TECHNOLOGY AND KNOWLEDGE

SYNTHESIS REPORT OF THE
NATIONAL RESEARCH AND TECHNOLOGY AUDIT

Prepared by the Foundation for Research Development for the Department of Arts, Culture, Science and Technology

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FOREWORD

The National Research and Technology Audit marks a significant milestone in the history of the development of science and technology in South Africa. It represents a bold step by the Department of Arts, Culture, Science and Technology to take both qualitative and quantitative snapshots in time and to create a foundation for better-informed policy formulation processes in the future. The results of this audit will undoubtedly provide an essential framework for the National Research Technology Foresight Project that is currently under way to plot a course for a science and technology-influenced future for South Africa.

The audit was a task of the magnitude that was always going to test our intellectual and management capacity. Its novelty in the South African context meant that every step of the project was in itself a learning process from the point of view of both the information unveiled and the business of managing such a project.

The set of reports and the National Research and Technology database provide a comprehensive picture, for the first time in South Africa's history, of the heart and soul of the science and technology system. What we see in this report is not all gloom. Certainly, there are serious shortcomings, but we must also recognise that our science and technology provide us with a solid foundation from which a national economic and social renaissance can occur in our new democracy. A critical blemish in our science and technology system results from policies, practices and tendencies of the past that ignored 85% of the population as a potential source of science and technology human resources. Science and technology are embedded in knowledge and skills in people. Each and every South African that is able and willing to become a contributor to our national effort should be enabled to do so.

We believe that science and technology in South Africa have more to offer than we have ever imagined. The challenge to us is not what science and technology can do for us as a nation, but how we should use and manage science and technology for the common good of the people. In many respects, science and technology provide the means for us to address the major socio-economic problems facing us. The results of the audit in the form of the reports and the database, provide the platform from which to begin to formulate policies and strategies that will allow us to use science and technology to achieve our social and economic objectives, for without science and technology, these objectives will not be achieved. However, further research is needed to reap the full benefit of the audit effort.

We recognise that without the support and commitment of the institutions, organisations and individuals that participated in the survey, the audit would not have been possible. Thanks are due to everyone involved.

K. Mokhele
President
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EXECUTIVE SUMMARY

In May 1996, the Department of Arts, Culture, Science and Technology, announced that a National Research and Technology Audit (NRTA) would be undertaken by the department. The stated object of the exercise was ‘an assessment of the strengths and weaknesses of South Africa’s science and technology system’ and to provide data and information to be used as a basis for policy.

The NRTA covered publicly funded S&T as well as the contribution and activities of the private sector. Whereas the data from the public sector was fairly comprehensive, that from the private sector is based on a carefully structured sample. It is therefore important to recognise that the NRTA did not capture total population data-sets, which naturally results in a need to harmonise information to achieve consistency between the individual survey reports.

The audit has produced the following outputs:

Five survey reports

?? *Scientific and Technological Infrastructure*
?? *Human Resources in Science, Engineering and Technology*
?? *Scholarship, Research and Development*
?? *Technology Base of the South African Business Sector*
?? *Research and Training Equipment in South Africa*

And two additional reports

?? *Scoping Scenario Trends*, and a
?? *Synthesis Report (Technology and Knowledge).*

The data collected in the surveys has been integrated into a single database. This will be made accessible via the Internet, as a means of making the data widely available.

1. Main findings of the National Research and Technology Audit

South Africa's science and technology system is endowed with a well-developed infrastructure of institutions with good potential and a core of skilled and knowledgeable people, with achievement of international stature. However, there are some structural, organisational and societal weaknesses.

1.1 Scientific and Technological Infrastructure

Science and Technology performers as a whole spend R9.66bn pa. This excludes the contribution of the private sector. The majority was spent on education and training (66%) with only 16% being spent on R&D. This sector employs 70 000 people of which under 50% are classified as professional and technical staff. Of these latter 33 000 technical staff, 54% are employed by the Higher Education sector.

A noticeable feature of the international survey was the number of countries (Japan, Taiwan, USA, Jordan) which have an aligning vision or a target set of objectives for the system. Where a similar strategically approach could be discerned in the SA system, it was more typically focussed around the objectives of the previous government, e.g. Defence.

At a macro level, the SA science and technology infrastructure does not compare favourably with international benchmarks. Key indicators here are:-

?? the estimated gross expenditure on research and development (including the business sector), as a percentage of gross domestic product (GERD/GDP), where South Africa's 0,9% is lower than that of technology leaders, such as Korea, Japan and USA (who average 2,5%), and on a par with Hungary, Spain, Portugal, New Zealand, Chile and Brazil. Our private sector, however, is a much more significant player than in the latter group of countries;

?? The number of science and technology staff, per million of the population, is far below that of comparable countries;

?? Our low output per capita in science and technology.

1.2 Human Resources in Science Engineering and Technology (SET)

Various scenarios were evaluated, but if one assumes that the present output trend in the Higher Education Sector persists, there will be a significant shortfall in engineering and related categories, and in medical and management sciences, while art, sports and entertainment graduates will be in oversupply, by a factor of more than 5. If much higher output in the scarce categories is to be achieved, a significant change in the numbers of learners receiving University exemptions in Matric Maths and Science will be required.

An analysis of post-graduate trends revealed that the output of masters and doctoral graduates is relatively low, in relation to the number of academic staff available to supervise them.

Despite recent progress in the eradication of gender and racial imbalances in the SET field in general, the majority of SET human resources are still white males. This imbalance is even more prevalent among research scientists.

1.3 Technology Base of SA Business Sector

The survey was conducted on the basis of structured interviews with a carefully constructed sample comprising 313 industrial companies.

South Africa's "R&D Investment" to "Sales Turnover" ratio is less than 1/3 of the comparable USA benchmark indicator. The SA Industry spends 90% of its R&D expenditure locally, of which 80% is spent by companies themselves. R&D funding, received from large companies, is still heavily skewed: about 1/3 of the total amount is spent in the electrical and electronic industries.

The three main drivers of technology are funding, the availability of resources, and R&D time. The shortage of skills was the most important issue affecting the business sector's ability to perform R&D. What was surprising, is how rare it was to find either an R&D culture in a company, or any perception that the lack of appreciation for R&D was proving a barrier to investment.

However, in both large companies and SMMEs, on average, about 70% of respondents perceive Government to be playing a minor, or often no role in promoting R&D and technology investment. There are, however, high expectations that this situation should be reversed with clear direction and priorities being established, especially in sectors where South Africa is able to compete internationally.

1.4 Scholarship Research and Development

The Higher Education Sector (HES) spends the largest proportion (50%) of its direct R&D expenditure on basic research, and the larger part of this is devoted to strategic, rather than fundamental research. This means that fundamental research currently makes up less than 25% of all research within the HES, and less than 5% of all R&D in the public sector. All performers in the public sector devote more than one third of their expenditure to applied research. There has been an overall increase, between 1993/4 and 1996/7, in R&D expenditure devoted to developmental, i.e. more mission-oriented, work. All of these trends support the global trend towards more application-driven forms of research in the public sphere. Concern about the adequacy of the core of basic research in our national research system, was also raised.

