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).

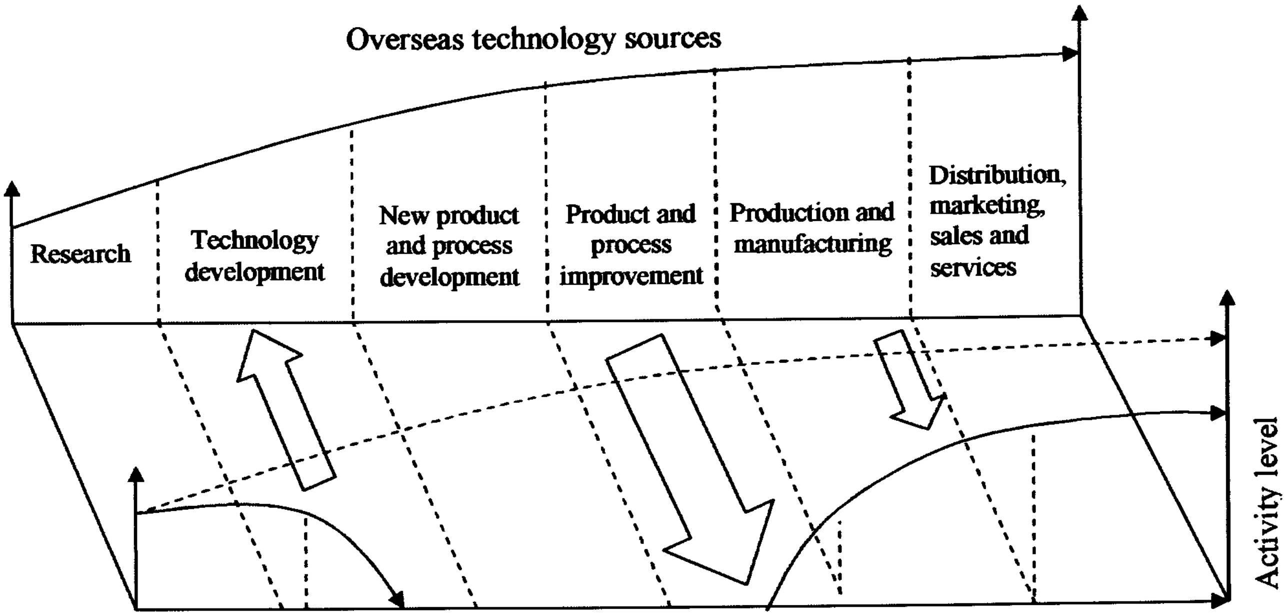

Figure 3-1. Product life cycle model in the case of technology colony according to the stages declared by Buys (2001), illustrated against the backdrop of the product life cycle of a developed overseas country (De Wet, 2000).

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.

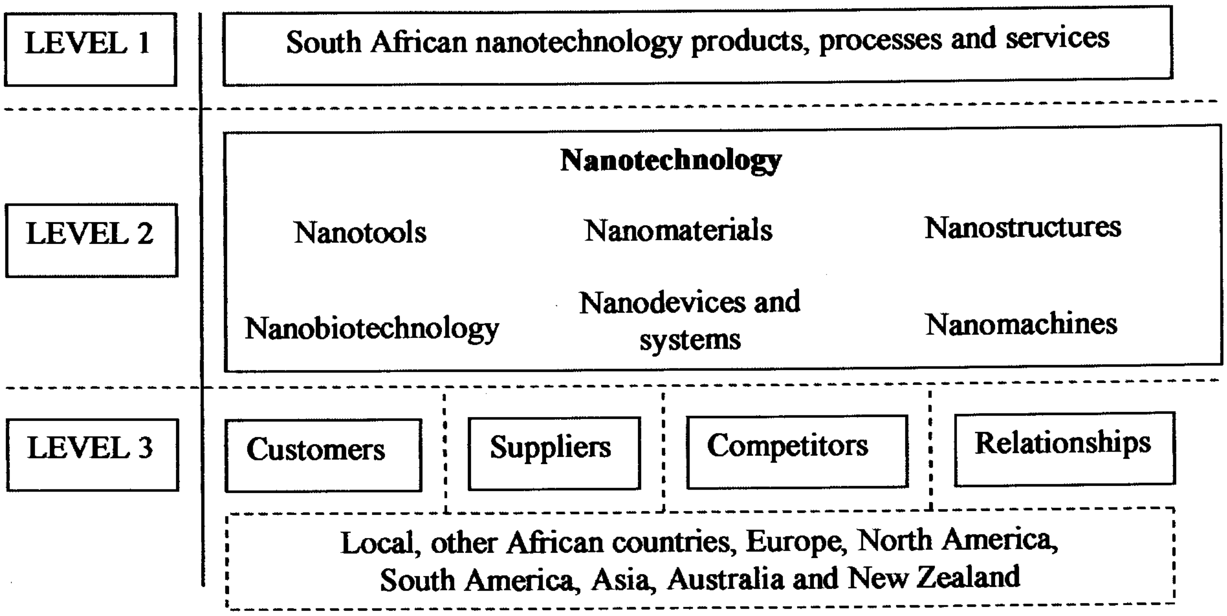

Figure 3-2. Level of analysis of the South African Nanotechnology system of innovation

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.

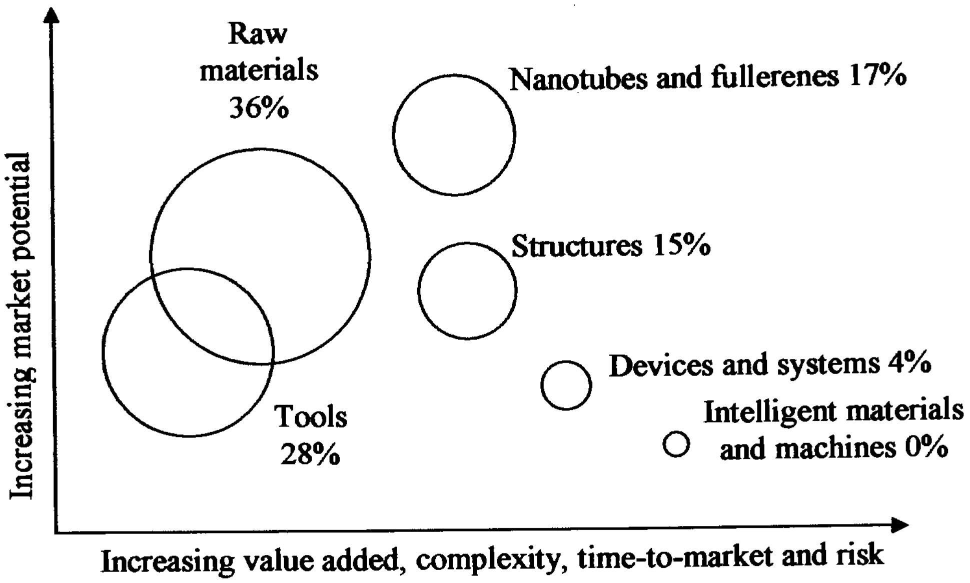

Figure 3-3. Nanotechnology segments and worldwide percentage of firms involved in each segment (Gordon 2002). Note that the size of the circle depicts the number of organisations registered worldwide in each nanotechnology segment in 2002.

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 Offensive/Aggressive strategies e.g. Market penetration	Overcome weaknesses by taking advantage of opportunities Developmental/Conservative strategies e.g. Capability learning
Threats – T	Use strengths to avoid or overcome threats Competitive strategy e.g. Product diversification	Minimise weaknesses and avoid threats Defensive strategies 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.

