THINKING SMALL: THE STATE OF NANOTECHNOLOGY RESEARCH AND DEVELOPMENT IN SOUTH AFRICA

M. GASTROW

ABSTRACT

In the context of government policy and international comparisons, the state of national nanoscience R&D is explored using bibliometric data as well as data sourced from the National Survey of Research and Experimental Development Inputs. This includes information about expenditure, ownership, collaboration and research fields. While the business sector performs the greatest proportion of nanotechnology R&D in South Africa, the higher education sector plays a critical role, and the science councils are common collaboration partners. In this context the development of catalysts and carbon nanotubes emerge as a key nanotechnology in South Africa.

Keywords: nanotechnology, research and development, South Africa

1. INTRODUCTION

In 2006 over 50 billion dollars worth of nano-enabled products were sold, and approximately 12.4 billion dollars were invested worldwide in nanotechnology research and experimental development (Hanekom, 2007). The term 'research and experimental development' (R&D) refers, within the findings of this paper, to the definitions provided in the OECD Frascati Manual (OECD, 2002). This definition includes most activities that provide new knowledge, and excludes routine activities such as quality assurance and market research. Interest in nanotechnology research and development (R&D) is currently high, and governments are taking nanotechnology R&D seriously: in 2007 the Russian president Vladimir Putin unveiled a plan to spend a billion dollars to develop Russian nanotechnology. The South African government has followed suit on a smaller scale, setting aside R450 million over three years (2006/7, 2007/8 and 2008/9) to support the South African Nanotechnology Strategy. The aim of this strategy is to position South Africa to take advantage of the rapidly growing nanotechnology market and to harness the potential of the technology to address development challenges.

The National Strategy was developed with the combined input of government, business, higher education institutions (HEIs) and the science councils, through the South African Nanotechnology Initiative, SANi (www.sani.org.za). However, the strategy was formed in the context of a paucity of quantitative data regarding nanotechnology R&D in South Africa: no previous studies have been conducted that could report on national survey data for nanotechnology R&D expenditure, funding, collaboration ownership and research fields.

This paper therefore offers a brief quantitative profile of South Africa's nanotechnology R&D. This serves two main functions: the first is to more clearly identify the scale, scope, direction, and other key indicators of national nanotechnology R&D in order to assess the strategy and inform future policy formation. The second is to provide baseline data for the future monitoring and evaluation of the National Nanotechnology Strategy. The data provided in this paper is for the 2005/6 financial year, and is therefore well positioned to be used as baseline data to measure the impact of the three-year (2006/7– 8/9) strategy.

2. MEASURING NANOTECHNOLOGY R&D

Numbers of scientific publications are commonly accepted as indicators of scientific performance in a particular technological sphere (Miyazaki and Islam, 2007). Examples of such analysis in the field of nanotechnology include studies by Meyer (2001), Hullman and Meyer (2003), Leydesdorff and Zhou (2006), Bhat (2005), Wonglimpiyarat (2005), Hung and Chu (2006), and Miyazaki (2007). Such bibliometric studies provide an interesting indication of the global state of nanotechnology R&D. Miyazaki (2007), in a study of the Elsevier COMPENDEX database of a 15-year timeframe, illustrated the rapid increase in nanotechnology research, from only two papers worldwide in 1990, to 1 789 in 2000 and 8 558 in 2004. In 2004 the major regional players in terms of published papers were mainland Asia (2 953), the USA (2 366), the EU (1 808) and Japan (1 044). Developing countries have a lower level of publications output, and even among this group South Africa performs relatively poorly. In 2005 747 nanotechnology-related papers were published by South African researchers, compared to 392 for Brazil, 864 for India, and 1 830 for South Korea.

However, as pointed out by Miyazaki (2007), bibliometric analyses have their limitations. Research activity is not perfectly measured through journal publications, particularly in the business sector, where a large proportion of R&D may be directed at applied research and product development, and may moreover be closely guarded by firms not wanting to jeopardise their competitive edge. Citation-based methods also face limitations due to the long time lag associated with the use of citations.

