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.

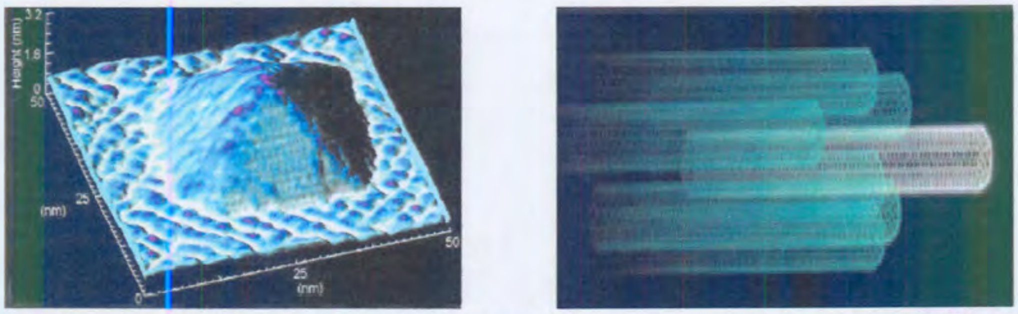


Figure 1-1. Quantum dot (Nanoscale pyramid of germanium atoms on top of a ground of silicon) and nanotubes formed out of fullerenes (National Science and Technology council, 1999).

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).

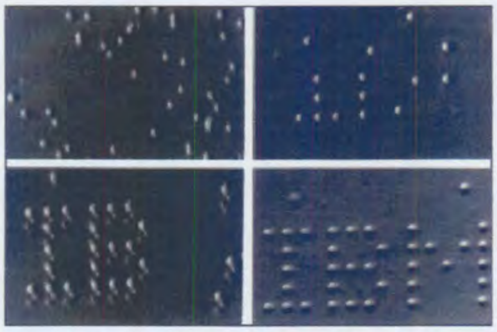


Figure 1-2. 'IBM' in 35 Xenon atoms (National Science and Technology council, 1999:6).

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.

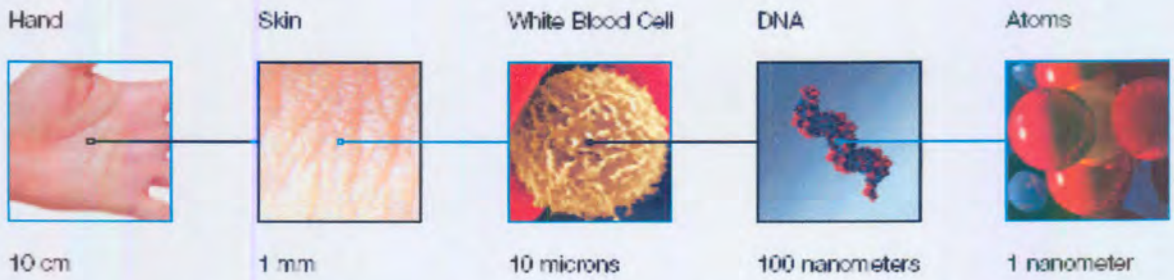


Figure 1-3. Illustration of the size of nanotechnology (Gann, 2003).

"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).

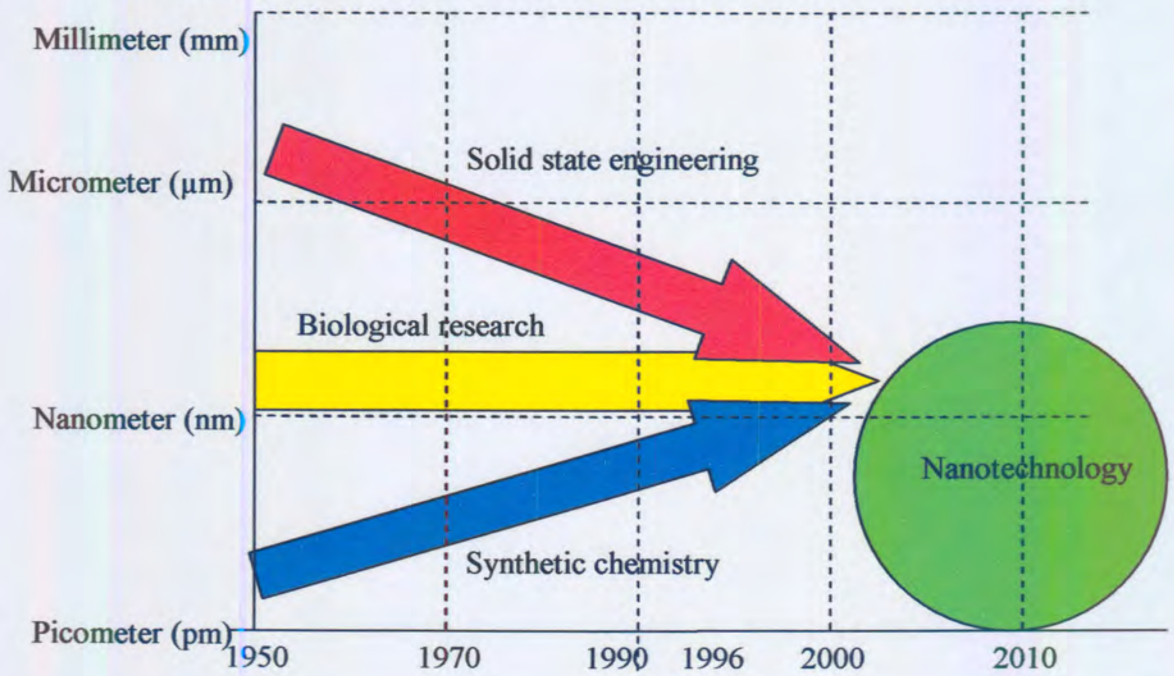


Figure 1-4. Convergence of different technologies towards nanotechnology (LuxCapital, 2003).