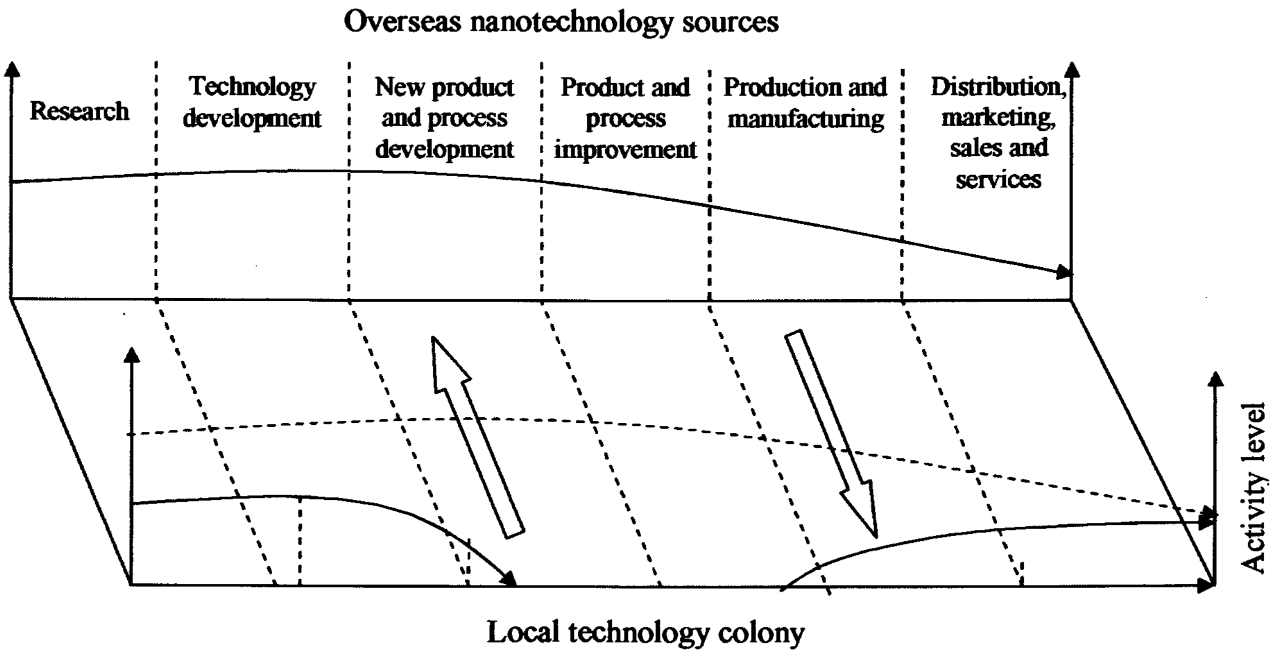

Figure 3-4. Technological system of the South African nanotechnology system in comparison to overseas nanotechnology sources.

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.

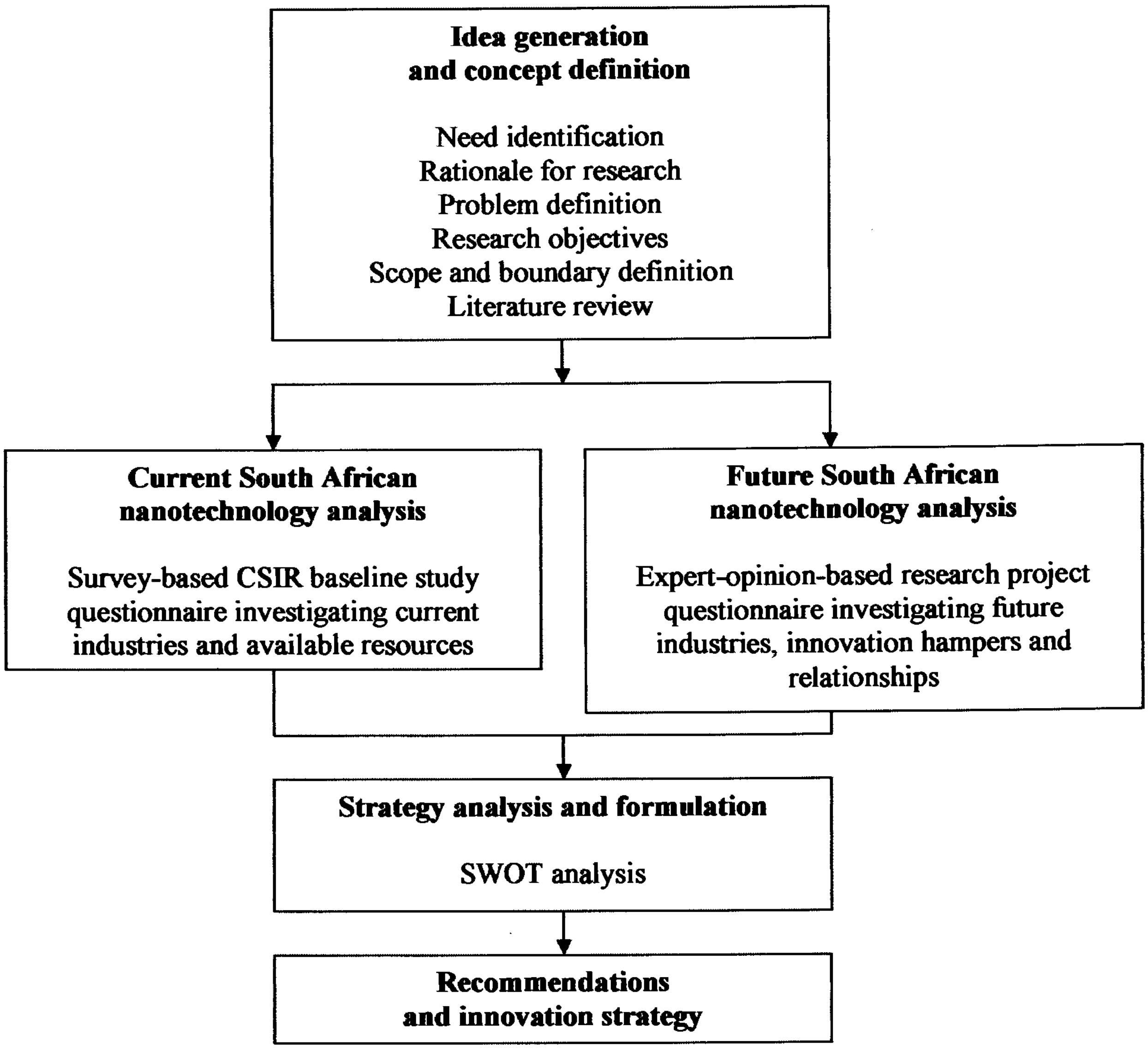

Figure 4-1. Elements of the research strategy.

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.