It is therefore useful to consider aggregate expenditure on R&D as an indicator of where actual R&D activity is taking place. Expenditure covers both research and experimental product development, and is therefore in many respects a more precise indicator of actual nanotechnology R&D. Moreover, developing countries appear to have found it easier to increase their publishing output in the area of nanotechnology than their actual expenditure on the performance of nanotechnology R&D, perhaps because the performance of more expensive nanoscience, applied research and experimental development require more resources.

This may be one of the causes of the disparity between publication indicators and expenditure indicators: as seen below the gap between the developed and developing world is considerably larger in terms of expenditure than in terms of the publication output described above.

However, like publication output data, worldwide data on nanotechnology R&D expenditure also reflects the rapid growth in the sector and the dominance of the triad economies of the USA, EU and Japan:

Table 1: Total worldwide expenditure on nanotechnology R&D

Year	US$ billion
2004	8.7
2005	9.6
2006	12.4

Source: Lux Research 2006, Hanekom 2007

Table 2 : Regional 2005 spending on nanotechnology R&D

Region	Government (US$ billion)	Corporate* (US$ billion)
North America (mostly USA)	1.7	1.9
Asia (mostly Japan)	1.7	1.7
EU (led by Germany)	1.1	0.85
Rest of the world	0.1	0.7
Total	4.6	5.15

**Established corporations, excludes venture capital*

Source: Lux Research 2006, Hanekom 2007

By comparison, South Africa spent approximately R237 million, or $33 million, on nanotechnology R&D in 2005/6, amounting to 0.3% of the world total (Table 2, Table 5). However this is not unusually low for an emerging economy: the combined R&D expenditure of all developing countries, approximately $800 million, constituted only 2.2% of the global total – again underscoring the dominance of the triad economies.

3. NANOTECHNOLOGY IN EMERGING ECONOMIES

Nanotechnology policies may differ between industrialised and emerging economies, as the latter have greater financial and human resource constraints, and also have different development objectives. In particular evolutionary and revolutionary nanotechnologies (Romig et al., 2007) present different challenges to systems of production. Evolutionary technology supports the current techno-economic paradigm, for example much of the activity in electronics-related nanotechnology. Revolutionary nanotechnologies could redefine manufacturing processes and workplace organisation and in time force a new techno-economic paradigm, potentially helping developing countries to leapfrog legacies of weak infrastructure.

However, policies directed at bolstering revolutionary nanotechnology must also take into account the potential risks. Economic risks are implicit: nanotechnology has the potential to creatively destroy old methods of manufacture, which could rapidly render old skills, technologies and infrastructures obsolete, thereby destabilising other sectors of the economy (Romig et al., 2007).

Aside from industrial development, it is claimed that nanotechnology has the potential to meet many of the most pressing needs of developing countries, including energy production and storage, provision of potable drinking water, improving agricultural production, storage of agricultural products, medical and health sector needs (Moodley, 2007).

A 2005 survey of nanotechnology R&D in developing countries (Maclurcan, 2005) found evidence of nanotechnology R&D in several developing countries. In India more than 30 institutions were involved in nanotechnology R&D, and a Nanoscience and Technology Initiative was formed in 2001 by India's Department of Science and Technology, establishing several laboratories for nanotechnology R&D; however, it was found that the development of the required skills and human resources presented a major obstacle in that country.

China is an interesting case, as its investment in both people and infrastructure for nanotechnology is higher than many developed nations. Several bilateral programmes, mainly with the USA, have been established. As in many other industries, in nanotechnology China often plays the role of fast follower and mass production specialist: although the US, the EU and Japan are leaders in the development of applications for carbon nanotubes, China manufactures more of these materials than all other countries combined (Venter, 2003). Moreover, in China a top-down policy approach has resulted in the establishment of national R&D laboratories and industrial parks that have helped China catch up with Japan in terms of publishing output (Miyazaki and Islam, 2007).

Several smaller countries are also active in nanotechnology R&D. Vietnam commenced nanotechnology research in 1992, and a national nanotechnology programme was launched in 2004. A national nanotechnology roadmap was developed in Thailand in 2004, and six institutions are active in nanotechnology in Malaysia and the Philippines. In Brazil over 300 PhD-level researchers were found to be working in nanotechnology R&D – indicating that this is by no means a technology confined to Asian developing economies.