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).

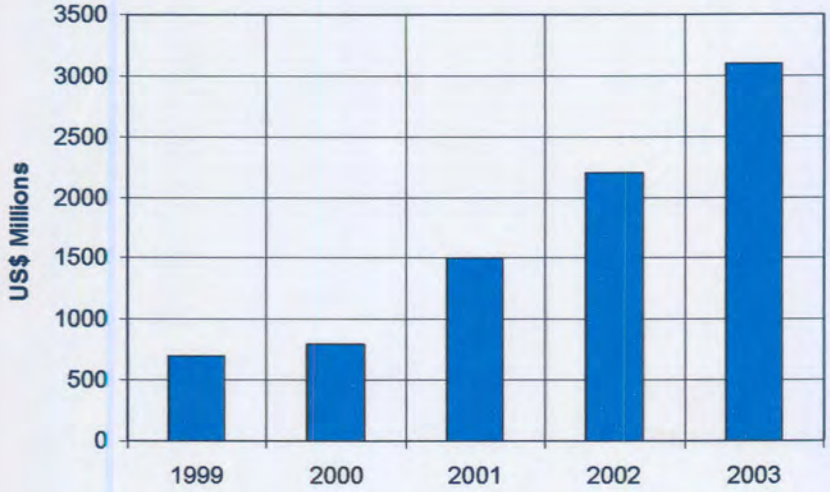


Figure 1-5. Bar chart of the total international nanotechnology funding from 1999 to 2003 (NanoInvestorNews, 2004).

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).

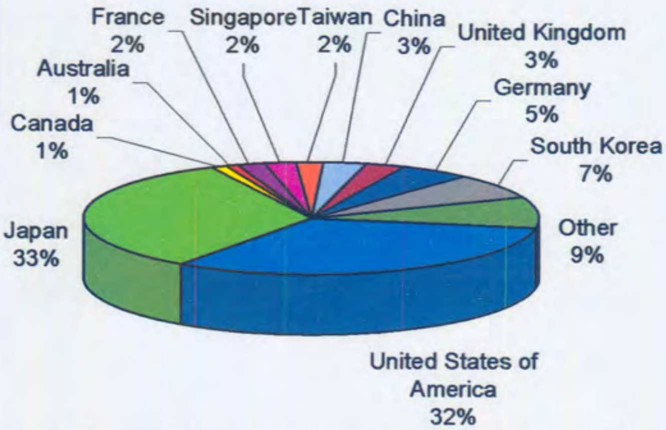


Figure 1-6. Pie chart of governments' role in the international nanotechnology funding (NanoInvestorNews, 2004).

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).

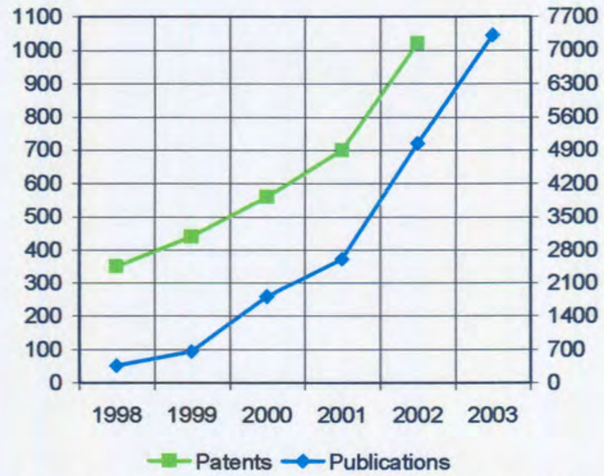


Figure 1-7. Interactive plots for the number of international patents (Y-axis on the left) and the number of publications (Y-axis on the right) mentioning 'nano' from 1998 to 2003 (LuxCapital, 2004).

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.

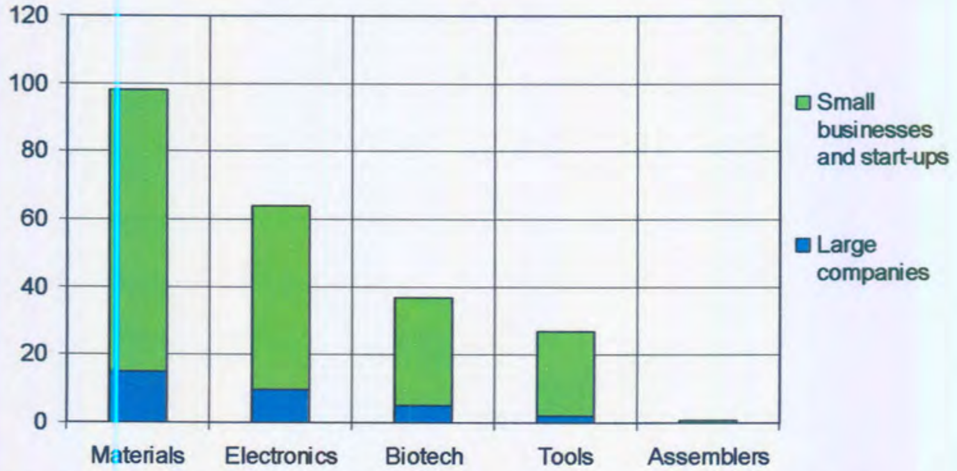


Figure 1-8. Bar chart of the number of start-up, small and large businesses active in various nanotechnology industries in 1999 (In Realis, 2002).

