000 | 4.000 | 4.000 | 4.000 |
| Std. Deviation | .957427 | 1.087811 | .885061 | .683130 | .966092 | .771902 |
| Variance | .916667 | 1.183333 | .783333 | .466667 | .933333 | .595833 |
| Skewness | -.765 | -.189 | -1.545 | -.358 | -1.014 | -.113 |
| Std. Error of Skewness | .564 | .564 | .564 | .564 | .564 | .564 |
| Range | 3.000 | 3.000 | 3.000 | 2.000 | 3.000 | 2.000 |
| Minimum | 2.000 | 2.000 | 2.000 | 3.000 | 2.000 | 3.000 |
| Maximum | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 |
| Sum | 62.000 | 58.000 | 70.000 | 68.000 | 64.000 | 65.000 |

**Table D-9. Statistics of the nanotechnology innovation hampers (part 1).**

| | Insufficient funding | Time to commercialisation | Regulations | Supplier/Buyer adoption rates | Technology replacement | Lack of collaborations |
|---|---|---|---|---|---|---|
| Valid | 15 | 16 | 16 | 16 | 16 | 16 |
| Missing | 1 | 0 | 0 | 0 | 0 | 0 |
| Mean | 4.26667 | 3.75000 | 2.12500 | 3.12500 | 2.62500 | 3.62500 |
| Std. Error of Mean | .248168 | .281366 | .179699 | .221265 | .286865 | .179699 |
| Median | 5.00000 | 3.50000 | 2.00000 | 3.00000 | 2.00000 | 4.00000 |
| Mode | 5.000 | 3.000 | 2.000 | 3.000 | 2.000 | 4.000 |
| Std. Deviation | .961150 | 1.125463 | .718795 | .885061 | 1.147461 | .718795 |
| Variance | .923810 | 1.266667 | .516667 | .783333 | 1.316667 | .516667 |
| Skewness | -1.172 | -.080 | -.192 | .392 | .558 | -.500 |
| Std. Error of Skewness | .580 | .564 | .564 | .564 | .564 | .564 |
| Range | 3.000 | 3.000 | 2.000 | 3.000 | 4.000 | 3.000 |
| Minimum | 2.000 | 2.000 | 1.000 | 2.000 | 1.000 | 2.000 |
| Maximum | 5.000 | 5.000 | 3.000 | 5.000 | 5.000 | 5.000 |
| Sum | 64.000 | 60.000 | 34.000 | 50.000 | 42.000 | 58.000 |

**Table D- 10. Statistics of the nanotechnology innovation hampers (part 2).**

## *D.1.4 Nanotechnology actors*

| | Local | Other African countries | Europe | North America | South America | Asia | Australia and New Zealand |
|---|---|---|---|---|---|---|---|
| Valid | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| Missing | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mean | 3.50000 | 2.68750 | 4.56250 | 4.43750 | 3.37500 | 4.50000 | 3.68750 |
| Std. Error of Mean | .353553 | .384261 | .257694 | .257694 | .286865 | .158114 | .284587 |
| Median | 4.00000 | 3.00000 | 5.00000 | 5.00000 | 4.00000 | 5.00000 | 4.00000 |
| Mode | 4.000 | 1.000 | 5.000 | 5.000 | 4.000 | 5.000 | 4.000 |
| Std. Deviation | 1.414214 | 1.537043 | 1.030776 | 1.030776 | 1.147461 | .632456 | 1.138347 |
| Variance | 2.000000 | 2.362500 | 1.062500 | 1.062500 | 1.316667 | .400000 | 1.295833 |
| Skewness | -.727 | .099 | -2.278 | -1.896 | -.558 | -.904 | -1.151 |
| Std. Error of Skewness | .564 | .564 | .564 | .564 | .564 | .564 | .564 |
| Range | 4.000 | 4.000 | 3.000 | 3.000 | 4.000 | 2.000 | 4.000 |
| Minimum | 1.000 | 1.000 | 2.000 | 2.000 | 1.000 | 3.000 | 1.000 |
| Maximum | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 |
| Sum | 56.000 | 43.000 | 73.000 | 71.000 | 54.000 | 72.000 | 59.000 |

**Table D-11. Statistics of the nanotechnology buyers.**

| | Local | Other African countries | Europe | North America | South America | Asia | Australia and New Zealand |
|---|---|---|---|---|---|---|---|
| Valid | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| Missing | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mean | 3.18750 | 1.50000 | 4.93750 | 4.93750 | 3.06250 | 4.81250 | 3.62500 |
| Std. Error of Mean | .367636 | .204124 | .062500 | .062500 | .280903 | .100778 | .271953 |
| Median | 4.00000 | 1.00000 | 5.00000 | 5.00000 | 3.00000 | 5.00000 | 4.00000 |
| Mode | 4.000 | 1.000 | 5.000 | 5.000 | 3.000 | 5.000 | 4.000 |
| Std. Deviation | 1.470544 | .816497 | .250000 | .250000 | 1.123610 | .403113 | 1.087811 |
| Variance | 2.162500 | .666667 | .062500 | .062500 | 1.262500 | .162500 | 1.183333 |
| Skewness | -.368 | 1.260 | -4.000 | -4.000 | -.459 | -1.772 | -.899 |
| Std. Error of Skewness | .564 | .564 | .564 | .564 | .564 | .564 | .564 |
| Range | 4.000 | 2.000 | 1.000 | 1.000 | 4.000 | 1.000 | 4.000 |
| Minimum | 1.000 | 1.000 | 4.000 | 4.000 | 1.000 | 4.000 | 1.000 |
| Maximum | 5.000 | 3.000 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 |
| Sum | 51.000 | 24.000 | 79.000 | 79.000 | 49.000 | 77.000 | 58.000 |