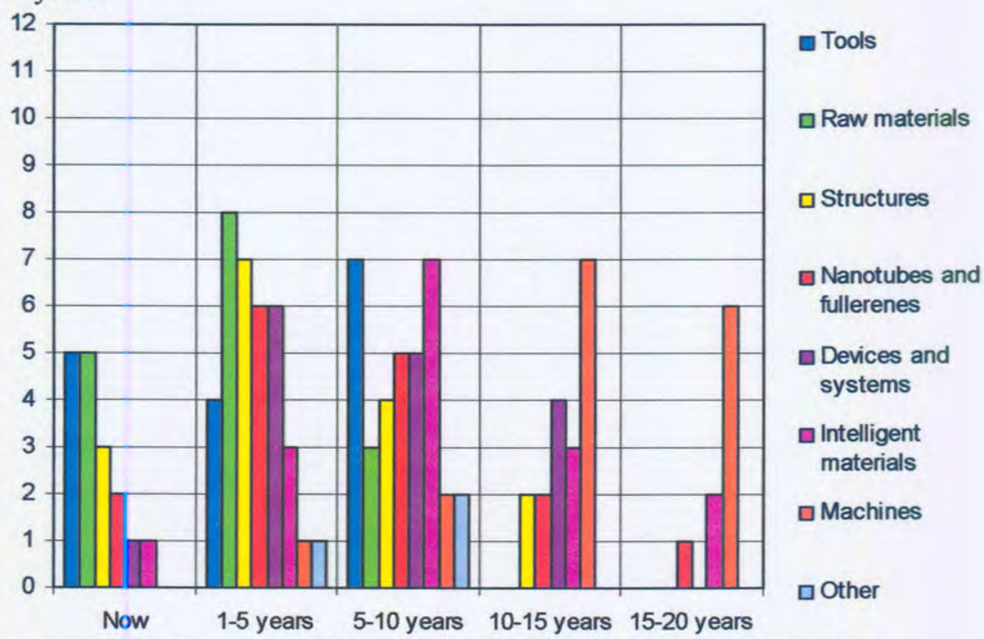

Figure 5-1. Bar chart of the time to market for nanotechnology segments.

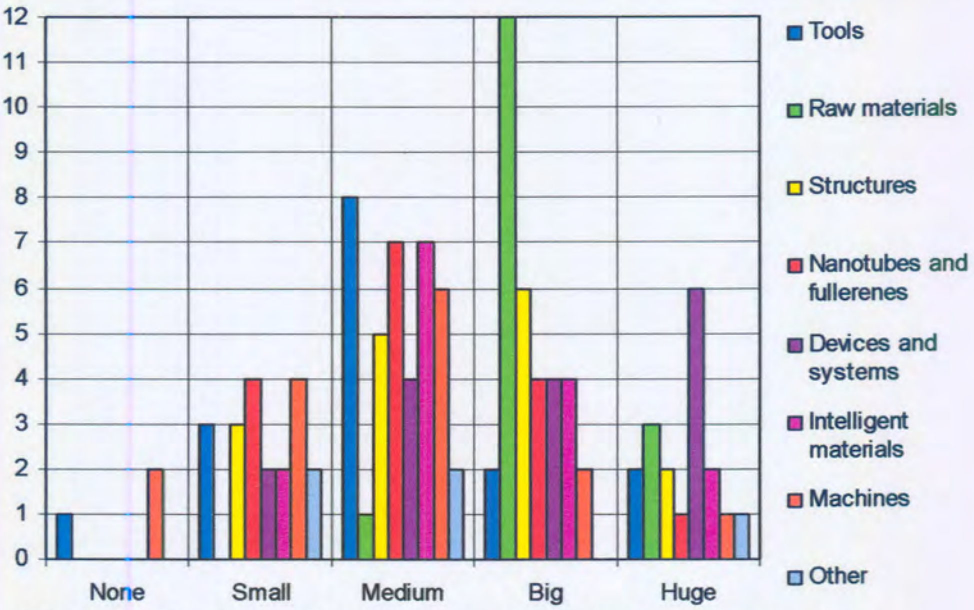

Figure 5-2. Bar chart of the market potential for nanotechnology segments.

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.

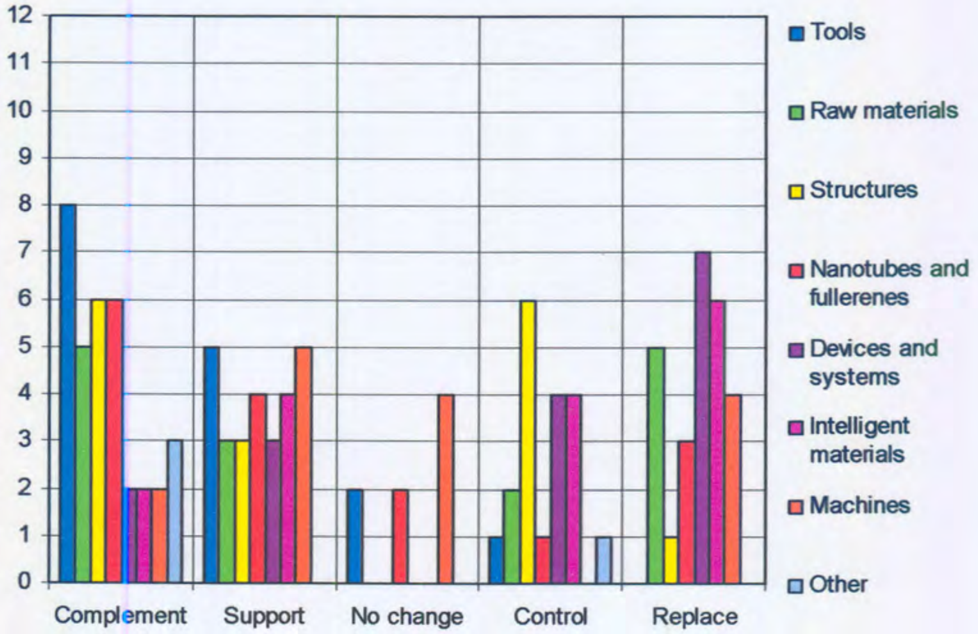

Figure 5-3. Bar chart of the disruptiveness of nanotechnology segments.

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

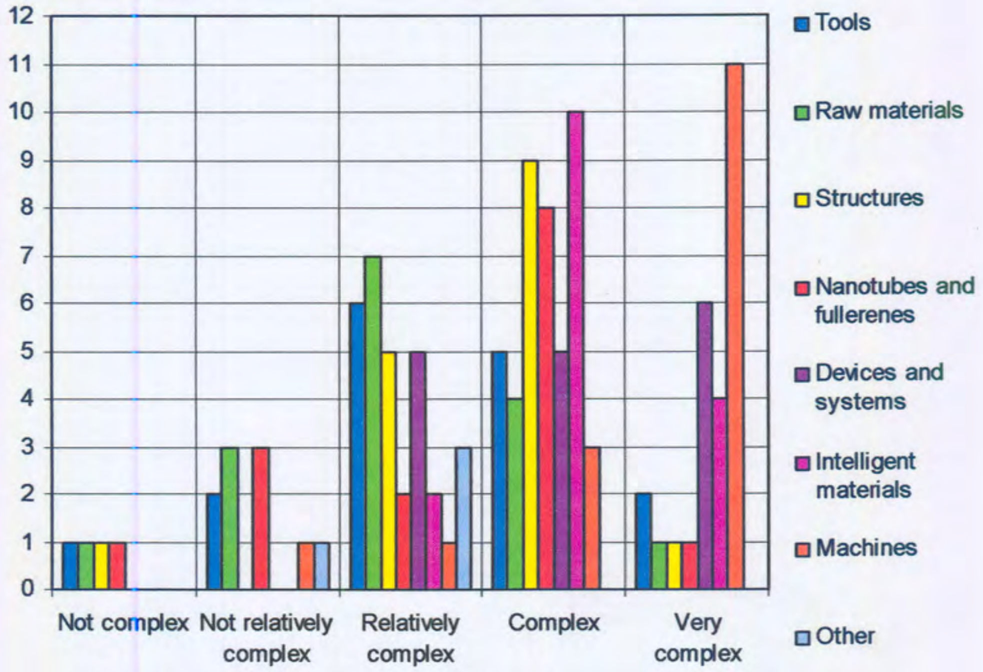

Figure 5-4. Bar chart of the complexity of nanotechnology segments.