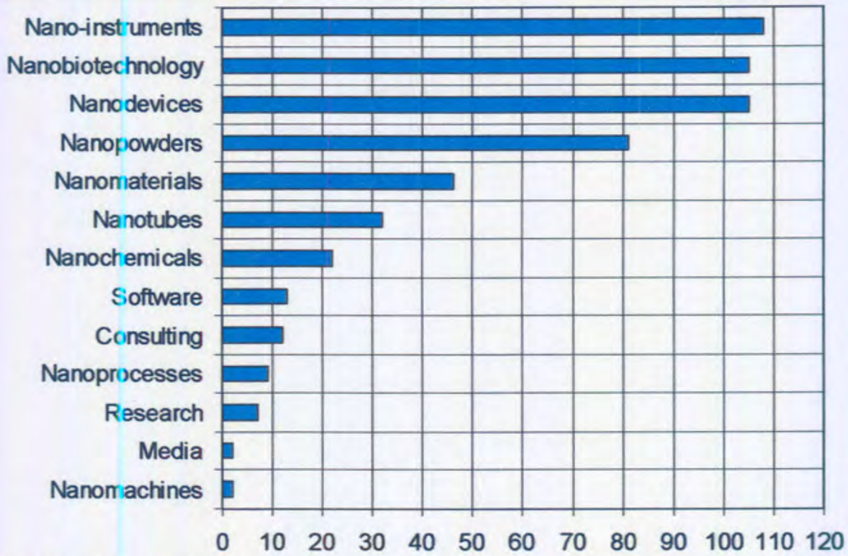


Figure 1-9. Bar chart of the number of international firms involved in various nanotechnology segments in 2003 (NanoInvestorNews, 2004).

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).

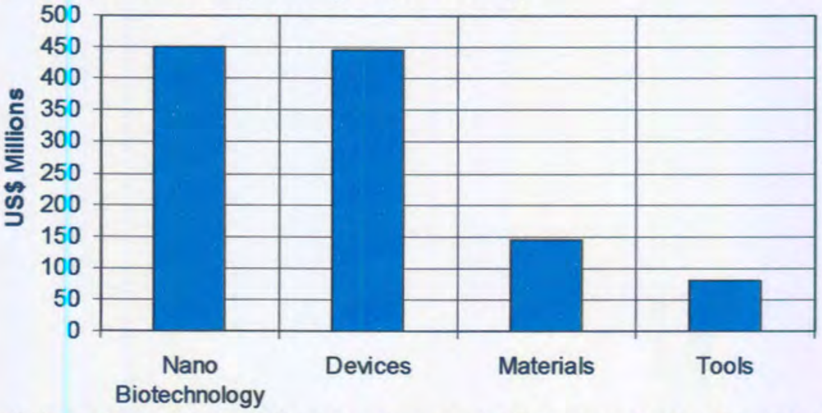


Figure 1-10. Bar chart of international venture capital investments (LuxCapital, 2004:v).

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.

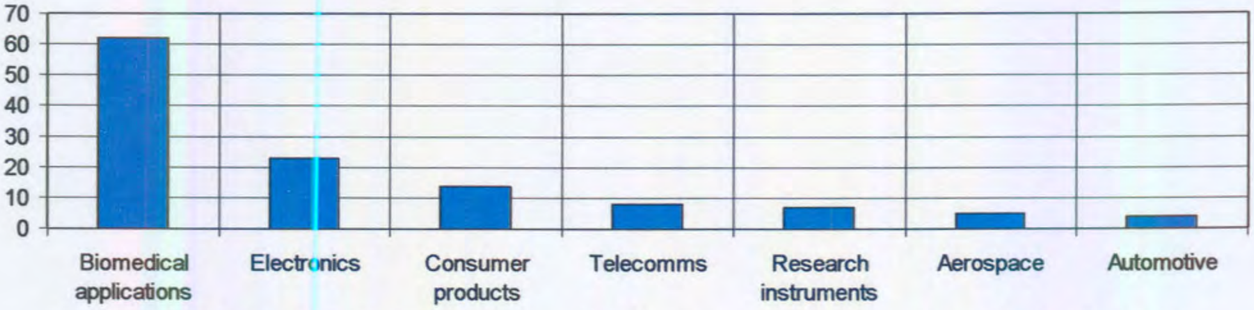


Figure 1-11. Bar chart of the greatest perceived investment returns per nanotechnology industry (NanoInvestorNews, 2004).

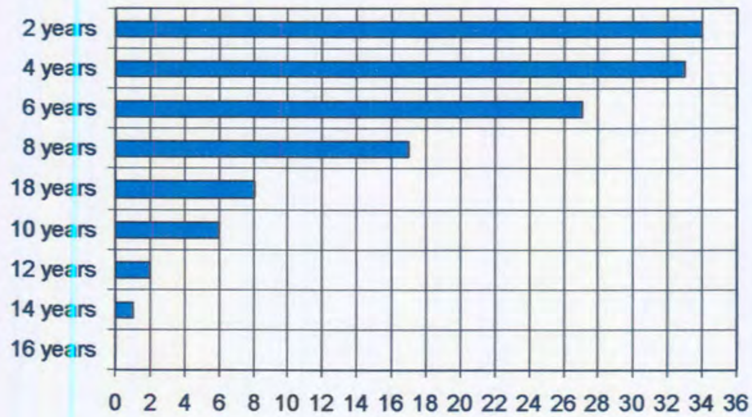


Figure 1-12. Bar chart of time estimate of when the first pure nanotechnology firm will reach $100 million in sales (NanoInvestorNews, 2004).