More than 50% of public sector expenditure (business excluded) is directed at three sectors, namely: agriculture, mining and manufacturing. This results in relatively low spending in areas such as health, community services, housing and energy. Expenditure in the higher education sector is more evenly spread, with a greater emphasis on education and social services. However, high priority (GEAR) areas, such as communication and information, and energy, receive little attention.

Interdisciplinary collaboration is highest in the fields of agriculture, basic medical sciences and chemical sciences. It is lowest in the arts, humanities and economic sciences. Overall inter-institutional collaboration, across sectors, is only 21%.

1.5 Research and Training Equipment in SA

The main findings of the local scene, consisting of more than 2000 items of equipment valued at R1.8bn, are as follows:

?? The cost of replacing and upgrading the existing infrastructure exceeds the capabilities of the individual players. More than R500m is estimated to be required for replacements up to the year 2000, and an additional R250m for immediate needs.

?? Equipment policy and management in the country, is far from best international practice, with the stakeholders aiming to address their problems individually.

2. Recommendations

The synthesis report makes four recommendations. Each recommendation has policy implications.

2.1 A directed science and technology system

Science and technology has become increasingly multi-dimensional and multi-disciplinary. In consequence, no single government department, acting on its own, will be able to maximise the positive impact that science and technology can have, on the multi-faceted problems faced by the country in an increasingly complex world.

The state currently commits R7.37b (including R4.2b to higher education) to the science and technology system. Analysis of the audit data suggests that, when assessed against established national objectives, this is not being employed optimally. There is accordingly a need to review and strategise the state's contribution to the science and technology system. This should be extended to a consideration also of the contributions made by other funders.

From a review of the South African policy environment, it is clear that the South African government has established clear socio-economic priorities, and that these were developed in a transparent manner involving many stakeholder groupings. It is also apparent, however, that the mechanism for translating these national priorities into desired outcomes and priorities for entities within the science and technology system, has yet to take effect.

Accordingly, there is a need for a more formal and structured approach, to ensure the conversion of accepted national priorities into concrete national programmes for the science and technology system. These programmes need to be more outcome- and output-orientated, and incorporate an explicit system for reviewing the efficiency and effectiveness of the resource commitment.

The creation of the Ministry and Department of Arts, Culture, Science and Technology in 1994, provided a vehicle for government to focus its role in developing a science and technology system that will respond to the demands set by the nation's socio-economic priorities. The *White Paper on Science and Technology* published in 1996, outlined priorities for, and challenges facing, the national science and technology system. There is, however, concern that the priorities enunciated in the White Paper are expressed in very general terms and do not translate into clear objectives, against which science and technology performers might be properly evaluated.

The White Paper also created governance structures for the S&T system, that allow the relevant line government departments to ensure that the system responds appropriately to socio-economic demands. These structures include the Ministers' Committee on Science and Technology and the Directors' General Committee on Science and Technology. In addition, the White Paper made provision for the creation of the National Advisory Council on Innovation, which comprises members, appointed by the Minister of Arts, Culture, Science and Technology, and drawn from different stakeholder groups in the national system of innovation. The National Science and Technology Forum continues to function as a non-governmental body which is used as a sounding board.

The structures and systems that are currently in place, appear to contain most of the necessary elements for an effective national system of innovation. The challenge that remains, is to ensure that these structures and systems will actually function to create a coherent interface, between the national science and technology system, and the national system of innovation. Such coherence will have to be reflected in the outputs and outcomes, related to the national macro-economic goals.

Recommendation 1
The strategic planning and strategic management of the national science and technology system requires a policy apparatus that will enjoy such a high degree of respect that government, business and civil society, as key stakeholders in the national system of innovation, will "take their cue" from it and adjust their activities to accord with its stated objectives and requirements. This inclusive apparatus would then set the basic tone for the strategic planning and strategic management of science and technology by ALL elements comprising the national system of innovation, and will inform the collective planning and management of the national system of innovation. Such an apparatus must give purpose to the science and technology system and, through incentives, remove conflicting interests that prevent or inhibit the science and technology system from working coherently.

2.2 Policy-directed growth in science, engineering and technology skills

GEAR sets ambitious objectives for growth in both the economy and human development over the period until 2000. Translating national objectives into requirements for the science and technology system, the audit has established that the country has an adequate number of higher education institutions with suitable capabilities. However, the audit has confirmed that there are some significant shortages of resources, particularly human resources, in a number of important disciplines. If the GEAR objectives are to be achieved, urgent action will need to be taken to improve the supply of these human resources, not only to fill the current shortfall, but to provide for the future growth expectations.

Training more people in science and technology related areas where shortages currently exist, could be an important spur to economic growth. In particular, if the development of the small business sector, which is employment-enhancing, is to proceed more rapidly, there will need to be a greater supply of persons with scientific, and particularly, technological skills. Training in, and the diffusion of, such technical skills will require a far more deliberative policy than has prevailed up to the present.

Most policy documents of government line departments make some reference to the required development of human resources and skills within the field of that department's competence. These invariably refer also to science and technology human resources and skills. In the absence of well co-ordinated policy formulation by different government departments, it is unavoidable that there will be incoherence in policy proposals on the development of science and technology human resources and skills. No single government department can alone develop a coherent human resource and skills development policy, that will meet the national requirement.

> ***Recommendation 2***
> *A coherent national human resource and skill development policy, and accompanying strategies, should be developed urgently. Such a policy should aim to negate all the undesirable features of historical policies, patterns and practices. The policy should ensure that human resources and skills, of appropriate quality and in appropriate quantities, are developed with a view to macro-economic policies and improving the human development index.*

2.3 A technologised[1] society

Operationally speaking, technology is the *system of competencies and capabilities* within an organisation or society, which amplifies the ability of humans (in other words, it is "human-plus") to achieve their objectives, and to satisfy their wants and needs. Technological innovation is therefore, not just a process of artefact improvement, but implies a general improvement in the *system of competencies and capabilities,* which support the artefact within an organisation, and within society.

Although modern technological innovation is often linked to scientific progress, scientific progress on its own is not sufficient to produce socially meaningful innovations. It is in fact possible for a country to have a highly advanced scientific capability, but a poorly developed capability for sustainable technological innovation, in so far as it applies to finding solutions to problems relating to economic growth and human development. The full benefits of global scientific advances over 200 years of scientific progress and industrial growth, are enjoyed by possibly no more than one fifth of the world's population. South Africa is a microcosm of the global situation, noted by growing poverty and a poor level of human development, with the majority of the country's population being marginalised and alienated from the technologically advanced industrialised sector of the country. For the latter, technology is often a perplexing

[1] *Technologising* implies the upliftment of people – a process of capacity generation where people can benefit in full from the fruits of technology.

subject, and innovation a threat. It is perceived to be a threat to their competence and capability to sustain themselves, and their families, in an ever more bewildering world, whereas, in fact, it should be a redeeming force.

Given her current state of economic and human development, South Africa cannot create a sustainable culture of technological development by simply focusing on building the science and technology system.