4. THE DEVELOPMENT OF NANOTECHNOLOGY IN SOUTH AFRICA

Very limited nanoscale microelectronics research began in South Africa in the late 1980s, but nanoscale research only really began to develop in the late 1990s (Venter, 2003). Early government efforts to develop a nanotechnology strategy followed a top-down approach, such as proposed centres of excellence that proved to be ineffective, apparently hamstrung by 'internal funding battles'. However, by 2002 there were sufficient projects and researchers to provide momentum for the establishment of a professional group for the field – the South African Nanotechnology Initiative (SANi).

SANi took the form of a broad-based stakeholder group, initially formed to coordinate R&D to obtain major funding, which developed into a network of engineers, scientists and organisations with an interest in nanotechnology R&D. SANi also acted as a networking hub internationally, as various SANi members are contact points for South Africa's bilateral nanotechnology programmes with the EU, Iran, Japan, and South Korea and for trilateral cooperation with India and Brazil, as well as having links with many other countries (Campbell, 2006). In 2003 SANi first met with the Department of Science and Technology (DST) to discuss the possibility of developing a National Nanotechnology Strategy. This engagement continued through to 2006, during which time nanotechnology continued to develop at universities and science councils, funded by the National Research Foundation's (NRF) Focus Areas programme, the Department of Science and Technology's Frontier Sciences programme, and grants from major firms.

The October 2002 SANi conference identified nanotechnology related to South Africa's mineral resources as a key focus area. This would be in line with South Africa's comparative advantages and would provide a niche in which South Africa could become a prominent player (Spicer, 2002). Nanotechnology has many applications in mineral beneficiation, resulting in improved recovery rates for the mining industry. For example, the China-America Technology Corporation developed a flotation technique for gold ranging in size from 10 nm to 100 nm, helping to solve one of the key problems in gold mining – that of extracting the smallest particles of gold from fine sand or 'slime'.

South Africa's minerals have valuable properties at the nanoscale: gold and platinum are both highly effective catalysts which have lucrative applications in the automotive industry. Catalytic converters using platinum are already one of South Africa's major exports. Gold and platinum also have useful optical properties that are being explored in South Africa by Mintek (Spicer, 2002). At the nano scale titanium dioxide has properties that allow a current to be generated, and therefore has potential applications for renewable energy. Vanadium dioxide at the nanoscale has properties that allow for the reflection of infra-red light at high temperatures and the transmission of this light at low temperatures – which has potential applications in the automotive sector (windscreens) and building construction (windows) to keep interiors cooler.

Discussions at SANi also suggested that South Africa might be better off playing a fast-follower role, learning from the basic research performed in well-resourced developed countries and using local capacity to carry out applied research and develop commercial applications – as has been successfully carried out in China.

Talks between SANi and the Department of Science and Technology culminated in the launch of the National Nanotechnology Strategy in April 2006, in which the government unveiled a plan to invest R450 million in nanotechnology over three years. The strategy has four focus areas: firstly, the establishment of **characterisation centres** providing researchers with the necessary advanced instrumentation and infrastructure; secondly, the establishment of research and innovation **networks** to increase collaboration; thirdly, a focus on initiatives to build capacity and expertise by investing in **postgraduate research**; and fourthly, the execution of a number of **flagship projects**. In the 'social cluster' these are concentrated on water, energy and health, while those in the 'industrial cluster' focus on chemical and bio-processing, mining and minerals, and advanced manufacturing. Of the R450 million over three years in available funding, it is proposed that the largest share be allocated to capacity development (R170 million), followed by infrastructure/characterisation centres (R90 million) and R&D networks and flagship projects (R50 million each) (DST, 2006). The funding is also structured to increase annually over the three years – R100 million in 2006/7, R150 million in 2007/8 and R200 million in 2008/9.

Table 3: Proposed funding streams in the National Nanotechnology Strategy (R million)

	2006/7	2007/8	2008/9	TOTAL
Capacity building	30	60	80	170
Research and innovation networks	10	20	20	50
Flagship projects	20	30	50	100
Characterisation centres	40	40	50	130
TOTAL	**100**	**150**	**200**	**450**

This strategy was initiated for the 2006/7 financial year. The data provided in this paper is for the 2005/6 financial year, and is therefore well positioned to be used as baseline data to measure the impact of this strategy in future years. Also, the amount and structure of current R&D expenditure on nanotechnology can be weighed against the planned expenditure framework of the strategy to set the strategy in a quantitative context.