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).

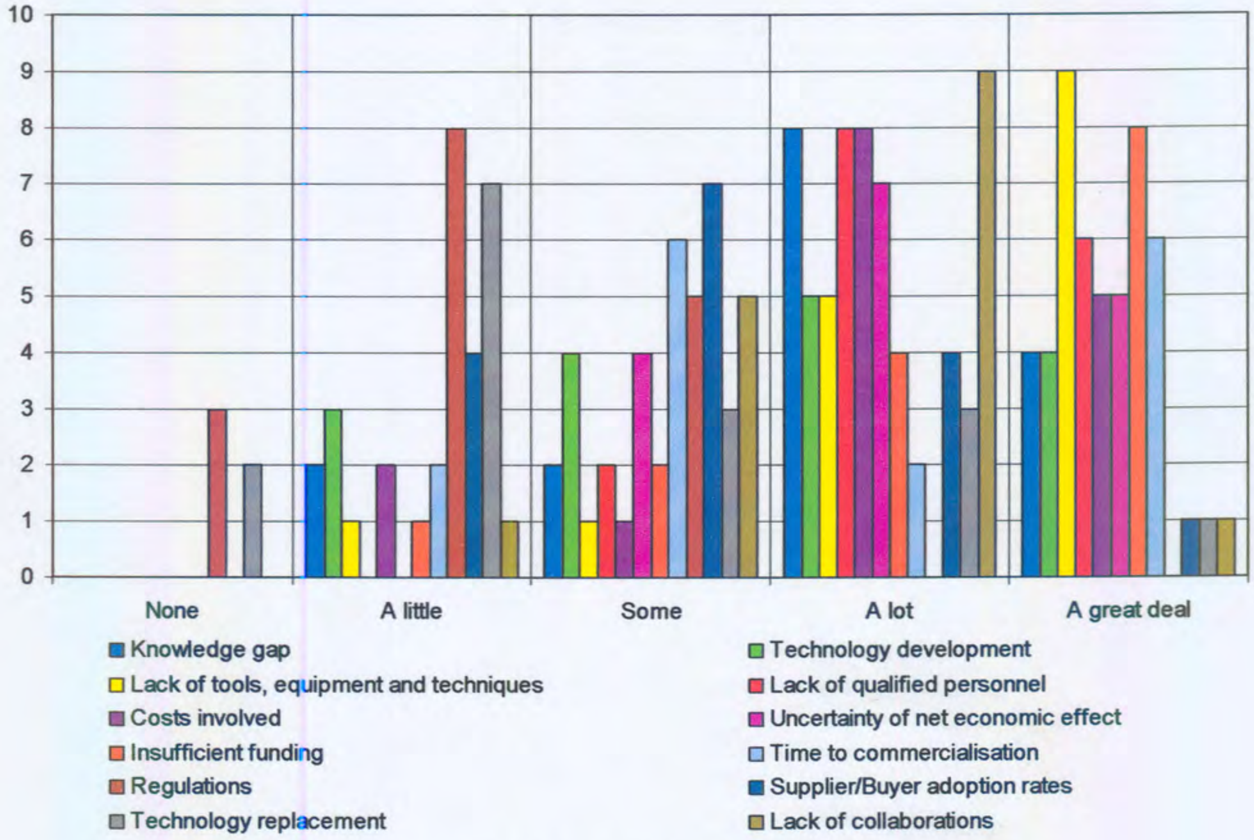

Figure 5-5. Bar chart of the nanotechnology innovation hampers.

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).

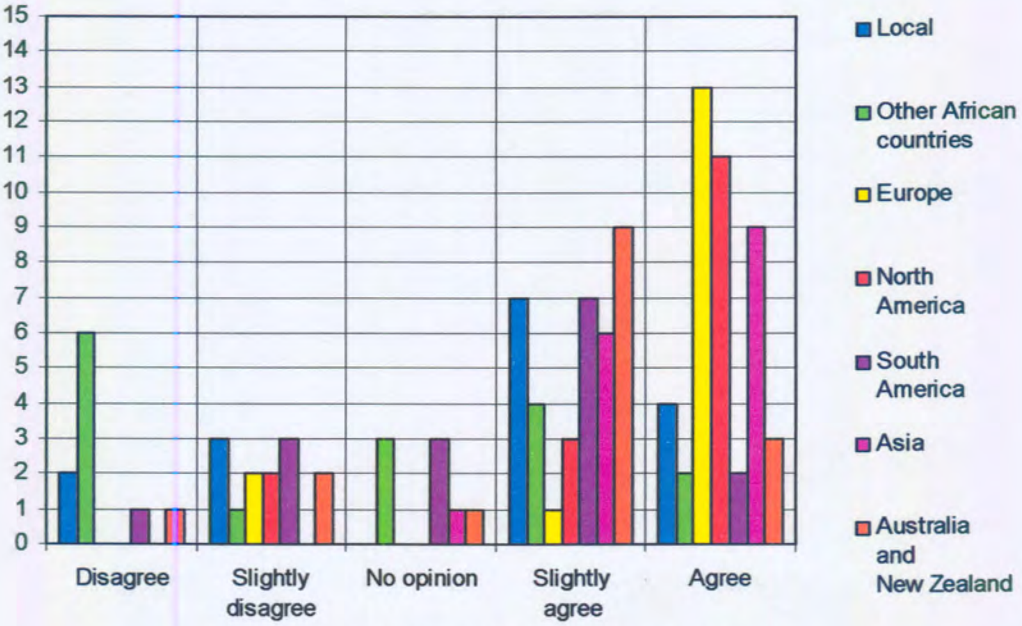

Figure 5-6. Bar chart of the nanotechnology buyers.

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.

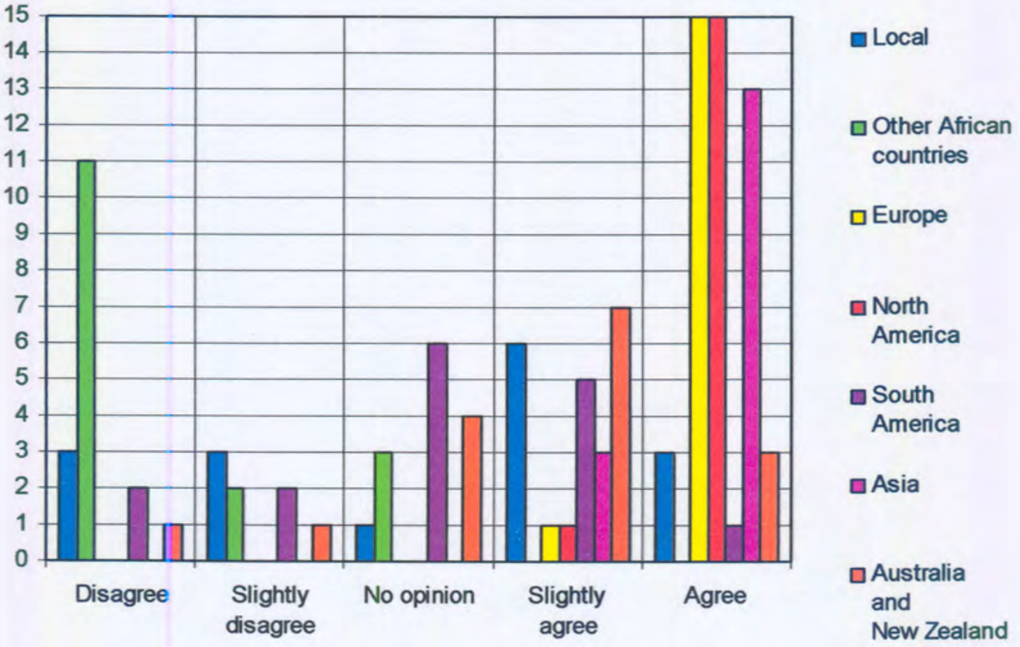

Figure 5-7. Bar chart of the nanotechnology suppliers.