South Africa will have to focus equally on removing the barriers to available technologies, that result from human attitudes to technology as both alien and alienating. The technological gap between different societies continues to widen, even as technologies become more widely available, depending, *inter alia,* on the attitudes of the various societies to technology. The competitive abilities of those societies that lack familiarity with technology, and consequently do not readily embrace available technologies, can significantly be impeded. South Africa should strive towards a technology-friendly society, in which its citizens of all social ranks, will embrace technological innovations as integral features of twenty-first century societies.

Recommendation 3
A programme should be developed and implemented to technologise South African society, as a sustainable process of re-creation and renewal that will include improving perspectives and understanding by all its people.

2.4 An enhanced national information infrastructure

The challenge to all nations, as they enter the twenty-first century, is to transform the economy by making far better use of information and knowledge. The science and technology system, in particular, is becoming increasingly dependent on considerably improved communication and information flows, among performers located in the various institutions of the system and sectors of the economy.

South Africa performs approximately 0.2% of all the world's research and development. Technological innovation, on the part of South Africans, will increasingly require access to global knowledge. Global scientific and technological knowledge and information will have to be exploited through effective international electronic communications and networking.

Increased person-to-person contact, more alliances and greater sharing and collaboration, the reductions of barriers between institutions – all will be significantly facilitated through better information systems. An enhanced information network will therefore be essential to the development of a more effective and efficient national science and technology system.

New knowledge needs to become known knowledge, by becoming available quickly to all those involved in research, education, diffusion and innovation.

Recommendation 4

The information network, including the human utilisation capacity, should be enhanced to serve the science and technology system and prepare the country for becoming a knowledge society, thereby allowing the people of the country to communicate, innovate and compete globally, more effectively.

CHAPTER 1

INTRODUCTION

1.1 RATIONALE FOR THE NATIONAL RESEARCH AND TECHNOLOGY AUDIT

South Africa faces many challenges, such as social and economic inequalities, an economy growing too slowly, significant unemployment, low productivity, vast health care and education needs, demographic complexity and an increased and evolving role in Africa. These challenges are likely to become~~attain~~ acute ~~dimensions~~ as the country enters the twenty-first~~21st~~ century. South Africa's nascent democracy will only survive if these challenges are addressed with the utmost urgency and if the high expectations of the majority of South Africans, who were previously denied the franchise, are met.

It is widely recognised in government and in the broader community that technology[2] (as well as the science[3] and research[4] that interact with it) is pivotal in tackling such problems. In essence, the nation's well~~-~~-being and economic competitiveness will depend largely on how the science and technology assets are strategically managed and exploited.~~its~~ It is widely accepted that successful nations are those which~~o~~ develop and nurture 'technologising'[5] policies that stimulate the processes whereby knowledge is gained and embodied in people, products and services.

It is one thing to recognise~~ing~~ the contribution that science and technology can make to meeting societal needs~~,~~ and quite another to question whether~~ing~~ the system has the capacity and capability to fulfil the~~se~~ expectation~~s~~ of contributing to the national~~South Africa's~~ social and economic well-being. This~~e above~~ issue ~~becomes pertinent~~ is especially significant in South Africa today because the current science and technology system[6] was designed, and evolved, to

[2] *Technology* is a set of means (a combination of techniques and skills) embodied in products, processes, machines and related services by which the physical and informational domains are manipulated.

[3] *Science* includes the natural, engineering, medical, health and human sciences.

[4] *Research* comprises creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and/or directed towards specific practical aims or objectives.

[5] *Technologising* implies the upliftment of people – a process of capacity generation whereby people can benefit in full from the fruits of technology.

[6] The *science and technology system* is formed by the relationship and interaction between all the participants (both funders and performers) in science and technology (in government, science councils, research institutions, higher education institutions, the business sector and non-government organisations).

play a role under the previous political dispensation, when the priorities of state were very different. The circumstances~~the conditions~~ that~~which~~ shaped the character of science and technology in South Africa have changed considerably, and new conditions have emerged, placing changed demands on the science and technology system. This necessitates a new evaluation of the capabilities~~y~~ and weaknesses of the system in relation to the altered expectations. Expressed differently, any effort to promote a better match between national objectives and the activities of the science and technology system~~,~~ will require an assessment of the capacity and capability of the ~~the~~ system. ~~Equally significant, i~~It is equally important to anticipate ~~which~~the areas in which South Africa~~n life~~ will need a greater contribution from science and technology and to commit sufficient resources to them~~science and technology~~.

It was against this background that the National Research and Technology A~~a~~udit was authorised by the government, in order to gain an ~~have som~~idea ~~about our~~of the capacity, capability and limitations of~~in~~ the science and technology~~science and technology~~ system~~,~~ as they relate to our current and future needs. If South Africa's~~O~~ investment in research and in science and technology is to make a positive contribution to the present and future well-being of the new nation, it must come to terms with the current health and status of the science and technology system. ~~if we are to compete globally while addressing domestic social and economic issues.~~

~~A principle objective of the audit was to provide information and data for policies directed at increasing the effectiveness of technological innovation as a contributor to industrial productivity, environmental sustainability and international competitiveness by way of sound recommendations and implementation strategies.~~

1.2 OBJECTIVES OF THE AUDIT

The principal objective of the National Research and Technology Audit, as accepted by the Ministers' Committee on Science and Technology, is to provide data and information to be used as a basis for policies directed at increasing the effectiveness of technological innovation[7] as a contributor to industrial productivity, economic growth, environmental sustainability and international competitiveness by way of sound recommendations and implementation strategies.

The audit was therefore initiated to allow the government to reach a better understanding of the forces that will shape the long-term future of South Africa's science and technology system and thus fashion a robust national ~~-~~system that:

?? maximises its effectiveness, efficiency and cultural impact
?? optimises the responsibilit~~y~~ies and accountabilit~~y~~ies of ~~the~~ stakeholders
?? minimises conflicting interests and objectives

It is on the basis of t~~T~~hese principles ~~will provide a means on which~~ that the current government's investment in science and technology can be judged.

In order to achieve these objectives, the audit was conceptualised to:

?? assess the strengths and weaknesses of South Africa's science and technology system and determine the efficacy, adequacy and value of the system
?? develop and communicate a better understanding of the forces that will shape the long-term effectiveness of the nation's science and technology system
?? provide direction and~~/~~ guidance on how to maximise the ~~S&T system's~~ effectiveness of the science and technology system to meet the future challenges facing South Africa

1.3 PROCESS OF THE AUDIT

The Department of Arts, Culture, Science and Technology contracted out to the Foundation for Research Development the responsibility for managing the initiatives of the National Research and Technology Audit. The process of the audit comprised the following discrete activities:

1.3.1 Surveys

The audit was carried out by way of five surveys, which were each contracted out to individual and separate consulting organisations. The five surveys were designed to cover the relevant

[7] *Innovation* is the introduction to the market of a new or changed product – *product innovation* – or a new or changed production process – *process innovation*. Innovation entails a combination of scientific, technological, organisational, financial and commercial activities.

aspects of the funders and performers in the science and technology system and obtain a measure of the operation and outputs. The surveys were on the following subjects:

1. Scientific and technological infrastructure
2. Human resources and skills
3. Research and scholarship output
4. Technology across the business sector
5. Research and training equipment

The consultants were contracted to conduct audit surveys, collecting data on the present situation and considering the implications of the findings. As far as the future is concerned, the survey of human resources and skills was required to include an estimate of supply and demand.