5. RESEARCH APPROACH

In this paper nanotechnology R&D expenditure data is sourced from South Africa's official national annual Survey of Research and Experimental Development Inputs, carried out by the Human Science Research Council's Centre for Science, Technology and Innovation Indicators (CeSTII), on behalf of the Department of Science and Technology, and forming part of official statistics for the National Statistics System. Through a purposive methodology, all organisations that could potentially be involved in R&D in South Africa are targeted in the survey. Specialised questionnaires are directed at the business sector, government, science councils, higher education institutions and non-profit organisations (NPOs). The statutory survey requires that all organisations performing research or experimental development return a survey questionnaire containing basic economic data and extensive R&D data.

CeSTII included a specific item on nanotechnology in the 2005/06 R&D survey that asked respondents to estimate the percentage of R&D expenditure allocated to that activity. Further background research identified some smaller firms that had potentially not reported their nanotechnology R&D as part of the survey. Organisations that were contacted included those involved in SANi or the various nanotechnology conferences that have taken place since the establishment of SANi in 2003.

The data from these additional firms were combined with those of the firms that answered positively to the nanotechnology question in the R&D survey to form the sample for this paper. On the whole this final data set represents the majority of nanotechnology R&D in South Africa.

However, R&D surveys are by nature imperfect, as they rely on the cooperation of respondents. This is particularly difficult in the business sector, where firms are reluctant to disclose sensitive information.

This limitation notwithstanding, one can provide tentative answers to the following questions: What organisations are performing nanotechnology R&D? What types of research are they doing? In what areas? How much is spent? Who pays for it? Where is it happening? Who owns nanotechnology R&D performing firms? How collaborative are nanotechnology R&D performers? Is there evidence of clustering and networking?

Moreover, these questions can be structured in order to better understand the relations between the three strands of the 'triple helix' arena of nanotechnology R&D (Leydesdorff and Meyer, 2006).

6. FINDINGS

Out of the total population of potential R&D performing organisations in South Africa, the sampling frame consisted of 639 positive respondents to the national R&D survey (this number excludes those that responded but reported no R&D). Of these, only those organisations that reported nanotechnology R&D to be taking place in-house, and a few that were identified through further background research, were included in the final sample of 25. The final sample consisted of organisations from the business sector, higher education and the science councils. While the survey also included government departments and non-profit organisations, none were found to be active in nanotechnology.

Table 4: Profile of sample frame and sample

	No of organisations performing R&D in the sampling frame	No of organisations performing R&D in the sample
Business	606	8
Science Councils	9	3
Higher Education	24	14
TOTAL	**639**	**25**

In the context of the above profile, more concrete questions may be asked of the data:

6.1 Expenditure

As shown in Table 5, approximately R237 million was spent on nanotechnology R&D in South Africa in the 2005/6 financial year. The business sector was the largest performer of R&D, spending approximately 59% of the total, followed by higher education (36%) and the science councils (5%).

Table 5: 2005/6 national expenditure on nanotechnology R&D

	Total R&D expenditure (R '000)	Total R&D expenditure (%)
Business	140 922	59.4%
Science Councils	11 130	4.7%
Higher Education	85 012	35.9%
TOTAL	**237 064**	**100%**

However, it must be noted that the HSRC survey questionnaire requests data about R&D performed *in-house*, and excludes outsourced R&D. This affects the final data. For example, the background research found that the mining houses have a strong interest in R&D, and finance a substantial proportion of South Africa's nanotechnology R&D research. However, this is largely outsourced to universities and science councils, and for this reason will be captured as nanotechnology R&D performed at these institutions. In other words the above data generally reflect the loci of the actual performance of nanotechnology R&D, rather than funding or control.

If one considers that the national nanotechnology strategy, through the national characterisation centres, has set aside R90 million over three years for infrastructure and equipment investment, it becomes clear that this, if effectively implemented, is likely to substantially increase overall investment in this area, approximating 40% of the total national expenditure in 2005/6. In terms human resources development, the national strategy has dedicated the largest share of the budget (R170 million over three years) to this area. When one takes into account that R85 million was spent by higher education institutions on nanotechnology in 2005/6, and that this was directed at investment, labour costs, and other expenses, it becomes clear that the R30 million set aside for the support of postgraduate students in 2007, increasing to R80 million in 2008/9, seems set to significantly bolster skills and capacity in this area.