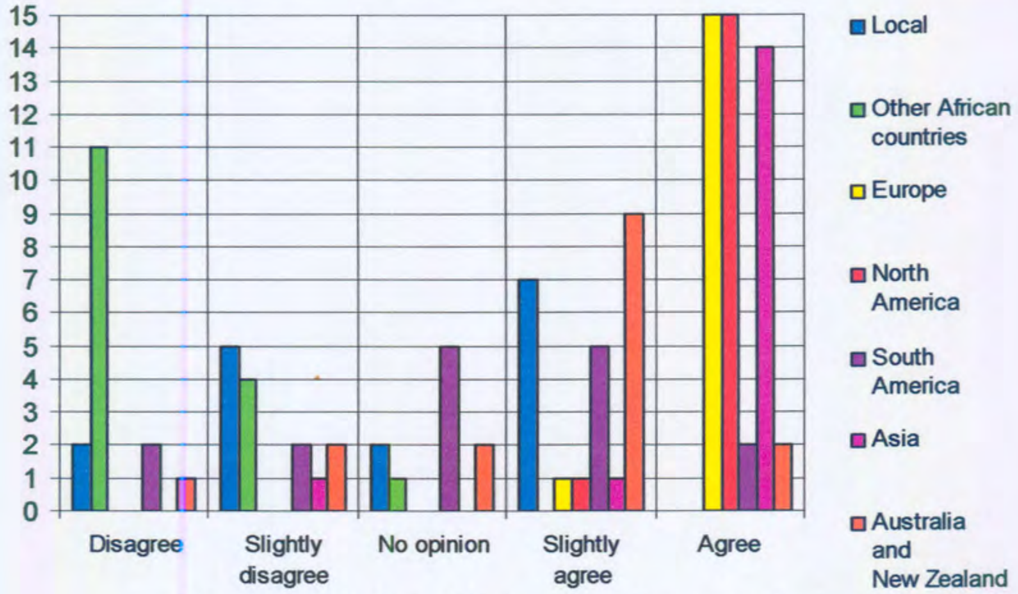

Figure 5-8. Bar chart of the nanotechnology competitors.

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.

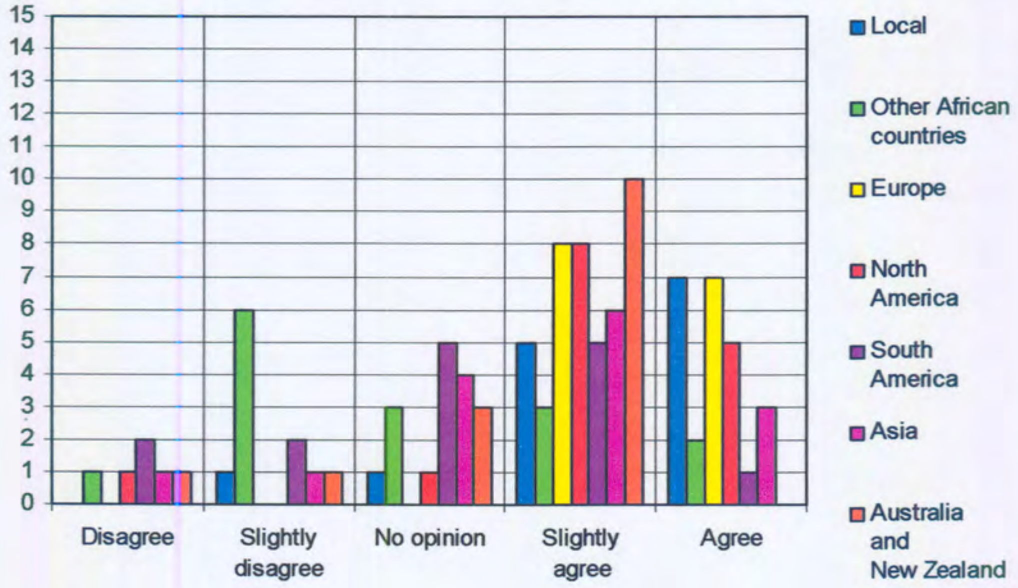

Figure 5-9. Bar chart of the nanotechnology relationships.

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 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 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).

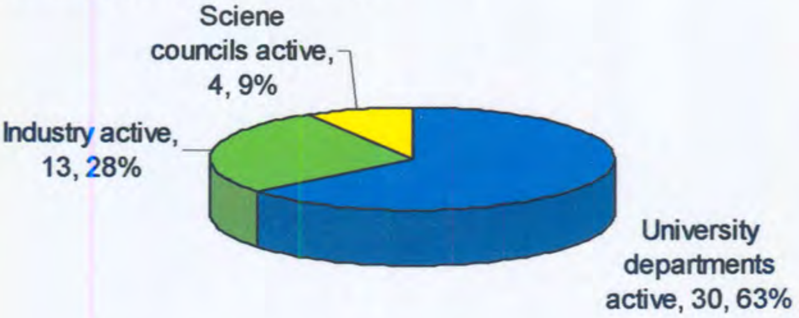

Figure 5-10. Pie chart of the CSIR baseline-study participants.

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).

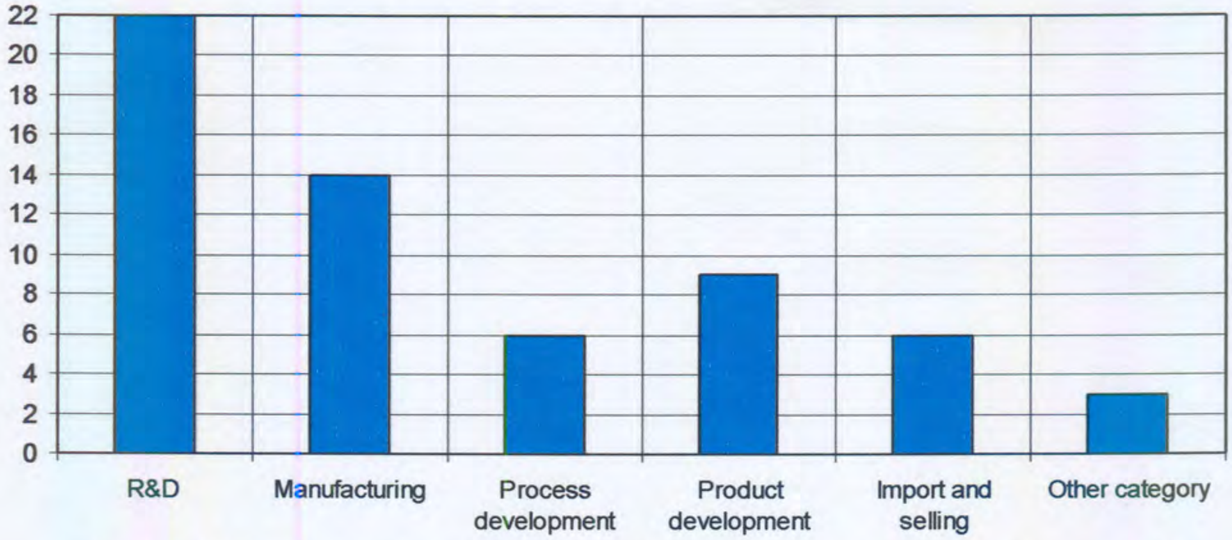

Figure 5-11. Bar chart of South African nanotechnology involvement. Note that the number of participants, not the number of activities is plotted.