1.3.2 Future trends

A study was commissioned to forecast future trends in the South African economy, environment and society with particular reference to the technology needs.

1.3.3 Report by the Foundation for Research Development

The management of the Foundation for Research Development undertook to produce an overall synthesis report, which would use the information and data collected in the audit to guide and motivate policy recommendations directed at increasing the effectiveness of the science and technology system in meeting the needs of the country. The Foundation for Research Development appointed an analytical task team to analyse the five surveys and the future study and, together with their own knowledge and individual experience, provide input to and guidance for this report and its contents. The Foundation for Research Development produced the report based on this input and sought further comment from three 'critical' readers before finalisation.

1.4 ~~NRTA~~ OUTPUTS OF THE AUDIT

The process of the audit produced the following tangible outputs:

1.4.1 Five survey reports

The following survey reports were produced:

1. *Scientific and Technological Infrastructure*
2. *Human Resources in Science, Engineering and Technology*
3. *Scholarship, Research and Development*
4. *Technology Base of the South African Business Sector*
5. *Research and Training Equipment in South Africa*

These reports are being published separately as stand-alone reports of the completed surveys. The data, findings, recommendations and conclusions of each of the surveys have been used as the basis for this synthesis report.

1.4.2 ~~An~~ O~~o~~n-line National Research and Technology D~~d~~atabase

The ~~An~~ on-line National Research and Technology D~~d~~atabase of the science and technology capabilities of South Africa was developed by integrating the data produced by~~of~~ the five surveys. ~~The database, in many ways, provides a landscape of the scientific and technological capabilities of the South African economy. Significantly,~~ T~~t~~his database provides a landscape of the science and technology capabilities of every sector of the South African economy and is structured to serve as a useful, readily accessible tool for well-informed decision-making by government, business and the public at large. It is installed on an audit computer system. The features of the database ~~does have, among others, the following characteristics~~ include:

?? profiles of enterprises, institutions and sectors
?? continuous updating facility
?? restrictions on sensitive data
?? in-built functionalities, including statistical analysis and graphical presentation of data
?? interactivity with the World Wide Web

1.4.3 Report of a study scoping socio-economic trends

A report, *Scoping Socio-economic Trends in South Africa: a Technological Perspective*, will also be available separately as a stand-alone study. The future scenarios presented in this study are used as a basis for the assessment of the needs that will make demands on the science and technology system, both now and in the future.

1.4.4 A synthesis report

This report, *Technology and Knowledge*, is a synthesis based on the five surveys and the study scoping socio-economic trends. The report also draws on the input of an analytical task team, the members of which brought their individual experience to bear on the audit survey findings and recommendations. The members of the analytical task team were not involved in any of the five surveys.

The report concludes with recommendations that have policy implications in the area of science and technology in South Africa.

CHAPTER 2

SCIENCE AND TECHNOLOGY ENVIRONMENT

2.1 OVERVIEW OF GOVERNMENT POLICY INITIATIVES

~~ed~~

A number of the current policy documents of the present government were~~ere~~ reviewed as part of the analytical framework to determine their relevance to, demands on and expectations of the science and technology~~science and technology~~ system of South Africa, as well as the extent of such demands. The policy documents reviewed included:

?? the Growth, Employment and Redistribution Strategy (GEAR)
?? the Green Paper on Science and Technology
?? the White Paper on Science and Technology~~ White Paper~~
?? the Green Paper on Skills Development Strategy for Economic and Employment Growth
?? the Green Paper on Higher Education
?? the White Paper on Higher Education
?? the Reconstruction and Development Programme

The determination of government and its various organs to ~~construct~~ develop an integrated approach to addressing the socio-economic needs of the country is evident in all the policy documents reviewed~~,~~.

Six common ~~ality in~~ themes~~which~~ emerge~~s~~ from the review of the policy documents, which~~s~~ constitute the six ~~"~~pillars~~"~~ of a globally competitive and nationally equitable South African economy. Science and technology have a significant role to play in achieving each of these pillars:

1. Promoting c~~C~~ompetitiveness and j~~J~~ob c~~C~~reation
2. Enhancing the q~~Q~~uality of l~~L~~ife
3. Developing h~~H~~uman r~~R~~esources
4. Working towards e~~E~~nvironmental s~~S~~ustainability

5. Promoting an information society
6. Producing more knowledge-embedded products and services

Figure 2.1

The relationship between the GEAR objectives for economic growth and social upliftment and the national science and technology system is illustrated in Fig. 2.1 on page 8. This relationship shows that the science and technology system forms part of the national system of innovation, a concept introduced by the White Paper on Science and Technology, and should be a catalyst in transforming government funding into valuable outcomes of knowledge and skills, technology, products and processes to serve both the business sector and the social development sector. In this way, government funding promotes the growth of the economy and improves the quality of life.

The other relevant policies contain instruments to achieve the GEAR objectives with maximum efficiency and effectiveness.

2.2 CURRENT AND FUTURE NEEDS OF SOUTH AFRICA

The most pressing need in South Africa at present is to raise economic growth, in accordance with the GEAR objectives, from its present rate of approximately 2% to an average of 4.2% per annum.

Other needs articulated in the GEAR objectives are employment growth averaging 2.3% per annum, as opposed to the present negative growth rate. The urgent minimum need is to create an average of 270 000 new jobs per annum over the five-year period 1996–2000.

Some of the other needs that flow from the policy documents include:

?? the redistribution of income and opportunities in favour of the poor and the previously disenfranchised
?? increases~~ing~~ in the quality and quantity of intermediate skills in the country
?? increases~~ing~~ in the quality, relevance and cost-effectiveness of skills development in the country
?? increased~~ing~~ ~~the~~ access by~~of~~ workers to education and training
?? a society in which sound health, education and other services are available to all
?? an environment in which homes are secure and places of work are productive

?? support for~~ing~~ the establishment of viable small, medium and micro enterprises

?? the establishment~~ing~~ of systems that are responsive to current and potential economic and social needs~~ whether immediately apparent or a tangible possibility in the future~~

?? the nurturing of ~~developing~~ a culture within which the advancement of knowledge is valued as an important component of national development~~.~~

?? the establishment~~ing~~ of an efficient, well-coordinated and integrated system of technological and social innovation

?? improved~~ing~~ support for~~all~~ innovation that is~~which is~~ fundamental to sustainable employment creation, equity and social development

It is necessary to translate South Africa's needs ~~are~~ into current and future demands on the science and technology~~-~~ system~~ as well as the role of the system itself?~~. It is equally important to consider what the contemporary role of the science and technology system should be, given the new socio-economic pressures.

2.3 ENVIRONMENT OF SCIENCE AND TECHNOLOGY SYSTEMS INTERNATIONALLY

2.3.1 National systems of innovation

An examination of successful nations around the world reveals that many countries with successful science and technology systems broadly consider the science and technology system to be part of a much larger system of innovation, frequently called a national system of innovation.