The science councils were found to play a minor role in terms of the above expenditure breakdown (only 4.7% of the total). However the chief function of the science councils is perhaps not in the scale of their expenditure, but in the manner of their involvement. In the analysis of collaboration patterns (Table 6) it becomes clear that science councils play an important role in what is a collaboration-intensive field, often playing a linking and facilitating role in business and higher education collaboration.

The total South African expenditure of R237 million amounts to 0.3% of the world total (Table 2, Table 5). In a research field as expensive as nanotechnology, this raises the question of whether South Africa is positioned to attain the critical mass needed to become competitive (OECD, 2007). The contribution of the National Nanotechnology Strategy is significant in terms of South Africa's current expenditure, but very small in the international context. This in turn raises the question of whether the strategy will provide sufficient support to achieve this critical mass and international competitiveness. However, the evidence below suggests that there are pockets of excellence and areas of concentration that may make the attainment of critical mass possible in certain research fields and collaborative networks where South African researchers exercise the country's comparative advantages.

6.2 Nanotechnology in the Business Sector

Ownership of nanotechnology R&D-performing firms is largely South African (5 of 8 firms), although the USA (1) and EU (1) have stakes, and one firm has split multinational ownership, the major shares being held by the USA and South Africa. The business sector questionnaire also included a question on collaboration, allowing for a useful analysis of the collaborative propensities of nanotechnology R&D performing firms. Table 6 reflects the number and type of collaborative partnerships at the eight firms that formed the business sector element of the sample. For example, of the eight firms, six collaborated with higher education institutions, and five with science councils.

Table 6: Collaboration among organisations performing nanotechnology R&D

	Collaboration mode	No. of firms (N = 8)
South African collaborators	Higher Education	6
	Science Councils	5
	Government	2
	Members of own company	4
	Other companies	7
	Non-profit organisations	1
International collaborators	Higher Education	3
	Science councils	1
	Government	2
	Members of own company	2
	Other companies	3
	Non-profit organisations	1

The majority of nanotechnology R&D-performing firms collaborate domestically with higher education institutions (6/8), science councils (5/8) and other companies (7/8). International collaborations are less common, but nonetheless important. This suggests that the emphases placed on collaboration and the strengthening of networks in the National Nanotechnology Strategy was not misplaced. Note that science councils, despite playing relatively minor roles in both the performance and funding of nanotechnology R&D, are common domestic collaborative partners.

6.3 Where is it happening?

Table 7: 2005/6 Geographical location of organisations performing nanotechnology R&D

	Business	Science Councils	Higher Education	TOTAL
Eastern Cape			2	2
Free State	1		2	3
Gauteng	7	3	4	14
KwaZulu-Natal			2	2
Limpopo			1	1
Mpumalanga				
Northern Cape				
North West			1	1
Western Cape			2	2
TOTAL	8	3	14	25

Nanotechnology R&D-performing organisations are concentrated in Gauteng (14/25), which forms the only significant cluster of activity. Business-sector nanotechnology R&D is particularly concentrated in Gauteng, with seven of the eight sample firms located in this province. All three science councils are concentrated in Gauteng. The only sector that illustrates a spread of activity is the higher education sector, but even here four of the 14 sample organisations are in Gauteng.

The emergence of such a distinct cluster of nanotechnology research may have utility for policy purposes. Clusters can enhance the effectiveness of funding, collaboration or other support initiatives (Robson et al., 2007). Cluster-based industry bodies have been successfully used to harness the potential of networks in the South African clothing, textiles and automotive industries. The National Nanotechnology Strategy has set aside considerable funding to support networking opportunities, and the incorporation of a regional nanotechnology R&D cluster may maximise opportunities in this regard.

However, the distribution of nanotechnology R&D is also affected by the sectoral breakdown of its performance. This is evidenced in the national survey data. The business sample was comprised of five distinct sectors: three firms were from the energy sector, two from the chemicals sector, and one each from the pharmaceutical, paper/packaging, and ICT sectors.