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.

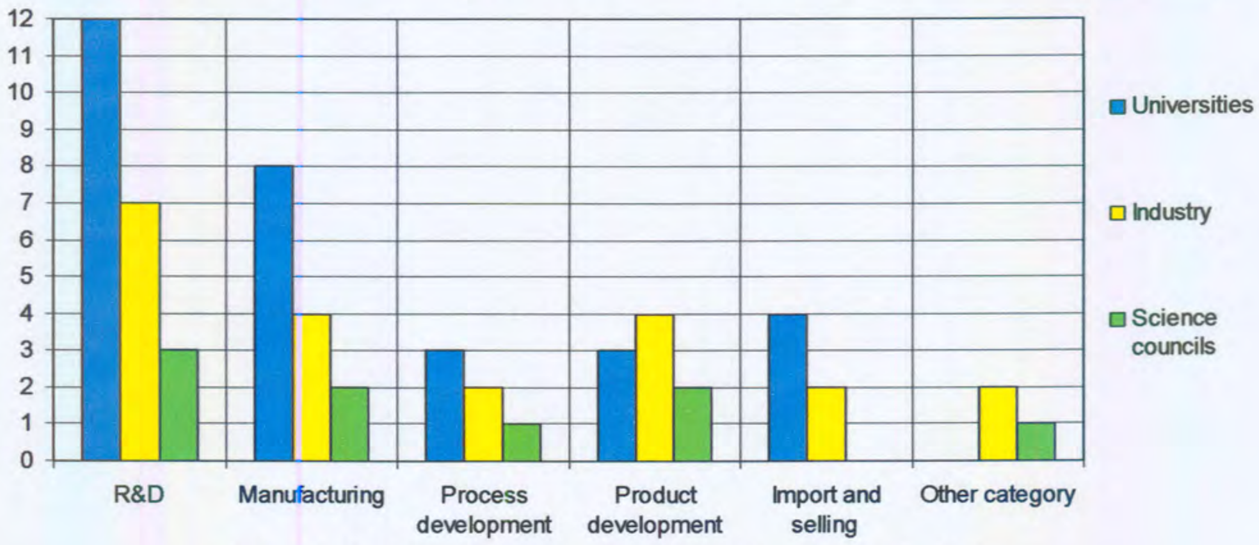

Figure 5-12. Bar chart of nanotechnology involvement per institution.

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).

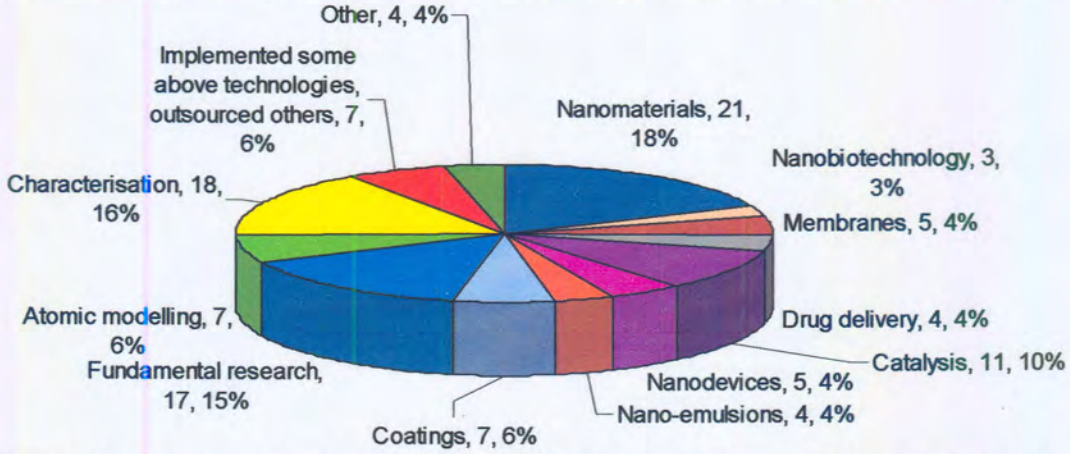

Figure 5-13. Pie chart of nanotechnology aspects in which all South African participants are involved.

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).

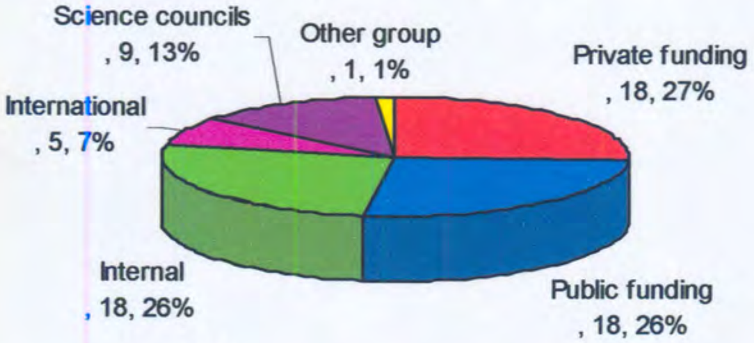

Figure 5-14. Pie chart of South African nanotechnology funding sources.

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).

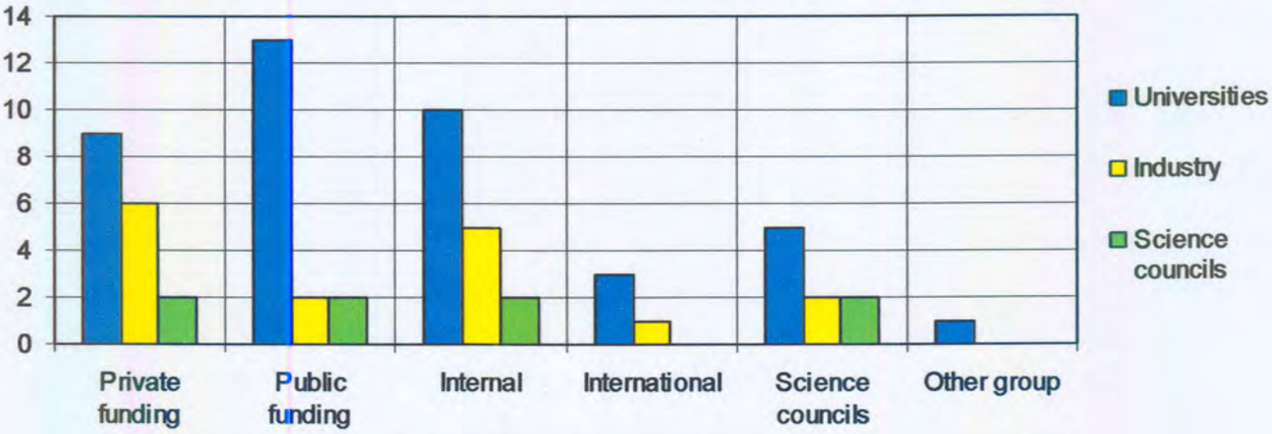

Figure 5-15 Bar chart of South African nanotechnology funding sources per institution.