A national system of innovation is defined as 'the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies'.[8] Innovation is regarded as the act of successfully introducing something new.

Several elements determine the characteristics of national systems of innovation. These elements include:

[8] Freeman C. (1987). *Technology Policy and Economic Performance: Lessons from Japan*. London: Pinter.

?? the size of the scientific community, its fields of research and its links with industry

?? the ability of the education system to provide highly qualified researchers and technicians

?? the structure of industry

?? the research and development activities of the public and private sectors

?? the way in which science and technology contribute to the accumulation of knowledge

?? the ability to translate research and development results into new or improved products, processes and services

?? the level of investment in the national system of innovation and the results achieved from this investment

?? the relative specialisation and international comparative advantage of the national system of innovation

Government policies play an important role in all the elements listed. This includes particularly the strategies for mobilising research and development, using technological resources and providing national support for efforts towards innovation. Policies on, for example, the extent of the resources mobilised, the industrial sectors chosen for support, the commitment to long-term national security, the types of institutions involved and the criteria for selecting innovations for support are all critical in defining national performance and technological style.

Apart from government, the business sector, higher education institutions, science councils and non-government organisations all play a role as funders of and performers in the system, thereby participating in shaping the nature and direction of a national system of innovation.

2.3.2 Trends influencing the evolution of national systems of innovation

A review of various national systems of innovation in both developed and developing countries reveals that the evolution of these systems and the manner in which they operate within national and international contexts are influenced by several discernible trends. These trends cannot be ignored if the South African science and technology system is to remain relevant in a global context.

The internationalisation of technology

This can be measured by the increase in the rate of cross-border technology flows, driven initially by multinational corporations and then increasingly by corporations of all sizes attempting to disseminate the results of research, exploit innovations in global markets, and acquire knowledge developed elsewhere. The internationalisation of technology is changing the mode, as well as the means, of knowledge accumulation. Greater importance is attached to the international integration of knowledge for innovative applications than to the classical accumulation of knowledge for academic purposes. Another result of the trend towards internationalisation is the growth in collaborative and cooperative ventures among business, government and higher education institutions, which allow the open sharing of technical knowledge.

Strategic management of national systems of innovation

Nations increasingly believe that technology is a key issue in determining economic growth and international competitiveness. They are leveraging the technological resources within national systems of innovation to achieve developmental, economic, industrial and social objectives. A component of this trend is the nurturing of five competencies that are necessary for managing technology in an effective and sustainable manner within a national system of innovation:

?? the **acquisition of technology** in the form of imported embodied technologies and technology developed in-house

?? the **development and fusion of technology**, which involves bringing together previously disconnected technologies to impact new beneficiaries or accelerate innovation, such as the convergence of communication and information technologies

?? the **deployment or uptake of technology**, which is the effective demonstration of established technologies as well as the packaging of technology to enhance knowledge transfer and technology application

?? the **diffusion of technology**, which is the classical sale of technology into end-use markets or the social diffusion of technology by various means

?? the **management of the technology framework**, which includes the instruments and techniques that can be employed to take advantage of the systemic interactions within the national system of innovation

Divergence between science and technology

There appears to be an increasing tendency towards deliberate strategies that focus on technological activities in selected fields. At the same time, scientific activities tend to be spread across a broader set of technical areas. Also, scientific and technological activities are diverging because the openness that characterises science communities is not possible among technologists due to the increasingly competitive nature of technological innovations. The rise of computational sciences, modelling and simulation (in contrast to classical theoretical and empirical methods) is also transforming the mode of knowledge production and the institutional forms that mobilise such knowledge.

Increasing degree of specialisation

It is common for countries not to show uniformly strong performance in all aspects of their national systems of innovation as measured by the strengths and weaknesses of their manufacturing industries. Such strengths and weaknesses can be attributed to:

?? the availability of natural resources and the existence of a domestic industry to exploit them
?? sectoral specialisation of production and trade in natural resource-based industries
?? the national demand structure and consumer tastes prompting technological development in particular directions

For a national system of innovation, the implications of increasing specialisation are positive as well as strategic. There is considerable evidence to suggest that there are technological, economic, industrial and competitive advantages to a nation if it specialises in certain technological areas. The technological fields selected for specialisation do not appear to be as critical as the degree of specialisation. In most technological fields, innovation activity is taking place in ever fewer countries because of increasing specialisation.

The barriers to entering certain technological areas and becoming globally competitive are growing. This has a significant impact on the character of national systems of innovation, particularly in developing and newly industrialised countries, as it calls in question the effectiveness of the classical mode of knowledge accumulation and generation. Within national systems of innovation, the generation and accumulation of knowledge for its own sake only are becoming less important, while the demonstration, integration, packaging and transfer of knowledge (or technology) are growing in importance. The concept of what constitutes knowledge is thus taking on new dimensions. This aspect of the national system of innovation offers significant opportunities for developing and newly industrialised economies to find alternative and rapid ways of achieving competitiveness and development simultaneously.

2.3.3 Characteristics of a functional national system of innovation

The significant characteristics of a functional national system of innovation include:

?? Technology, of local origin, is embodied as packages which can be demonstrated in the context of appropriate end-user groupings.

?? Innovation and technology projects are performed by transdisciplinary, often international, teams.

?? All the competencies of strategic technology management are developed and employed to manage the national system of innovation so as to achieve national objectives.

?? The national system of innovation operates within a technologising environment, which enables national relevance to communities and develops international competitiveness in selected areas of the economy.

?? The system is outcome-oriented and outcome-driven. The outcomes are developed and agreed upon by the appropriate stakeholder groups to ensure the long-term sustainability of the national system of innovation. Outcomes strongly influence the resource allocation strategy, with the result that national systems of innovation tend to apply outcome-based allocation and funding methods.

?? The strong, self-reinforcing linkages among business, government, development agencies, higher education institutions and other types of organisation are enhanced and maintained through collaborative projects, some of which are sponsored by the government.

?? The national system of innovation is managed as a system with high-level objectives and performance measures (both qualitative and quantitative) based on national priorities and aligned with the agendas of government departments.

?? The national system of innovation facilitates technological and sectoral specialisation by means of technology and innovation projects aimed at fostering unique competencies, as well as by developing the networks and institutional support necessary to sustain specialised technology.

2.4 CURRENT AND FUTURE ROLES OF THE SCIENCE AND TECHNOLOGY SYSTEM

The present science and technology system is a legacy of our past.~~a point~~ The system was designed, and evolved, to perform a particular role and deliver specific outputs. Does~~,~~ the system have the flexibility and capacity to adjust to the changing socio-economic environment? Since the forces that shaped the system have~~s~~ changed significantly, it is imperative to reconsider the role of the system itself against the new demands being placed on it. New conditions and demands thus necessitate the formulation of new roles for the system.