The mining sector plays a significant role in nanotechnology R&D, but through outsourcing rather than in-house R&D. Given that domestic expenditure on R&D is very small by international comparison, this fractured structure potentially provides an additional hurdle towards achieving critical mass. However, a closer examination of the research fields constituting national nanotechnology R&D reveals a different picture.

6.4 What technologies are involved?

Using the sample organisations as a basis, the specific research fields characterising South African nanotechnology R&D were further investigated. There were two main sources for this. Firstly, direct contact with sample organisations by e-mail and telephone. Secondly a literature and internet search, including the proceedings of previous SANi conferences (SANi, 2006). In line with the R&D Survey's collaboration data, many of the reported nanotechnology research projects were collaborative in nature. It again became clear that the centre of South African nanotechnology is a network of research collaboration in Gauteng, which includes the University of the Witwatersrand (Wits), the CSIR, and Mintek. The geographically close North West University is also connected to these institutions. There is also a smaller network involving the University of Cape Town (UCT), the University of the Western Cape (UWC), the University of Stellenbosch, and the Cape Peninsula University of Technology (CPUT).

Combining several research fields within nanotechnology, much of South Africa's nanotechnology R&D is directed at the development of catalysts. In light of South Africa's gold and platinum-group metal resources this is unsurprising. According to the Department of Science and Technology's head of natural resources, Boni Mehlomakulu, "it is possible that in the area of catalytic conversion, where platinum is a key component, SA could become a global knowledge hub" (PBMR website, 2006).

This research is spread across several institutions. Wits University undertakes several research projects into gold catalysis. The Eskom Centre for Electro-Catalysis at the University of the Western Cape undertakes research into nanoscale catalysts and membranes. The most active specific research area within the broader umbrella of nanotechnology R&D, and closely related to research into catalysts, appears to be that of carbon nanotubes (CNTs). The DST/NRF Centre of Excellence in Strong Materials at Wits undertakes a range of research activities in this direction. This includes the use of organometallic complexes for CNT synthesis, functionalising CNTs, synthesising templates for the production of CNTs, the use of CNTs as catalyst supports, investigating the role of gases and additives during the synthesis of CNTs, and the study of the relationship between vibrational, structural and electronic properties of CNTs. In this research Wits has collaborated with the University of Stellenbosch, Mintek, and the Tshwane University of Technology.

Research into CNTs has also taken place at the University of Limpopo (into noble metal nanotubes), the University of Johannesburg (CNTs and nanospheres as supports in catalysts) and at iThemba Labs (using an atomic force microscope to image and physically manipulate CNTs to produce single electron transistors). The CSIR also undertakes research into the preparation and characteristics of CNT-metal composites.

Other research areas represent pockets of interest across the country: Wits undertakes research into nanoscale drug delivery systems. The CSIR, with the North West University, has investigated the properties of clay containing polymer composites, the properties of polycrystalline solids, and the generation of MnO2 nanoparticles using simulated amorphisation and recrystallisation. UCT and UWC have investigated nanocrystalline silicon thin films. Research projects at iThemba Labs include the development of doped zinc oxide nano-rods, nanostructures of Cr2O3, plasma grown nanostructures of vanadium dioxide, and nano-characterisation of single and double graphene-layers deposited on silicon dioxide. At the University of Pretoria research is undertaken into the development of nano-sized structures on the surface of semiconductors, the development of nanocrystals, and applications of nanotechnology in desalination. The University of Zululand has undertaken research into the synthesis of semiconductor nanoparticles using single-source precursors, biofunctionalised gold nanoparticles for potential applications in biosystems, the growth dynamics of anisotropic silver nanoparticles, and selenium based nanoparticles.

Research focus areas in the business sector are more closely guarded. However, some information was provided by firms; some is publicly available. In the pharmaceutical sector nanotechnology-based molecules are currently the subject of three stage II and III clinical trials. In the paper/pulp sector research includes nanopolymers and nanoparticles to reduce the cost of treating effluent water, nanosilica and nanocoatings to improve the properties of paper and board, and nanosensors in trees to improve the management of forests. In collaboration with UCT, nano-inks are being developed to allow the printing onto paper of low-tech electronic circuits. In the energy sector research is undertaken into electro-catalysis, and electro-conductive membranes and nanostructures. The large majority of R&D for the mining sector is outsourced to universities – particularly the catalyst/CNT research described above.