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.

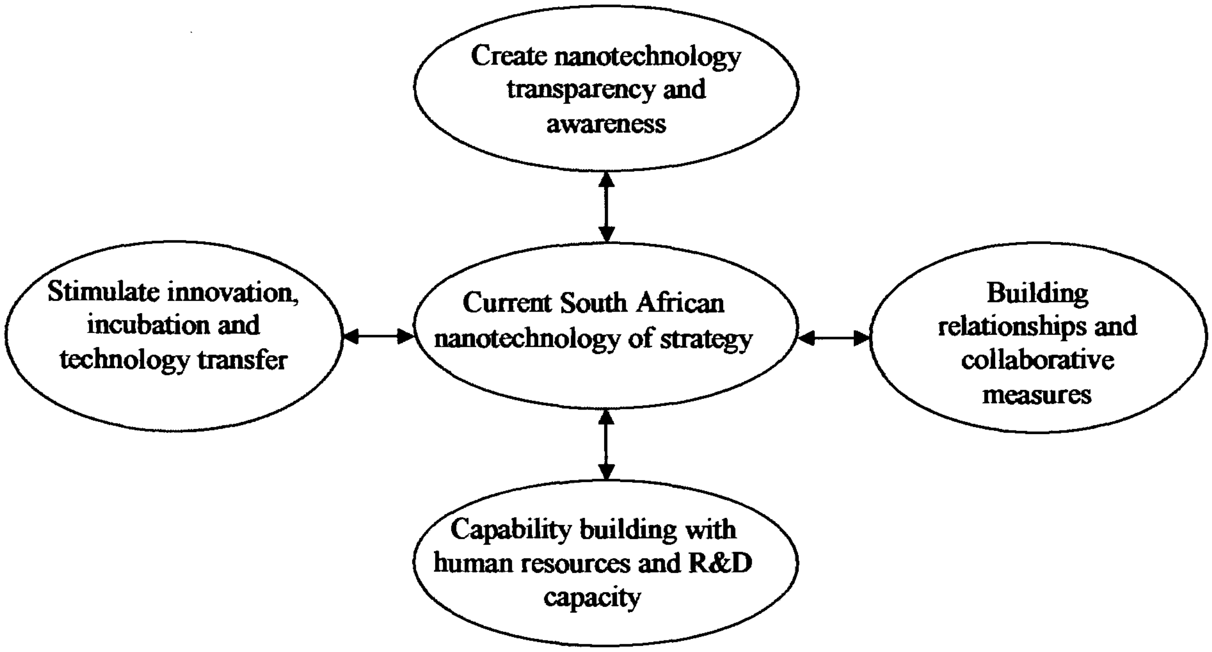


Figure 1-13. Five South African Nanotechnology Strategy interventions (SANi, 2003a:2).

Goals
1. Gain business and competitive advantages 2. Provide better quality of life to everyone 3. Move towards a knowledge economy 4. Build a technology base for future development 5. Create technology awareness in the South African industry and public 6. Facilitate involvement of South African industry in nanotechnology
Propositions
1. Any industry not investigated and strategising around nanotechnology runs a great business risk. 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. 3. To ensure global competitiveness South Africa must respond to global trends, with wealth creation as a function. These global trends include nanotechnology. 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 2. Developed countries are high-end technology or knowledge economies. 3. Education and knowledge are key characteristics of developed countries. 4. Developed countries invest heavily in new technology 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 Low cost distribution or portable power generation Alternative fuels
Water	Disinfection Purification Toxic element and organic pollutants' removal
Health	Drug carriers and delivery Biomaterials (prostheses) Cosmetics and sunscreens
Industrial development cluster	**Some examples**
Processing	Cost effective processing Emission and effluent control
Mining and minerals	Beneficiation and other alternative value adding advanced tools and materials
Materials and manufacturing	Advanced coatings and paints Improved processes for current materials 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.