The policies of the new government indicate the following roles for the science and technology system:

?? promoting national development, sustainable economic growth, employment creation and social equity by contributing to the six pillars described previously

?? creating an environment that~~which~~ facilitates ~~knowledge~~ the role of strategic knowledge and skills

?? contributing to knowledge-intensive processes and technology to allow South Africa to compete globally

?? forming an integral part of ~~f~~a greater innovative environment, which aims to create a society that~~which~~ is more aware of science and technology and ~~more~~ read~~il~~y to accept~~s~~ and appreciate the contribution ~~of~~ science and technology can make to ~~the~~ increased national well-being – a technologising society

?? leading the economy and society to accept and institutionalise the new modes of knowledge acquisition, transfer and diffusion and the opportunities for mass employment within the information society~~f all members osociety~~

?? ~~being proactive in~~ enhancing the international standing of South Africa

?? promoting innovation to create competencies in the economy

?? improving the productivity of present commerce and industry

2.5 MAJOR CHALLENGES TO~~FOR~~ THE SCIENCE AND TECHNOLOGY SYSTEM

The issues discussed~~demands and roles listed~~ above present major challenges to South Africa's science and technology system because of the country's historical development and the assumptions on which the system was initially based. Integrati~~o~~ng South Africa into the new global economy (based on knowledge and technology innovation), whil~~est~~ at the same time addressing the aspirations and needs of South Africans~~,~~ is probably the most difficult challenge in the medium term. The opening of the South African economy to global business has created pressure of international competition on local industry. The m~~aj~~ost~~r~~ important dilemma that this challenge presents to decision-makers is how to maintain a balance or, better, achieve synergy, between becoming internationally competitive and addressing the ~~current and~~ pressing needs of our society. The science and technology system should be able to assist government and industry in their response to the situation.

This tension between an economy of globality and one of proximity is not unusual internationally, but our challenge is to~~is will require the~~ transform ~~ation of an~~the economy from one driven by a combination of energy and matter (and land use), to one driven by information and knowledge. A~~This~~ transformation of this kind ~~,~~represents a ~~major~~significant departure from current thinking within the productive sectors of the economy~~in as far as~~ in terms of the delivery of products and services.

Strategic thinking and action will be required to develop ~~the~~ appropriate options for South Africa in order to mutually reinforce the balance between being globally competitive and serving local needs.

S~~the~~uccess ~~in facing the above challenges and dealing with the socio-economic problems~~ will depend largely ~~be dependant~~ on the responsiveness, flexibility and capabilities of the science and technology system. Given the limited capacity of the science and technology system to address ~~amid~~ the multiple~~,~~ and sometimes competing~~,~~ demands, the following challenges~~is section~~ need to be met~~stating the following~~:

- optimising and maximising the contribution of science and technology to~~in~~ addressing the mounting social and economic demands
- technologising society

?? ~~do~~increasing the efficiency and effectiveness of the system

?? ~~do~~prioritising our choices in the system, given the multiple demands

?? ~~do~~strategically managing and practically leveraging the system in a coherent and coordinated fashion without eroding the existing infrastructural and skills base

2.6 VALUE OF THE NATIONAL RESEARCH AND TECHNOLOGY AUDIT IN THE CURRENT POLICY ENVIRONMENT

The National Research and Technology Audit was sanctioned at the highest level of government in South Africa, which is an indication that it has the potential to ~~can~~ add value to the implementation of government policy initiatives. Furthermore, the rationale and objectives ~~articulated~~ unambiguously position the audit as the first national effort to come to terms with the capacity, capabilities and limitations of South Africa's science and technology system. The audit~~has become~~ is needed in order to determine the competing demands on the system and also to serve as a basis for benchmarking the system.

The audit ~~This~~provides~~s~~ a ~~the~~ mechanism for~~to~~ strategically managing~~e~~ the relationship between national policy objectives and South Africa's science and technology~~science and technology~~ system as part of a national system of innovation. In addition, it allows the performance of the science and technology system to be measured against strategic national objectives. In establishing the capacity and capabilities of the present~~of~~ science and technology~~science and technology~~ system, the audit enables an assessment of its strengths and weaknesses measured against the societal demands. It also ~~. Similarly significantly, it~~ provides~~s~~ an~~the~~ opportunity for communicating~~e~~ the contribution~~positive achievements~~ of the science and technology system ~~in contributing~~ towards achieving national goals. This will lead to an a~~This will increase the a~~wareness and appreciation of the fruits of public investment in science and technology.

The audit~~audit~~ has created for the first time~~,~~ an electronic database that, through continuous updating and maintenance, will provide information which will assist decision-making by government (whether national, provincial or local), business, the higher education sector, labour organisations, civic organisations and the public at large. The quality of the information will enhance decision~~-~~making on the role of the science and technology system in future; for the first time in the history of South Africa, it will be possible to base decisions ~~made~~ on relevant and current ~~hard and analysed~~ data.

CHAPTER 3

MAIN FINDINGS OF THE NATIONAL RESEARCH AND TECHNOLOGY AUDIT

3.1 AUDIT SURVEYS: INTRODUCTION

The audit was conducted by means of five surveys, as previously stated. Each of these surveys collected a large number of data on the science and technology system, which have been captured in the National Research and Technology Database. The actual survey reports are extensive stand-alone documents, and hence are not reproduced in this synthesis report. This chapter identifies some of the essence of the outcomes and outputs of the surveys.

These outcomes and outputs can be identified as one of the following:

i) data as a snapshot in time (generally for 1995/96)
ii) some trend data
iii) international comparisons of data
iv) projections based on the GEAR objectives and other government policies
v) interpretations

The discussions of the survey reports that follow cover some of the relevant data and impressions used for synthesis and recommendations. For a fuller understanding of the outputs of the surveys, the survey reports themselves should be consulted.

3.2 SCIENTIFIC AND TECHNOLOGICAL INFRASTRUCTURE

Survey of the Scientific and Technological Infrastructure

LHA Management Consultants

The scientific and technological infrastructure is defined as including all activities that help maintain and/or expand the knowledge base. It includes:

?? research and development

?? education and training (post matriculation)

?? generation of information, development of knowledge, standards and guidelines, patents and licensing

Terms of reference

The primary aim of the survey was to collate, interpret and assess data related to the national pattern of science and technology funding and performing activities in South Africa, excluding the business sector and public corporations.

Research design

Relevant information was gathered from science and technology performers and funders in the government sector, higher education institutions, science councils, non-profit, multi-client private sector research organisations (for example, the Leather Industry Research Institute) and a selected number of non-government organisations and national heritage institutions. In total, 189 organisations were covered.

Information was gathered from available documentation, personal contact and by means of a questionnaire.

The report yielded the following findings:

3.2.1 Performers of science and technology

Science and technology performers, excluding the business sector, spent an amount of R9.55 billion in 1995/96. The expenditure can be broken down as indicated in Table 3.2.1.

Table 3.2.1 Expenditure in the science and technology system, by performer: 1995/96

Performer	R (million)	%
Government	654	7
Higher education	6756	70
Science councils	1470	15
National heritage institutions	112	1
Non-government organisations	558	7
TOTAL	**9550**	**100**

The activity split of this expenditure can be broken down as indicated in Table 3.2.2.

Table 3.2.2 Activity split of science and technology expenditure: 1995/96

Activity	R (million)	%
Research and development	1500	16
Education and training	6311	66
Other*	1739	18
TOTAL	**9550**	**100**

* Includes deployment of knowledge, standards and guidelines, patents and licensing

The science and technology performance sector (excluding the business sector) employs just over 70 000 people, approximately half of whom are categorised as professional scientific and technical staff, as indicated in Table 3.2.3.