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.

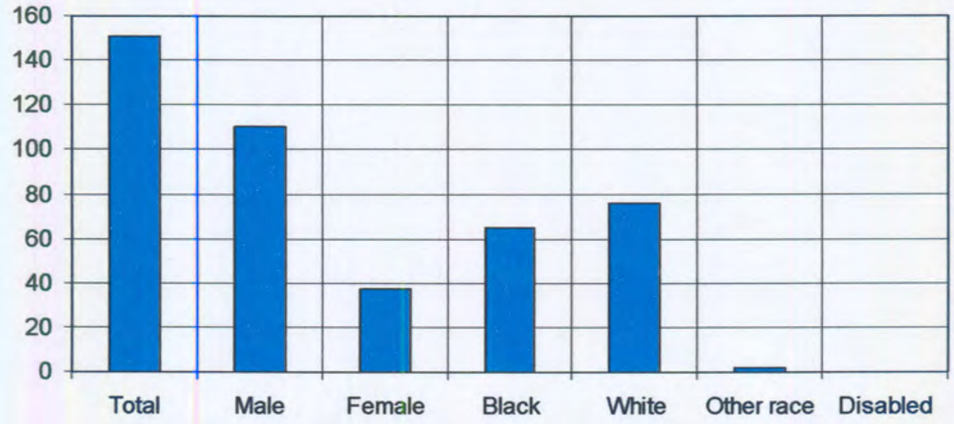

Figure 5-16. Bar chart of the nanotechnology personnel demographics.

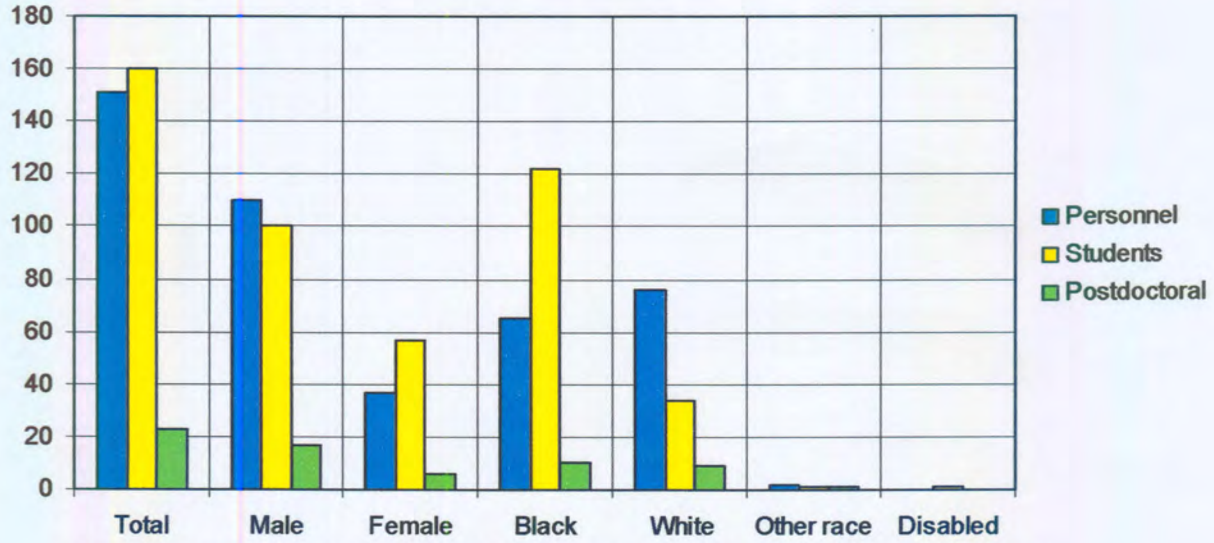

Figure 5-17. Bar chart of the nanotechnology personnel demographics per institution.

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.

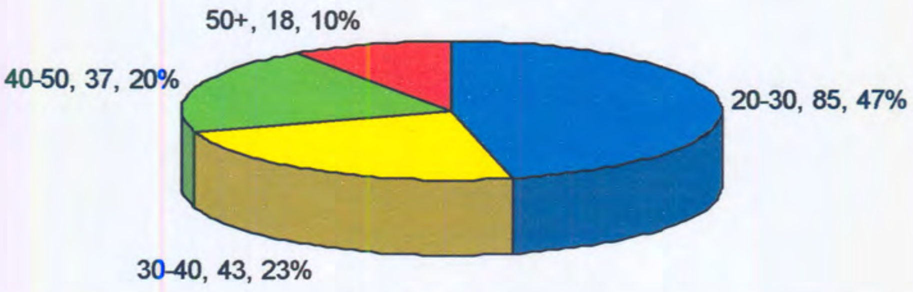

Figure 5-18. Pie chart of South African nanotechnology personnel age.

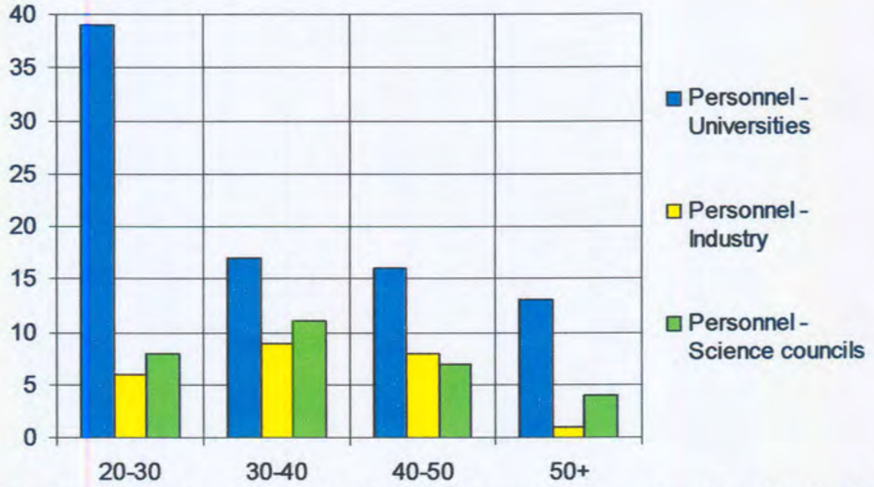

Figure 5-19. Bar chart of South African nanotechnology personnel employed per institution per age.

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.