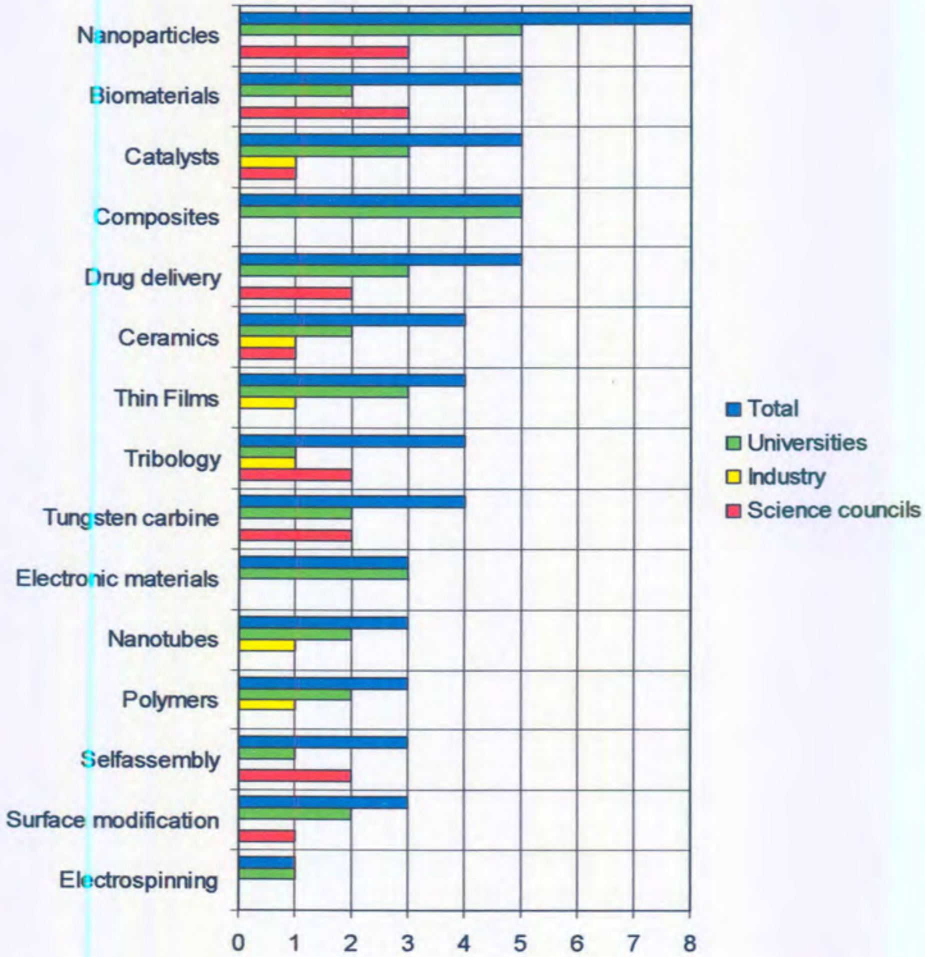


Figure 1-14. Bar chart of South African nanotechnology involvement by universities, industry and science councils (SANi, 2003b:11).

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.

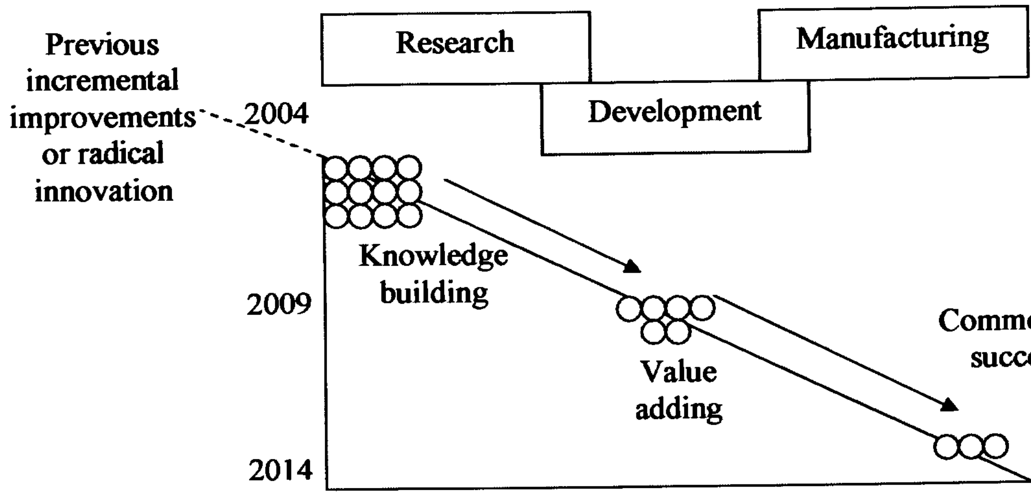


Figure 1-15. Illustration of new technology growth as seen by Mr. Manfred Scriba of the CSIR.

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 Good economic infrastructure Long-term economic vision towards 2014 Good concept to market skills Well-developed marketing sector Incentives for small, medium and micro enterprises	Great distance from world markets Unattractive fluctuation of the Rand value Shortage of start-up support Shortage of venture capital High interest rates Lack of tax breaks
Technological	
Technologically sound manufacturing base Abundance of natural resources and well-developed related infrastructures Well-developed and strong energy sector World-class expertise in several areas (for example catalysis, water, mining and agriculture research) Technology sector not over-regulated and fairly well developed	Low awareness and understanding of nanotechnology South Africa mainly a technology importer, thus usually pays high licence fees Limited industrial scale-up knowledge or design capability in South African industry Lack of industrial R&D culture, coupled with low technology diffusion rate
Relational	
Good network and database formed by SANi Still building trade and other relations Gateway to Africa via bilateral agreements and NEPAD	
Human	
High levels of grass roots participation Small nucleus of highly skilled workforce Open and forward-thinking entrepreneurial society, which are willing to take risks Relatively cheap and efficient R&D workforce	Large and almost completely unskilled workforce Losing skilled workforce (brain drain) mainly due to the lack of opportunities and security Demographically skewed science and technology base HIV/Aids has huge impact on the workforce
Governmental	
Pace-setting government, which is positive to change and growth Strong governmental science policy 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) 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 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) Environmental nanotechnology applications	Limited access to fundamental chemistry and physics training Limited development of technically feasible materials and processes Thus far South Africa has been unable to build critical mass of R&D capacity in nanotechnology South Africa pays substantial annual technology licence fees to manufacture goods, pharmaceuticals, chemicals, etc. and runs the risk to continue in that trend Industrial awareness and support of nanotechnology Fragmented nature of the South African research landscape Multidisciplinary nature of nanotechnology Patchiness of mechanisms to facilitate the transfer of technology 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 Limited private sector support of nanotechnology R&D Uncoordinated funding