Table 3.2.3 Staff profile of science and technology performers: 1995/96

Performer	Staff Category				
	Professional/ Technical Support	Admin-istration	Unskilled labour	Unspecified	Total
Science councils	7 965	2 466	832	406	11 669
Universities	14 362	8 307	8 677	5 327	36 673
Technikons	3 732	2 733	2 185	–	8 650
Government	5 521	41	–	701	6 263
National heritage institutions	448	128	232	977	1 785
Non-government organisations	1 231	228	168	3 994	5 621
TOTAL	**33 259**	**13 903**	**12 094**	**11 405**	**70 661**
%	**47**	**20**	**17**	**16**	**100**

3.2.2 Funders and funding of science and technology

The government is the major funder of the science and technology system. Its contribution amounts to R7.37 billion, which is earmarked as indicated in Table 3.2.4.

Table 3.2.4 Government funding to the science and technology system: 1995/96

	R (billion)	%
Transfer funding	6.24	85
In-house funding	0.65	9
Contract funding	0.48	6
TOTAL	**7.37**	**100**

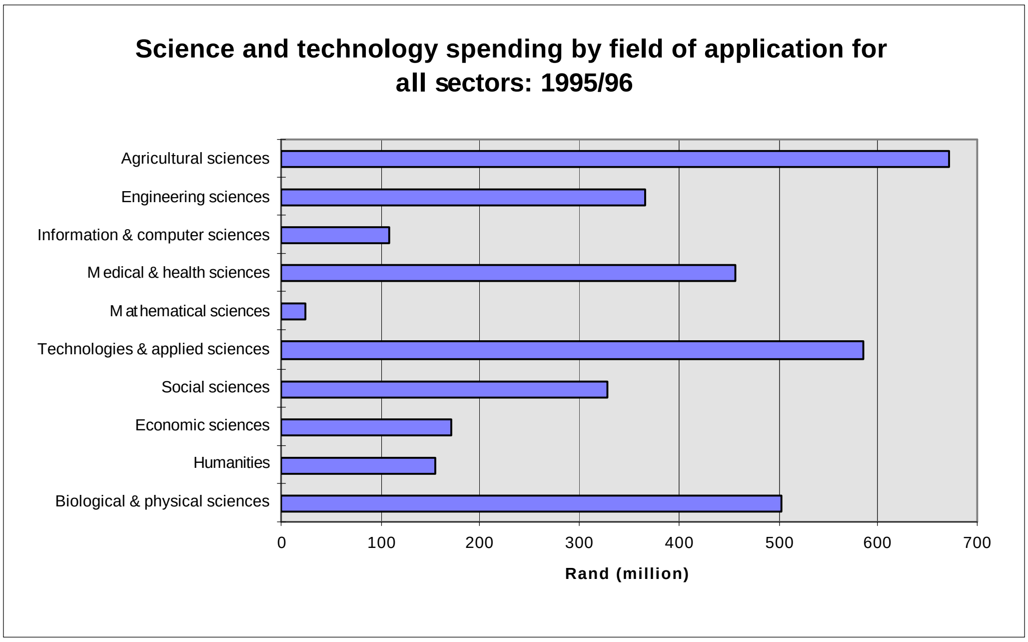
3.2.3 Application of the funds

Disregarding the large education and training component (R6.3 billion), the balance of science and technology spending (R3.3 billion) is allocated by broad field of application as indicated in Table 3.2.5 and Fig. 3.2.1.

Table 3.2.5 Allocation of science and technology spending by broad field of application (excluding education and training funding): 1995/96

Field of application	R (million)	%
Agricultural sciences	671	20
Medical and health	456	14
Engineering, technology & applied sciences	952	28
Biological, physical and mathematical, information & computer sciences	635	19
Human sciences	653	19
TOTAL	**3367**	**100**

Fig. 3.2.1



The main performers in the agricultural sciences are the science councils (55% of the spending) and the government (31%), while in the medical and health field, the main performers are a non-government organisation – the South African Institute for Medical Research – which is responsible for 55% of spending, and the universities, which are responsible for 26%. The other application field activities are more evenly spread among all performing sectors.

3.2.4 The South African science and technology infrastructure in the international context

The science and technology system of South Africa was compared with international competitors at the macro level. Some of the key issues which came out of the comparison were:

?? The estimated gross expenditure (R4.5 billion) for 1995/96 on research and development (GERD) (including the business sector) as a percentage of the gross domestic product of South Africa (R4.84 billion) amounts to 0.9%. This is low compared with most of the developed and developing countries with which South Africa has strong science and technology relationships, and with which it has to compete in international markets.

?? The value of 0.9% places South Africa on the same level as Hungary, Spain, Portugal, New Zealand, Chile and Brazil.

?? Associated with this observation is the small number of science and technology staff per million of the population of South Africa when compared with these other countries.

?? There appear to be signs that South Africa is producing fewer science and technology outputs per capita than the countries mentioned above which have similar ratios of GERD to gross domestic product.

Meaningful international comparisons, however, require an intensive study based on sound, compatible data.

3.2.5 Conclusion

The overall impression from this study is that the South African science and technology infrastructure, although reasonably provided with structures, performers and funding, lacks cohesion and a clear vision of purpose within a coherent network addressing national objectives. The contribution of the science and technology system will only be optimised in securing the necessary growth and improvement in the socio-economic system if the expertise and facilities within the public sector are integrated, through networking, and are aligned with the needs of the business sector by means of partnerships.

3.3 HUMAN RESOURCES

Survey of Human Resources in Science, Engineering and Technology

E. van Zyl, E. Hall, L. Albertyn, J. Roodt and A. Whiteford
Human Sciences Research Council

Terms of reference

The study had two components:

i. An analysis of the supply of and demand for science, engineering and technology human resources
ii. An analysis of human resources in research and development

Research design

The following research methodology was used:

Existing databases were analysed and estimates made of the supply of and demand for science, engineering and technology human resources. The GEAR macro-economic strategy was used as the basis for labour demand projections.

Questionnaires on employment issues (for example, research and development posts, labour turn-over, shortages) were completed by organisations actively involved in research and development, such as higher education institutions, science councils and government.

The survey yielded the following salient findings:

3.3.1 Growth in the supply of skilled human resources

The output of graduates from the higher education sector has grown consistently over the last five years. The growth in the output of university graduates with a first degree has been 3% per annum, and the growth in the output of diplomates from technikons has been 10% per annum, as illustrated in Table 3.3.1. The number of university graduates has grown by over 5% in some disciplines, such as communication, physical education, health education and leisure, and public administration and social services. Numbers have shrunk in other disciplines, such as agriculture (-13%) and architecture (-5%). At technikons, the growth rate has been more dramatic, particularly in disciplines with small numbers, such as language (65%) and library studies (51%), while there has been a decline in diplomates in industrial arts, trades and technology (-4%).