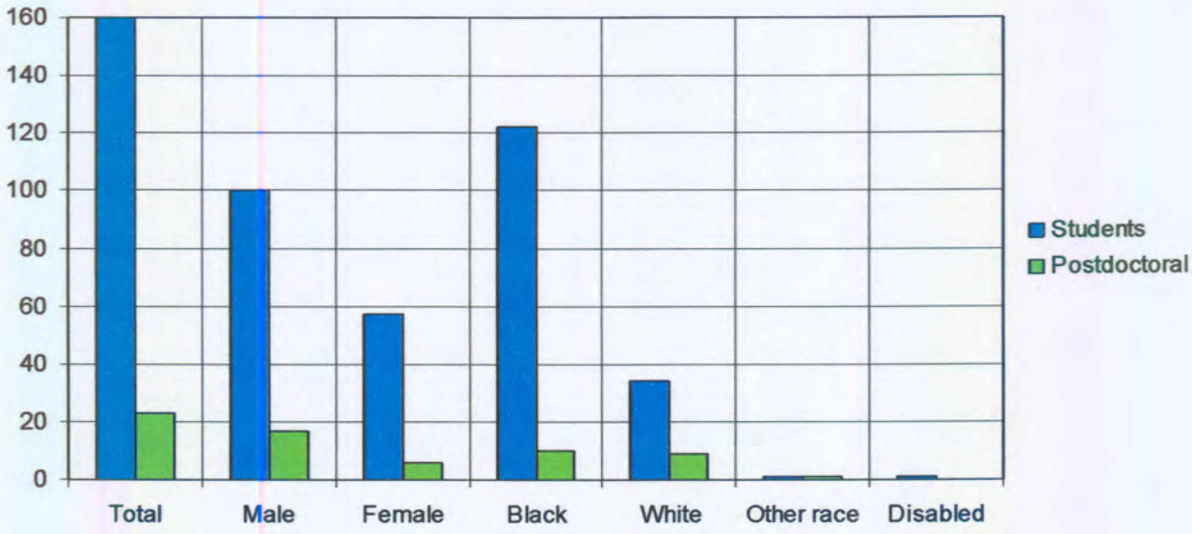

Figure 5-20. Bar chart of South African nanotechnology students.

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.

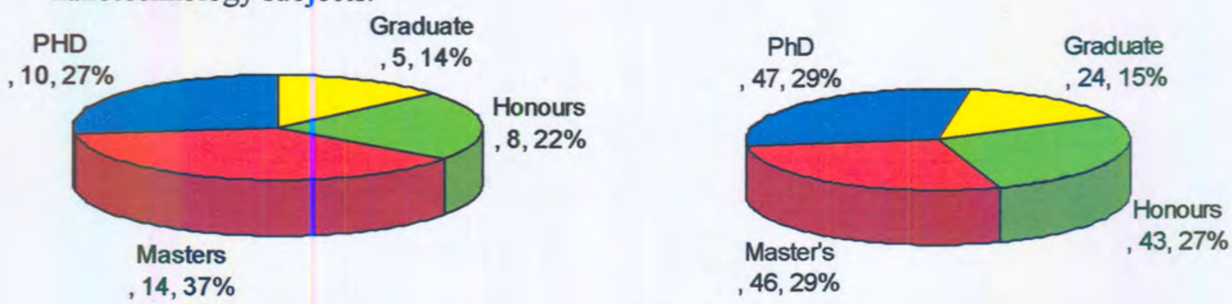

Figure 5-21. Pie charts of South African nanotechnology university curricula and their enrolled students.

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).

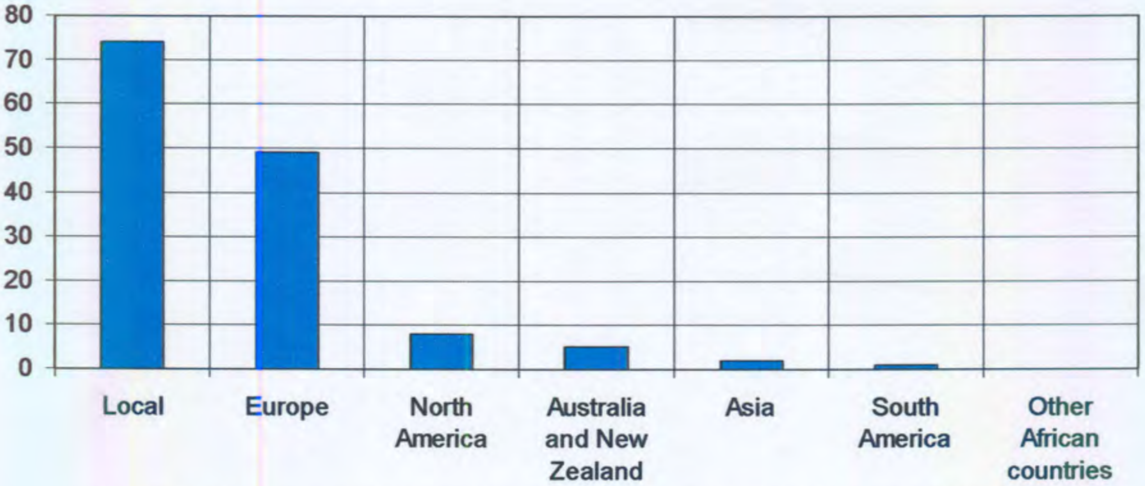

Figure 5-22. Bar chart of the number of South African nanotechnology collaborations.

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?

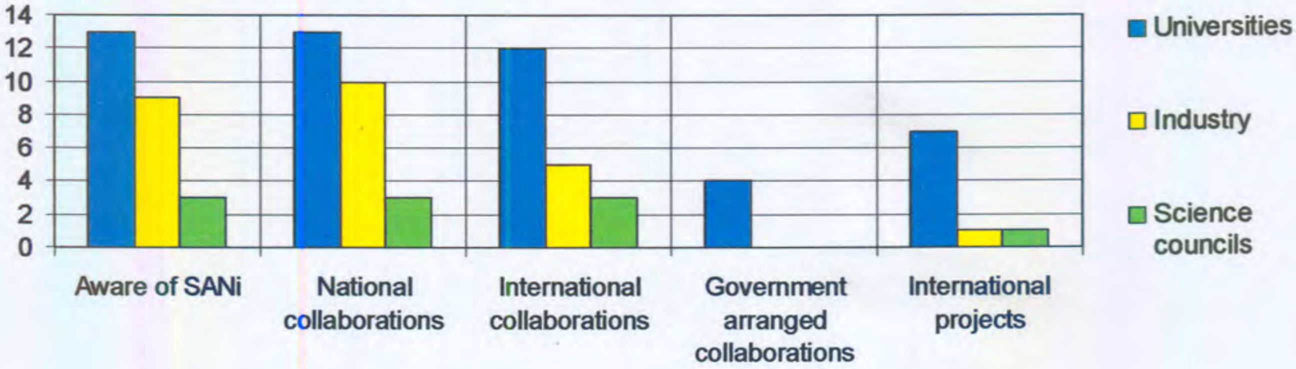

Figure 5-23. South African nanotechnology relations and networking.

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.

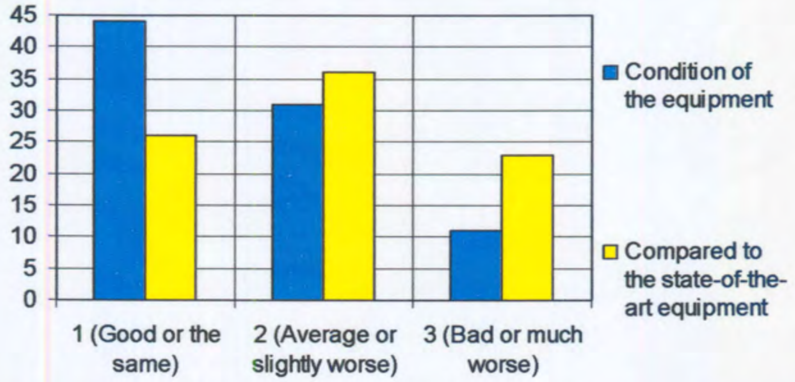

Figure 5-24. Bar chart of South African nanotechnology equipment condition and comparison with modern equipment.

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.