**Table D-12. Statistics of the nanotechnology suppliers.**

| | Local | Other African countries | Europe | North America | South America | Asia | Australia and New Zealand |
|---|---|---|---|---|---|---|---|
| Valid | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| Missing | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mean | 2.87500 | 1.37500 | 4.93750 | 4.93750 | 3.18750 | 4.75000 | 3.56250 |
| Std. Error of Mean | .286865 | .154785 | .062500 | .062500 | .305761 | .193649 | .273385 |
| Median | 3.00000 | 1.00000 | 5.00000 | 5.00000 | 3.00000 | 5.00000 | 4.00000 |
| Mode | 4.000 | 1.000 | 5.000 | 5.000 | 3.000 | 5.000 | 4.000 |
| Std. Deviation | 1.147461 | .619139 | .250000 | .250000 | 1.223043 | .774597 | 1.093542 |
| Variance | 1.316667 | .383333 | .062500 | .062500 | 1.495833 | .600000 | 1.195833 |
| Skewness | -.331 | 1.505 | -4.000 | -4.000 | -.405 | -3.443 | -1.056 |
| Std. Error of Skewness | .564 | .564 | .564 | .564 | .564 | .564 | .564 |
| Range | 3.000 | 2.000 | 1.000 | 1.000 | 4.000 | 3.000 | 4.000 |
| Minimum | 1.000 | 1.000 | 4.000 | 4.000 | 1.000 | 2.000 | 1.000 |
| Maximum | 4.000 | 3.000 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 |
| Sum | 46.000 | 22.000 | 79.000 | 79.000 | 51.000 | 76.000 | 57.000 |

**Table D-13. Statistics of the nanotechnology competitors.**

| | Local | Other African countries | Europe | North America | South America | Asia | Australia and New Zealand |
|---|---|---|---|---|---|---|---|
| Valid | 14 | 15 | 15 | 15 | 15 | 15 | 15 |
| Missing | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| Mean | 4.28571 | 2.93333 | 4.46667 | 4.06667 | 3.06667 | 3.60000 | 3.46667 |
| Std. Error of Mean | .244243 | .315725 | .133333 | .266667 | .300264 | .289499 | .236375 |
| Median | 4.50000 | 3.00000 | 4.00000 | 4.00000 | 3.00000 | 4.00000 | 4.00000 |
| Mode | 5.000 | 2.000 | 4.000 | 4.000 | 3.000 | 4.000 | 4.000 |
| Std. Deviation | .913874 | 1.222799 | .516398 | 1.032796 | 1.162919 | 1.121224 | .915475 |
| Variance | .835165 | 1.495238 | .266667 | 1.066667 | 1.352381 | 1.257143 | .838095 |
| Skewness | -1.368 | .414 | .149 | -1.944 | -.461 | -.814 | -1.821 |
| Std. Error of Skewness | .597 | .580 | .580 | .580 | .580 | .580 | .580 |
| Range | 3.000 | 4.000 | 1.000 | 4.000 | 4.000 | 4.000 | 3.000 |
| Minimum | 2.000 | 1.000 | 4.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| Maximum | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 | 5.000 | 4.000 |
| Sum | 60.000 | 44.000 | 67.000 | 61.000 | 46.000 | 54.000 | 52.000 |

**Table D-14. Statistics of the nanotechnology relationships.**

# D.2 CSIR baseline study questionnaire

## *D.2.1 Original nanotechnology segments*

| | Nanotechnology involvement area | | | | | |
|---|---|---|---|---|---|---|
| Product life cycle | Nano materials | Nano biotechnology | Membranes | Drug delivery | Catalysis | Nano Devices |
| Research | | | | | | |
| Count | 8 | 2 | 3 | 3 | 4 | 3 |
| % of column | 16.67% | 22.22% | 23.08% | 23.08% | 18.18% | 20.00% |
| | Technology development | | | | | |
| Count | 14 | 3 | 3 | 4 | 7 | 3 |
| % of column | 29.17% | 33.33% | 23.08% | 30.77% | 31.82% | 20.00% |
| | Product and process development | | | | | |
| Count | 10 | 2 | 4 | 3 | 4 | 4 |
| % of column | 20.83% | 22.22% | 30.77% | 23.08% | 18.18% | 26.67% |
| | Product and process improvement | | | | | |
| Count | 1 | 0 | 0 | 0 | 0 | 0 |
| % of column | 2.08% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% |
| | Manufacture | | | | | |
| Count | 9 | 2 | 2 | 2 | 5 | 3 |
| % of column | 18.75% | 22.22% | 15.38% | 15.38% | 22.73% | 20.00% |
| | Import and selling | | | | | |
| Count | 4 | 0 | 1 | 0 | 1 | 2 |
| % of column | 8.33% | 0.00% | 7.69% | 0.00% | 4.55% | 13.33% |
| | Other | | | | | |
| Count | 2 | 0 | 0 | 1 | 1 | 0 |
| % of column | 4.17% | 0.00% | 0.00% | 7.69% | 4.55% | 0.00% |
| | Total | | | | | |
| Count | 48 | 9 | 13 | 13 | 22 | 15 |
| % of column | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |

**Table D-15. Frequency table of the cross tabulation of the Nanotechnology product life cycle and involvement areas (Part A).**

| | Nanotechnology involvement area | | | | | |
|---|---|---|---|---|---|---|
| Product life cycle | Nano emulsions | Coatings | Atomic modelling | Characterisation | Other | Total |
| | | | Research | | | |
| Count | 3 | 3 | 4 | 9 | 2 | 44 |
| % of column | 23.08% | 15.79% | 22.22% | 21.43% | 16.67% | 19.64% |
| | | | Technology development | | | |
| Count | 3 | 4 | 6 | 13 | 2 | 62 |
| % of column | 23.08% | 21.05% | 33.33% | 30.95% | 16.67% | 27.68% |
| | | | Product and process development | | | |
| Count | 3 | 6 | 4 | 7 | 3 | 50 |
| % of column | 23.08% | 31.58% | 22.22% | 16.67% | 25.00% | 22.32% |
| | | | Product and process improvement | | | |
| Count | 0 | 0 | 0 | 0 | 0 | 1 |
| % of column | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.45% |
| | | | Manufacture | | | |
| Count | 3 | 4 | 3 | 10 | 2 | 45 |
| % of column | 23.08% | 21.05% | 16.67% | 23.81% | 16.67% | 20.09% |
| | | | Import and selling | | | |
| Count | 1 | 2 | 1 | 3 | 1 | 16 |
| % of column | 7.69% | 10.53% | 5.56% | 7.14% | 8.33% | 7.14% |
| | | | Other | | | |
| Count | 0 | 0 | 0 | 0 | 2 | 6 |
| % of column | 0.00% | 0.00% | 0.00% | 0.00% | 16.67% | 2.68% |
| | | | Total | | | |
| Count | 13 | 19 | 18 | 42 | 12 | 224 |
| % of column | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |

**Table D-16. Frequency table of the cross tabulation of the Nanotechnology product life cycle and involvement areas (Part B).**

## *D.2.2 New nanotechnology segment groupings*

| | Tools | Nano materials | Nano structures | Nano devices and Nano systems | Nano machines | Nano Biotech | Other | Total |
|---|---|---|---|---|---|---|---|---|
| **Research** | | | | | | | | |
| Count | 13 | 18 | 3 | 6 | 0 | 2 | 2 | 44 |
| % of col. | 21.67% | 17.48% | 21.43% | 21.43% | 0.00% | 22.22% | 16.67% | 19.47% |
| **Technology development** | | | | | | | | |
| Count | 19 | 28 | 3 | 7 | 0 | 3 | 2 | 62 |
| % of col. | 31.67% | 27.18% | 21.43% | 25.00% | 0.00% | 33.33% | 16.67% | 27.43% |
| **Product and process development** | | | | | | | | |
| Count | 11 | 23 | 4 | 7 | 0 | 2 | 3 | 50 |
| % of col. | 18.33% | 22.55% | 28.57% | 25.00% | 0.00% | 22.22% | 25.00% | 22.32% |
| **Product and process improvement** | | | | | | | | |
| Count | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| % of col. | 0.00% | 0.98% | 7.14% | 0.00% | 0.00% | 0.00% | 0.00% | 1.77% |
| **Manufacture** | | | | | | | | |
| Count | 13 | 21 | 2 | 5 | 0 | 2 | 2 | 45 |
| % of col. | 21.67% | 20.39% | 14.29% | 17.86% | 0.00% | 22.22% | 16.67% | 19.91% |
| **Import and selling** | | | | | | | | |
| Count | 4 | 8 | 1 | 2 | 0 | 0 | 1 | 16 |
| % of col. | 6.67% | 7.77% | 7.14% | 7.14% | 0.00% | 0.00% | 8.33% | 7.08% |
| **Other** | | | | | | | | |
| Count | 0 | 3 | 0 | 1 | 0 | 0 | 2 | 6 |
| % of col. | 0.00% | 2.91% | 0.00% | 3.57% | 0.00% | 0.00% | 16.67% | 2.65% |
| **Total** | | | | | | | | |
| Count | 60 | 102 | 14 | 28 | 0 | 9 | 12 | 224 |
| % of col. | 100% | 100% | 100% | 100% | 0% | 100% | 100% | 100% |

**Table D-17. Frequency table of the cross tabulation of the nanotechnology product life cycle and involvement areas.**