STUDY OF THE SOUTH AFRICAN NANOTECHNOLOGY SYSTEM

DERRICK LOUIS VAN DER MERWE
99159032

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

MASTER OF TECHNOLOGY MANAGEMENT

in the

FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY

UNIVERSITY OF PRETORIA

October 2004

© University of Pretoria

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

STUDY OF THE SOUTH AFRICAN NANOTECHNOLOGY SYSTEM

DERRICK LOUIS VAN DER MERWE

99159032

Supervisor : Prof. A.J. Buys
Department : Department of Engineering and Technology Management
            UNIVERSITY OF PRETORIA
Degree : MEng (Technology Management)

Abstract

The study of the nanotechnology system in South Africa is an analysis of the South African nanotechnology innovation system, with a discussion of background information regarding nanotechnology awareness, involvement, funding, personnel, education, networking and equipment, and illustration of the level of nanotechnology activities for each product life cycle and per institution. The document contains a classification of nanotechnology industries regarding time to market, market potential, disruptiveness and complexity, identifies innovation hampers for the South African nanotechnology community and ranks nanotechnology national and international nanotechnology buyers, suppliers, competitors and relationships. Lastly, innovative strategies are formulated from information gathered on internal South African nanotechnology strengths and weaknesses, and external nanotechnology opportunities and threats.
The author of the research project was fortunate enough to meet Mr. Manfred Scriba, the convenor and project coordinator of the South African Nanotechnology Initiative (SANi). Without him, the research project would not have been a success. Mr. Manfred Scriba is an invaluable asset to any South African nanotechnology-related study. He possesses a great deal of knowledge regarding the South African nanotechnology national system of innovation, technical knowledge on a number of nanotechnology fields and collaborations with many of the South African nanotechnology community members. In January 2004, the research project author and the author of the CSIR baseline questionnaire, Mr. Manfred Scriba, reached an agreement regarding the bidirectional usage of data gathered, analysed and discussed in both studies.

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

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

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

Richard Feynman 1959, the father of nanotechnology.
Study of the nanotechnology system in South Africa by Derrick L. van der Merwe

Abstract

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

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

Dr. Peter Doyle, Unilever
# Table of contents

1 Introduction and background ........................................................................... 1  
  1.1 Introduction ................................................................................................. 1  
  1.2 Brief history of nanotechnology .................................................................... 2  
  1.3 Definition of nanotechnology ....................................................................... 3  
  1.4 International nanotechnology industry .......................................................... 5  
    1.4.1 International nanotechnology funding activities ...................................... 5  
    1.4.2 International nanotechnology technical output activities ....................... 6  
    1.4.3 International nanotechnology industries ............................................... 7  
  1.5 Nanotechnology investment survey results .................................................. 9  
  1.6 South African nanotechnology industry ....................................................... 11  
    1.6.1 South African nanotechnology strategy ............................................... 11  
    1.6.2 South African nanotechnology products and services ......................... 13  
    1.6.3 South African nanotechnology strengths, weaknesses, opportunities and threats ........................................................................................................... 15  
  1.7 Research project problem definition ............................................................ 18  
  1.8 Research project rationale ............................................................................ 18  
  1.9 Research project objectives .......................................................................... 19  
  1.10 Deliverables ................................................................................................. 20  
2 Theory and research review ............................................................................. 21  
  2.1 South Africa as a technology colony .............................................................. 21  
  2.2 Classification of nanotechnology segments .................................................. 25  
  2.3 Innovation theories, models and methods ..................................................... 27  
    2.3.1 Definition of innovation ......................................................................... 27  
    2.3.2 Stages of innovation .............................................................................. 27  
    2.3.3 Types of innovation .............................................................................. 28  
    2.3.4 Systems of innovation ......................................................................... 30  
    2.3.5 Innovation strategies ............................................................................ 33  
      2.3.5.1 Strategy selection and implementation ............................................. 33
Study of the nanotechnology system in South Africa by Derrick L. van der Merwe