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

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

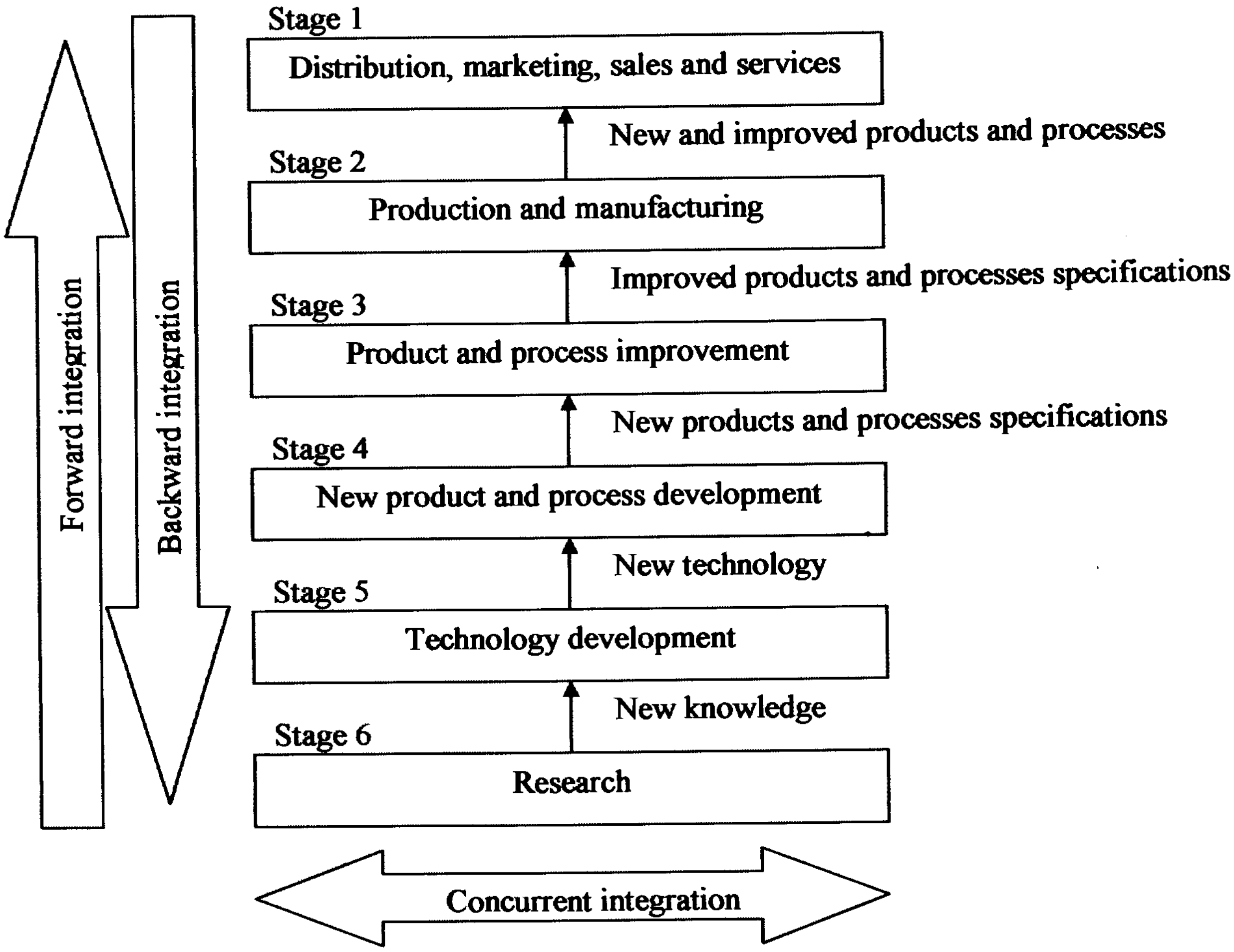


Figure 2-1. The one-directional linear model of the innovation process (Buys, 2001).

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.