7. CONCLUSIONS

The R237 million spent on nanotechnology in South Africa in 2005/6 makes it a very small player in the global context of US$12.4 billion (R150 billion) in 2006. This is not to say that nanotechnology is not important locally – on the contrary it is an important technology for the future trajectories of several key sectors of the South African economy, including mining, pharmaceuticals, paper and pulp, automotives, and energy. More generally, nanotechnology is an enabling technology that is considered an important element the medium and long term growth potential of developing economies.

Using quantitative data from the national Survey of Research and Experimental Development Inputs, an overview of nanotechnology R&D in South Africa was developed and discussed in the context of the National Nanotechnology Strategy. Expenditure on nanotechnology R&D in South Africa is concentrated in the business sector (59%), followed by higher education (36%) and the Science Councils (5%). The business sector is also a major source of funding for the other sectors.

The findings also revealed that nanotechnology R&D shows signs of collaboration-intensive activity. Here the roles of higher education and science councils were found to be particularly important as collaboration partners with the business sector. Moreover a distinct cluster of activity emerged in Gauteng, a finding which may inform the implementation of the strategy's networking plan.

The implementation of the strategy could, for example, establish a forum through which nanotechnology researchers and research managers in Gauteng's universities, firms, and science council's could network through face-to-face interaction, workshops on shared issues, joint engagement with government and policy, data sharing, expertise sharing, and the establishment of collaborative research projects. While the benefits in terms of knowledge dissemination and productive engagement could be substantial, this would be a low-cost intervention since logistics would be minimised to the Gauteng region, and no capital equipment would be required.

Such a forum would be beneficial because researchers in the region share not only geographical proximity, but also share common research fields, namely in the areas of catalyst technology and carbon nanotube technology. These areas of research are commonly pursued at many of South Africa's higher education institutions, and are financially supported by mining firms. This is an area in which South Africa may indeed be building a critical mass, and moreover is a technology which takes advantage of South Africa's natural resources. This is in line with the government's policy aim of increasingly adding value to our natural resources, rather than simply extracting and exporting them. Gold and platinum-group metals in catalysts have been utilised in the automotive catalytic converter industry to create significant new manufacturing capacity, and have also been extensively used to increase efficiencies in mineral beneficiation in the mining industry.

However, it is important that research be directed at more diversified uses of nanotechnology and platinum-group metals.

Mining and catalytic converter applications add value, but do not add substantially to the 'non-traditional exports' which South Africa needs to foster in order to diversify its economy and thus become less dependant on commodities and vulnerable to fluctuations in commodity markets.

The National Nanotechnology Strategy could foster such diversification by using it as a funding criterion. If implemented effectively, the National Nanotechnology Strategy should more than double the current national expenditure on nanotechnology research, making it possible for this strategy to shift the orientation of nanotechnology R&D towards more diverse applications. Once again a region-based forum would be a useful structure in the application of such an initiative.

A number of questions remain: while the national nanotechnology strategy is promising, South African expenditure in the area will remain low by international standards, raising questions of critical mass and international competitiveness. Will South Africa build up sufficient expertise to compete in a global knowledge economy? Will the funding promised by the research strategy be sufficient to retain skills in South Africa and to develop sufficient skills in the next generation of scientists? Does South Africa indeed have the human resources capacity to nearly double its current level of nanotechnology R&D? These questions of capacity and implementation will be best answered by an iterative monitoring and evaluation exercise once further implementation data become available.

There also remains the question that can be asked of many public funding initiatives: whether increased government spending will have a positive or negative impact on private spending; in other words whether firms will see the increased financial support for nanotechnology R&D as an incentive to invest, or whether they will reign in their spending in the hope of receiving government support. Another key question that remains is whether the political will exists to effectively implement this strategy, and whether the promises of funding can be converted into efficient and effective spending. To assess this, the current data can be used as a baseline, and data from future surveys can be used to assist in the monitoring and evaluation of what appears to be a promising strategy.