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2.2 Nanotechnology funding</td>
<td>78</td>
</tr>
<tr>
<td>5.2.3 Nanotechnology personnel</td>
<td>79</td>
</tr>
<tr>
<td>5.2.4 Nanotechnology education</td>
<td>81</td>
</tr>
<tr>
<td>5.2.5 Nanotechnology networking and collaborations</td>
<td>83</td>
</tr>
<tr>
<td>5.2.6 Nanotechnology equipment information</td>
<td>84</td>
</tr>
<tr>
<td>6 Data analysis</td>
<td>86</td>
</tr>
<tr>
<td>6.1 Research project questionnaires</td>
<td>86</td>
</tr>
<tr>
<td>6.1.1 Nanotechnology segments</td>
<td>86</td>
</tr>
<tr>
<td>6.1.2 Innovation hampers</td>
<td>92</td>
</tr>
<tr>
<td>6.1.3 Nanotechnology actors</td>
<td>94</td>
</tr>
<tr>
<td>6.1.4 SWOT analysis</td>
<td>97</td>
</tr>
<tr>
<td>6.2 CSIR baseline study questionnaire</td>
<td>101</td>
</tr>
<tr>
<td>6.2.1 South African nanotechnology activity formulation</td>
<td>101</td>
</tr>
<tr>
<td>6.2.2 South African product life activities</td>
<td>103</td>
</tr>
<tr>
<td>6.2.3 South African nanotechnology focus area activities</td>
<td>107</td>
</tr>
<tr>
<td>7 Conclusions and recommendations</td>
<td>109</td>
</tr>
<tr>
<td>7.1 Summary of research results</td>
<td>109</td>
</tr>
<tr>
<td>7.1.1 Background</td>
<td>109</td>
</tr>
<tr>
<td>7.1.2 Nanotechnology activities, segments, innovation hampers and relationships</td>
<td>111</td>
</tr>
<tr>
<td>7.2 Implications for and contributions to the South African nanotechnology community</td>
<td>120</td>
</tr>
<tr>
<td>7.3 Self assessment</td>
<td>122</td>
</tr>
<tr>
<td>7.4 Recommendations</td>
<td>124</td>
</tr>
<tr>
<td>7.4.1 Nanotechnology community</td>
<td>124</td>
</tr>
<tr>
<td>7.4.2 Future studies</td>
<td>127</td>
</tr>
<tr>
<td>8 References</td>
<td>128</td>
</tr>
<tr>
<td>9 Personal Information</td>
<td>134</td>
</tr>
<tr>
<td>Appendix A. Research project questionnaires</td>
<td>A-1</td>
</tr>
<tr>
<td>A.1 First research project questionnaire</td>
<td>A-1</td>
</tr>
<tr>
<td>A.2 Second research project questionnaire (feedback form)</td>
<td>A-10</td>
</tr>
<tr>
<td>Appendix B. CSIR baseline study questionnaire</td>
<td>B-16</td>
</tr>
</tbody>
</table>
List of figures

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). 3

Figure 1-2. ‘IBM’ in 35 Xenon atoms (National Science and Technology council, 1999:6). 3

Figure 1-3. Illustration of the size of nanotechnology (Gann, 2003). 4

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

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

Figure 1-6. Pie chart of governments’ role in the international nanotechnology funding (NanoInvestorNews, 2004). 5

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). 7

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). 7

Figure 1-9. Bar chart of the number of international firms involved in various nanotechnology segments in 2003 (NanoInvestorNews, 2004). 8

Figure 1-10. Bar chart of international venture capital investments (LuxCapital, 2004:v). 8

Figure 1-11. Bar chart of the greatest perceived investment returns per nanotechnology industry (NanoInvestorNews, 2004). 10

Figure 1-12. Bar chart of time estimate of when the first pure nanotechnology firm will reach $100 million in sales (NanoInvestorNews, 2004). 10

Figure 1-13. Five South African Nanotechnology Strategy interventions (SANi, 2003a:2). 11

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

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

Figure 2-1. The one-directional linear model of the innovation process (Buys, 2001). 22
Study of the nanotechnology system in South Africa by Derrick L. van der Merwe

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). 23

Figure 2-3. Three of level of analysis technology systems within the NSI. 32

Figure 2-4. Dynamic forces in an organisation’s evolution (Burgelman and Grove, 1996). 33

Figure 2-5. Framework for evaluation of innovative capabilities (Burgelman, Maidique and Wheelwright, 2001:11). 34

Figure 2-6. The competitive forces model (Porter, 1979). 36

Figure 2-7. The technology adoption life cycle (Moore, 1999). 40

Figure 2-8. An S-Curve illustration of technology life cycle and diffusion characteristics combined (Zikmund and d’Amico, 2002). 41

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). 46

Figure 3-2. Level of analysis of the South African Nanotechnology system of innovation. 47

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. 49

Figure 3-4. Technological system of the South African nanotechnology system in comparison to overseas nanotechnology sources. 52

Figure 4-1. Elements of the research strategy. 57

Figure 4-2. Example of ordinal questions used by research project questionnaires. 59