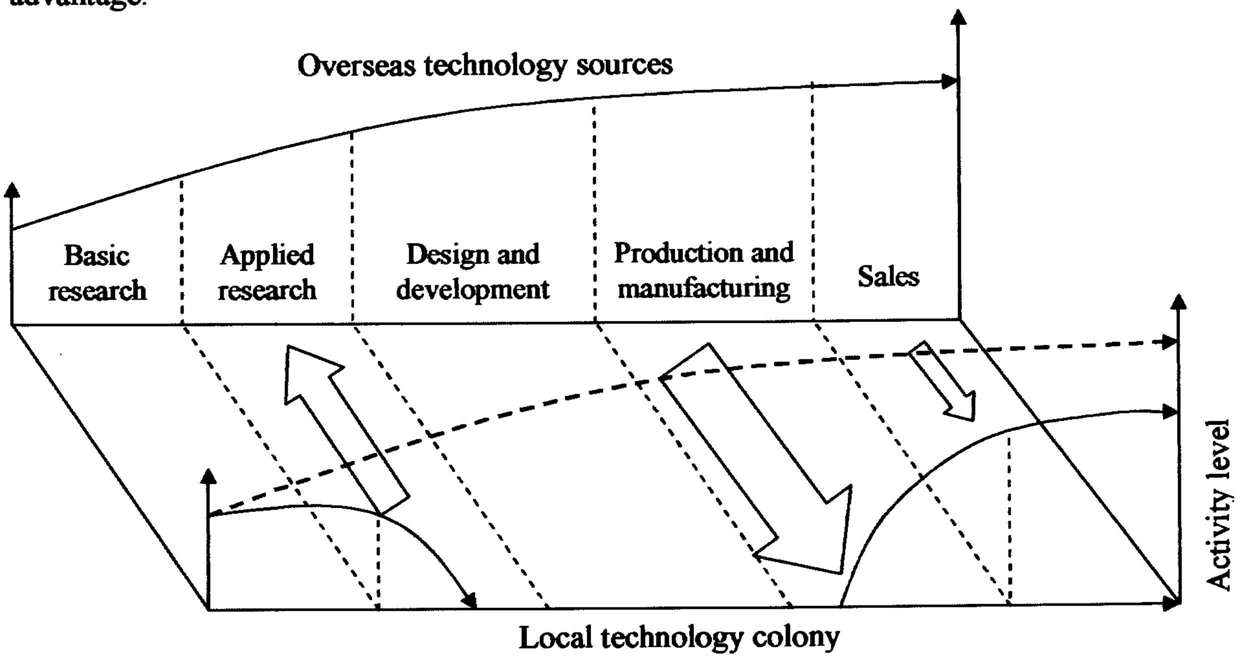


Figure 2-2. Product life cycle model in the case of technology colony, illustrated against the backdrop of the product life cycle of a developed overseas country (De Wet, 2000).

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

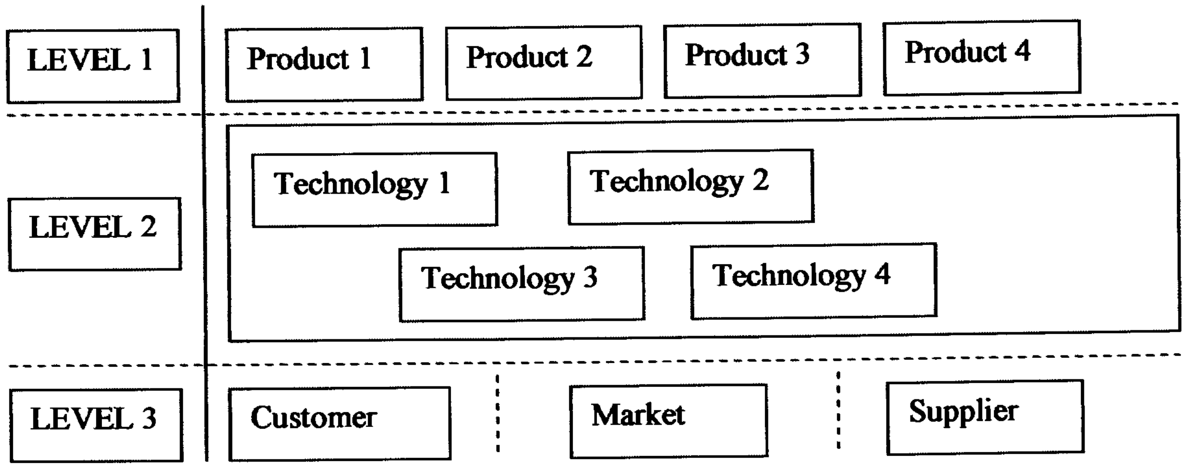


Figure 2-3. Three of level of analysis technology systems within the NSI.

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.

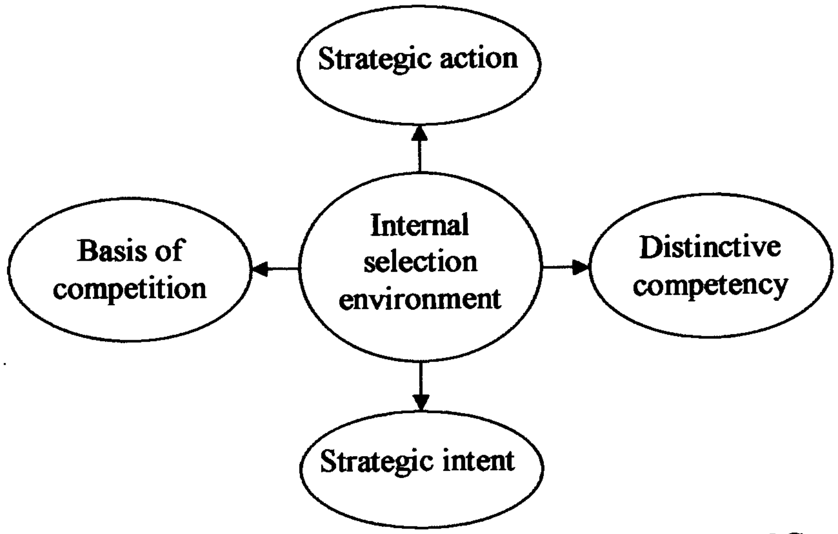


Figure 2-4. Dynamic forces in an organisation's evolution (Burgelman and Grove, 1996).

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.