8. REFERENCES

Bhat, J.S.A. 2005. Concerns of new technology based industries – the case of nanotechnology. *Technovation* 25 (5), 457–462.

Campbell, K. 2003. Nanotechnology R&D: sweating the small stuff. *Martin Creamer's Engineering News,* 23 (27).

Campbell, K. 2006. Nanotech: South Africa strategises to exploit the big opportunities of the very small. *Martin Creamer's Engineering News,* 26 (15).

Council for Scientific and Industrial Research (CSIR). http://researchspace.csir.co.za/dspace/handle/10204/930/browse-title.

Department of Science and Technology. 2006. The National Nanotechnology Strategy. www.dst.gov.za.

Hanekom, D. 2007. Opening speech of the World Nano-Economic Congress, CSIR International Convention Centre, April 23–24 2007.

Hullmann, A. and Meyer, M., 2003. Publications and patents in nanotechnology: an overview of previous studies and the state of the art. *Scientometrics* 58 (3), 507–527.

Hung, S. and Chu, Y. 2006. Stimulating new industries from emerging technologies: challenges for the public sector. *Technovation* 26 (1), 104–110.

Leydesdorff, L. and Zhou, P. 2006. The emergence of China as a leading nation in Science. *Research Policy* 35, 83–104.

Leydesdorff, L. and Meyer, M. 2006. Triple Helix indicators of knowledge-based innovation systems. *Research Policy* 35, 1441–1449.

Lux Research, 2006. *The Nanotech Report, 4th Edition: Investment Overview and Market Research for Nanotechnology*.

Maclurcan, D. C. 2005. Nanotechnology and Developing Countries. *Azojono: Journal of Nanotechnology Online*. Posted 19 October 2005. http://www.azonano.com/ Details.asp?ArticleID=1429.

Meyer, M. 2001. Patent citation analysis in a novel field of technology: an exploration of nano-science and nano-technology. *Scientometrics* 51 (1), 163–183.

Miyazaki, K. and Islam, N. 2007. Nanotechnology systems of innovation – an analysis of industry and academia research activities. *Technovation,* In Press, Corrected Proof, Available online 6 July 2007.

Moodley, N. 2007. Nanotech capsules may aid TB treatment. *Martin Creamer's Engineering News*, 23 April 2007.

National Nanotechnology Initiative
http://www.nano.gov/html/facts/whatIsNano.html.

Organisation for Economic Cooperation and Development. 2002. *Proposed Standard Practice for Surveys on Research and Experimental Development Frascati Manual.* Paris: Organization for Economic Cooperation and Development.

Organisation for Economic Cooperation and Development (OECD). 2007. *Review of South Africa's Innovation System.*

Pebble Bed Modular Reactor website.
http://www.pbmr.com/index.asp?Content=101&MState=DT&Article=73.

Pouris, A. 2007. Nanoscale research in South Africa: a mapping exercise based on Scientometrics. *Scientometrics* 70 (3), 541-553.

Robinson, D.K.R., Rip, A. and Mangematin, V. 2007. Technological agglomeration and the emergence of clusters and networks in nanotechnology. *Research Policy*, 36 (6), 871–879.

Romig A.D. Jr., Baker, A.B., Johannes, J., Zipperian, T., Eijkel, K., Kirchhoff, B., Mani, H.S., Rao, C.N.R. and Walsh, S. 2007. An introduction to nanotechnology policy: Opportunities and constraints for emerging and established economies. *Technological Forecasting and Social Change*, doi:10.1016/j.techfore.2007.04.003.

SANi Nanoafrica conference 2006 programme.
http://www.sani.org.za/pgm.pdf.

South African Nanotechnology Initiative. www.sani.org.za

Spicer, D. 2002. SA mineral resources will be key building block for nanoresearch. *Martin Creamer's Engineering News*, 15 November 2002.

University of the Witwatersrand Department of Chemistry, CatOmCer project homepage. http://www.chem.wits.ac.za/catomcer/overview.html.

Venter, I. 2003. The science of small things: cover story. *Martin Creamer's Engineering News*, 23 (15).

Wonglimpiyarat, J., 2005. The nano-revolution of Schumpeter's Kondratieff cycle. *Technovation* 25 (11), 1349–1354.