Figure 5-1. Bar chart of the time to market for nanotechnology segments. 66

Figure 5-2. Bar chart of the market potential for nanotechnology segments. 67

Figure 5-3. Bar chart of the disruptiveness of nanotechnology segments. 67

Figure 5-4. Bar chart of the complexity of nanotechnology segments. 68

Figure 5-5. Bar chart of the nanotechnology innovation hampers. 69

Figure 5-6. Bar chart of the nanotechnology buyers. 70

Figure 5-7. Bar chart of the nanotechnology suppliers. 70

Figure 5-8. Bar chart of the nanotechnology competitors. 71

Figure 5-9. Bar chart of the nanotechnology relationships. 71

Figure 5-10. Pie chart of the CSIR baseline-study participants. 75
Study of the nanotechnology system in South Africa by Derrick L. van der Merwe

Figure 5-11. Bar chart of South African nanotechnology involvement. Note that the number of participants, not the number of activities is plotted. 76

Figure 5-12. Bar chart of nanotechnology involvement per institution. 77

Figure 5-13. Pie chart of nanotechnology aspects in which all South African participants are involved. 77

Figure 5-14. Pie chart of South African nanotechnology funding sources. 78

Figure 5-15 Bar chart of South African nanotechnology funding sources per institution. 79

Figure 5-16. Bar chart of the nanotechnology personnel demographics. 80

Figure 5-17. Bar chart of the nanotechnology personnel demographics per institution. 80

Figure 5-18. Pie chart of South African nanotechnology personnel age. 80

Figure 5-19. Bar chart of South African nanotechnology personnel employed per institution per age. 81

Figure 5-20. Bar chart of South African nanotechnology students. 82

Figure 5-21. Pie charts of South African nanotechnology university curricula and their enrolled students. 82

Figure 5-22. Bar chart of the number of South African nanotechnology collaborations. 83

Figure 5-23. South African nanotechnology relations and networking. 84

Figure 5-24. Bar chart of South African nanotechnology equipment condition and comparison with modern equipment. 85

Figure 6-1. Bar chart of the nanotechnology segments’ mean regarding time to market, market potential, disruptiveness and complexity. 87

Figure 6-2. Bar chart of the nanotechnology segments’ standard deviation regarding time to market, market potential, disruptiveness and complexity. 87

Figure 6-3. Interaction plots for nanotechnology segments’ mean regarding time-to-market, market potential, disruptiveness and complexity. 89

Figure 6-4. Interaction plots for nanotechnology segments’ standard deviation regarding time to market, market potential, disruptiveness and complexity. 89

Figure 6-5. Bar chart of grouped nanotechnology segment’ mean regarding time to market, market potential, disruptiveness and complexity. 91

Figure 6-6. Bar chart of grouped nanotechnology segments’ standard deviation regarding time to market, market complexity, disruptiveness and complexity. 91

Figure 6-7. Innovation hampers’ mean and standard deviation. 93

Figure 6-8. Bar chart of the nanotechnology actors’ mean regarding each of the roles fulfilled. 95
Figure 6-9. Bar chart of the nanotechnology actors’ standard deviation regarding each of the roles fulfilled. 95

Figure 6-10. Interactive plots for nanotechnology actors’ means regarding each country. 96

Figure 6-11. Interactive plots for nanotechnology actors’ standard deviations regarding each country. 96

Figure 6-12. Bar chart of cross tabulation for nanotechnology product life cycle and involvement areas. 103

Figure 6-13. Bar chart of South African nanotechnology product life cycle activities. 104

Figure 6-14. Bar chart of possible South African nanotechnology product life cycle activities relating to the import of nanotechnology products and processes. 105

Figure 6-15. Bar chart of South African nanotechnology product life cycle activities according to universities, industry and science councils. 106

Figure 6-16. Bar chart of current South African nanotechnology segment activities. 107

Figure 6-17. Bar chart of current South African nanotechnology segment activities according to universities, industry and science councils. 108

Figure 7-1. Time to market versus market potential of nanotechnology segments. The area of each bubble is the current amount of South African activities in each nanotechnology segment. 112

Figure 7-2. Time to market versus disruptiveness of nanotechnology segments. The area of each bubble is the current amount of South African activities in each nanotechnology segment. 113

Figure 7-3. Time to market versus market potential of nanotechnology segments. The area of each bubble is the current amount of South African activities in each nanotechnology segment. 113

Figure 7-4. Stacked area chart of South African nanotechnology activities. 116

Figure 7-5. Stacked area chart of South African nanotechnology activities per nanotechnology segment. 118