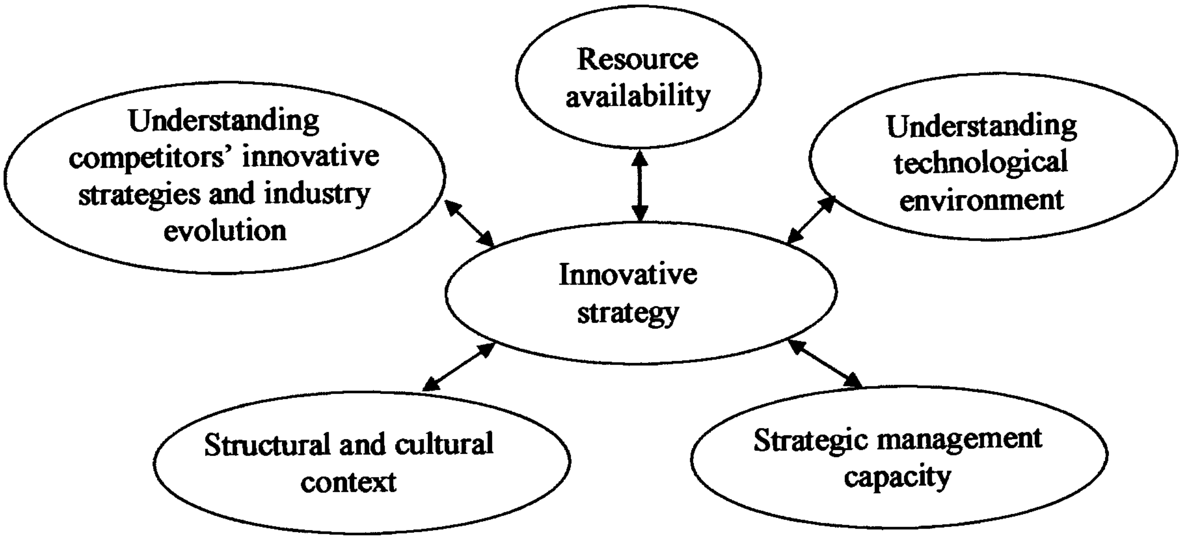


Figure 2-5. Framework for evaluation of innovative capabilities (Burgelman, Maidique and Wheelwright, 2001:11).

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 Venture nurturing Educational acquisition	Venture capital Venture nurturing Educational acquisition
	New but familiar	Internal market development Acquisition	Internal venture Acquisition Licensing	Venture capital Venture nurturing Educational acquisition
	Existing	Internal development or acquisition	Internal product development Acquisition 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.

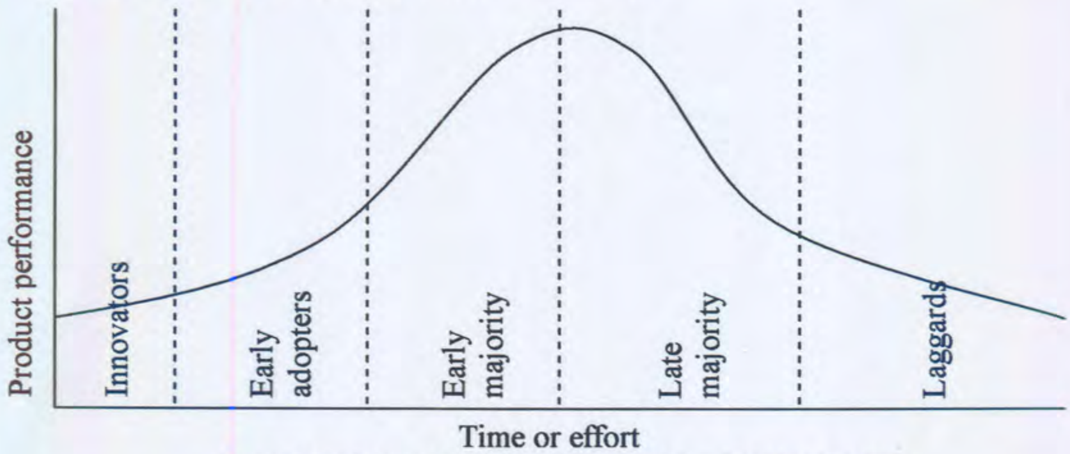
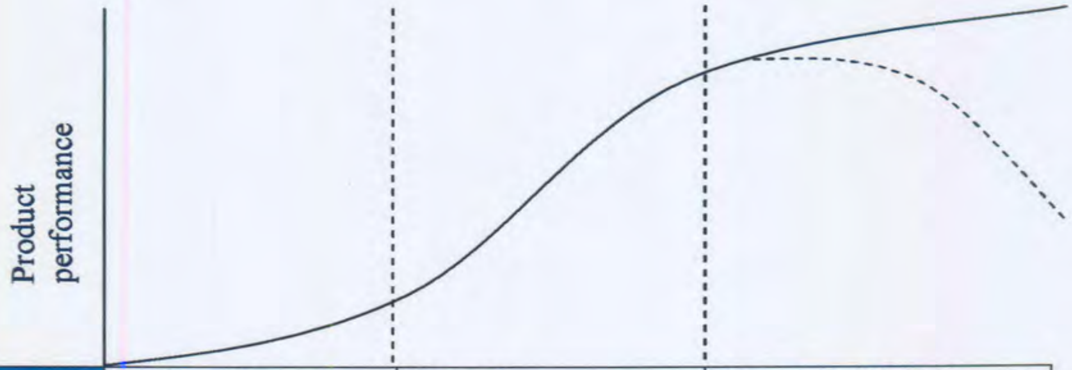


Figure 2-7. The technology adoption life cycle (Moore, 1999).

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).