Figure 7-6. Stacked area chart of South African nanotechnology activities per institution. 118

Figure 7-7. Logical illustration of supposed placement of a technology facilitator. 126
List of tables

Table 1-1. Estimated distribution of nanotechnology funding for 2004 (LuxCapital, 2004) 6
Table 1-2. Some nanotechnology incorporating products (LuxCapital, 2004). 9
Table 1-3. The South African Nanotechnology Strategy’s national goals, propositions and assumptions (SANi, 2003a). 12
Table 1-4. South African Nanotechnology Strategy’s (SANi, 2003a) focus areas. 12
Table 1-5. Some strengths and weaknesses (SANi, 2003:9-11). 16
Table 1-6. Some opportunities and threats (SANi, 2003:9-11). 17
Table 1-7. SWOT analysis from the Advanced Materials Technology Core Team (2002:161) 17
Table 2-1. Simplified classification of nanotechnology segments by Gordon (2002). 25
Table 2-2. A framework for defining innovation (Henderson and Clark, 1990). 28
Table 2-3. Framework for choosing the appropriate form of collaboration (Roberts and Berry, 1985). 35
Table 2-4. Generic leadership and differentiation strategies (Porter, 1988). 36
Table 2-5. Technology strategy types (Narayanan, 2001:255). 37
Table 2-6. Description of the stages associated with the S-Curve model (Khalil, 2000:81). 38
Table 2-7. The technology life cycle and the competitive advantage (Khalil, 2000) (Burgelman, Maidique and Wheelwright, 2001:11) (Gerybadze, 1994). 40
Table 2-8. Comparison between different forecasting techniques’ strengths, weaknesses and uses (Khalil, 2000). 44
Table 3-1. Examples of performance measures for an emerging technological system (Carlsson, Jacobsson, Holménb and Rickne (2002:243). 50
Table 3-2. The SWOT-analysis matrix (David, 2001:206). 51
Table 3-3. Research project hypotheses. 53
Table 4-1. Ordinal scales used in the multiple-choice questions. 59
Table 4-2. Innovation hampers used in research project questionnaire. 61
Table 4-3. Nanotechnology actors used in research project questionnaires. 62
Table 4-4. Nanotechnology focus areas of the CSIR baseline study questionnaire. 63
Table 5-1. Strengths and weaknesses from research project questionnaire. 73
Table 5-2. Opportunities and threats from research project questionnaire. 74
Study of the nanotechnology system in South Africa by Derrick L. van der Merwe

Table C-14. Statistics of nanotechnology areas South African participants are involved in. C-33

Table C-15. Statistics of South African nanotechnology funding sources per institution. C-33

Table C-16. Statistics of the South African nanotechnology personnel demographics per institution. C-33

Table C-17. Statistics of South African nanotechnology personnel employed per institution per age. C-33

Table C-18. Statistics of South African nanotechnology students. C-34

Table C-19. Statistics of the number of South African nanotechnology collaborations. C-34

Table C-20. Statistics of South African nanotechnology relations and networking. C-34

Table C-21. Statistics of South African nanotechnology equipment. C-34

Table D-1. Statistics of the nanotechnology segments’ time to market. D-35

Table D-2. Statistics of the nanotechnology segments’ market potential. D-35

Table D-3. Statistics of the nanotechnology segments’ disruptiveness. D-36

Table D-4. Statistics of the nanotechnology segments’ complexity. D-36

Table D-5. Statistics of the grouped nanotechnology segments’ time to market. D-37

Table D-6. Statistics of the grouped nanotechnology segments’ market potential. D-37

Table D-7. Statistics of the grouped nanotechnology segments’ disruptiveness. D-38

Table D-8. Statistics of the grouped nanotechnology segments’ complexity. D-38

Table D-9. Statistics of the nanotechnology innovation hampers (part 1). D-39

Table D-10. Statistics of the nanotechnology innovation hampers (part 2). D-39

Table D-11. Statistics of the nanotechnology buyers. D-40

Table D-12. Statistics of the nanotechnology suppliers. D-40

Table D-13. Statistics of the nanotechnology competitors. D-41

Table D-14. Statistics of the nanotechnology relationships. D-41

Table D-15. Frequency table of the cross tabulation of the Nanotechnology product life cycle and involvement areas (Part A). D-42

Table D-16. Frequency table of the cross tabulation of the Nanotechnology product life cycle and involvement areas (Part B). D-43

Table D-17. Frequency table of the cross tabulation of the nanotechnology product life cycle and involvement areas. D-44