Table 3.3.1 First degrees/diplomas awarded at universities and technikons: 1991–1995

Disciplines	First degrees awarded at universities		First degrees/diplomas awarded at technikons	
	Total 1991–95	Growth 1991–95	Total 1991–95	Growth 1991–95
Agriculture & renewable natural resources	1537	-13%	2014	10%
Architecture & environmental design	2595	-5%	2466	-1%
Arts, visual & performing	2428	0%	2516	-1%
Business, commerce & management science	24008	2%	16288	7%
Communication	2068	8%	1372	-1%
Computer science & data processing	1963	3%	2547	1%
Education	14971	5%	338	28%
Engineering & engineering technology	6990	1%	10622	2%
Health care & health science	15675	5%	4578	11%
Home economics	959	5%	3252	23%
Languages, linguistics & literature	14055	3%	170	65%
Law	12229	2%	112	16%
Libraries & museums	882	4%	507	51%
Life science & physical science	7177	3%	2528	14%
Mathematical science	2953	2%	141	25%
Philosophy, religion & theology	4006	6%	–	–
Physical education, health education & leisure	1037	6%	82	57%
Psychology	10761	4%	23	-20%
Public administration & social services	5636	6%	5013	33%
Social sciences & social studies	20390	2%	2268	8%
TOTAL	**152320**	**3%**	**56876**	**10%**

3.3.2 Shortages of skilled human resources

All the sectors covered by the audit reported shortages of highly skilled scientists, especially in the natural sciences, most engineering disciplines, information technology and computer science, as well as in the economic and business sciences.

In the business sector, 77% of the survey sample identified occupations in which shortages were currently being experienced, even before the growth levels expected of GEAR are taken into consideration. These were predominantly professional engineers (21% of cases) and artisans (23% of cases), followed by engineering technicians.

The demand for black physical science, engineering and technology human resources far exceeds the supply, and much greater efforts to increase the supply of black human resources are required. Only about 20% of all research and development scientists are black.

3.3.3 Future supply of and demand for skilled human resources

The survey developed some human resource supply and demand scenarios based on the GEAR strategies and various supply projections. The scenarios are listed in Table 3.3.2, and the results of the analysis are presented in Table 3.3.3. The indications are that if the present growth trend in higher education output continues, there will be sufficient human resources in each category for the 'Base' GEAR strategy, but not for the 'Integrated' GEAR strategy. There would be a shortage of certain skills, particularly in engineering, medical and managerial occupations. If the output of the higher education sector remains static at the 1995 level, there will be a shortage for both the 'Base' and the 'Integrated' GEAR demand strategies. With no increase in the present output, there will be shortages, not only in the fields mentioned above, but also in the business, commercial and management sciences. However, if the profile of outputs in the various disciplines from the higher education institutions were changed to meet the needs of the GEAR strategies, it is possible that the total output of graduates and diplomates could be reduced.

Table 3.3.2 Scenarios for the supply of and demand for human resources

Overall scenario =	Demand scenario +	Supply scenario
A	Base (GEAR)	Trend in higher education output (1991–1995) is maintained until the year 2000
B	Base (GEAR)	Higher education output remains constant at 1995 level until the year 2000
C	Integrated (GEAR)	Trend in higher education output (1991–1995) is maintained until the year 2000
D	Integrated (GEAR)	Higher education output remains constant at 1995 level until the year 2000

Note: The base and integrated scenarios refer to alternative scenarios incorporated in the GEAR objectives.

Table 3.3.3 Supply of science, engineering and technology human resources expressed as a proportion of the demand: 2000

OCCUPATIONAL CATEGORY	SCENARIO			
	A	**B**	**C**	**D**
Engineering, engineering technicians, architects & related	1.1	1.0	0.9	0.8
Natural science occupations	1.7	1.5	1.3	1.2
Medical, dental & related health services	1.0	0.8	0.7	0.6
Education & related	1.8	1.7	1.1	1.1
Legal occupations	3.2	3.0	2.7	2.6
Social sciences & humanities	1.9	1.5	1.4	1.1
Business commercial & management sciences	1.2	1.1	1.0	0.9
Art, sport & entertainment	6.6	6.1	5.3	4.9
Managerial & administrative	1.1	0.9	0.9	0.7
Other	9.1	7.4	6.7	5.5
TOTAL	**1.4**	**1.3**	**1.1**	**1.0**

Note: A figure of less than one indicates a shortage.

3.3.4 Relevant school education

The limited output of secondary mathematics and physical science education represents one of the most serious weaknesses of the education system when seen from the perspective of the supply of and demand for science, engineering and technology human resources.

Table 3.3.4 shows that of the 518 000 matriculation candidates that wrote six or more subjects in 1996, 54% passed. Only half of the 42% of all candidates that wrote mathematics and 67% of the less than a quarter (23%) of all candidates that wrote physical science passed these subjects.

Table 3.3.4 Matriculation results (1996)

	CANDIDATES WHO WROTE (1000s)			CANDIDATES WHO PASSED (1000s)			% WHO PASSED		
	Male	**Female**	**Total**	**Male**	**Female**	**Total**	**Male**	**Female**	**Total**
Mathematics	106	113	218	58	51	109	55%	45%	50%
Physical Science	67	58	124	48	35	84	72%	62%	67%
TOTAL	228	290	518	133	146	279	58%	50%	54%

3.3.5 Postgraduate performance

The availability of researchers is closely associated with the number of postgraduate students (especially masters and doctoral students) that qualify from universities. In the period 1991–1995, approximately 17 500 masters degrees and 3 400 doctorates were awarded by South African universities. University staff included some 4 500 doctoral academics (Table 3.3.5).

Table 3.3.5 Postgraduate qualifications awarded by institution (1991–1995) and number of doctoral academics*

	Academics with doctorates*		Masters degrees awarded			Doctorates awarded		
University	**N**	**Percentage of total academics with doctorate**	**n**	**Percentage of total masters degrees awarded**	**Degrees per doctoral academic**	**N**	**Percentage of total doctorates awarded**	**Degrees per doctoral academic**
Cape Town	411	9.1%	1750	10.1%	4.3	372	11.0%	0.9
Durban-Westville	176	3.8%	414	2.4%	2.4	52	1.5%	0.3
Fort Hare	63	1.4%	24	0.1%	0.4	2	0.1%	0.0
Medunsa	44	1.0%	186	1.1%	4.2	17	0.5%	0.4
Natal	298	6.6%	1155	6.7%	3.9	208	6.2%	0.7
North	71	1.6%	5	0.03%	0.1	5	0.1%	0.1
Free State	309	6.8%	1293	7.5%	4.2	254	7.1%	0.8
Port Elizabeth	120	2.6%	337	2.0%	2.8	111	3.3%	0.9
Potchefstroom	250	5.5%	802	4.6%	3.2	152	4.5%	0.6
Pretoria	568	12.5%	2677	15.5%	4.7	547	16.2%	1.0
Rand Afrikaans	188	4.1%	1707	9.9%	9.1	298	8.8%	1.6
Rhodes	149	3.3%	401	2.3%	2.7	109	3.2%	0.7
South Africa	572	12.6%	1817	10.5%	3.2	432	12.8%	0.8
Stellenbosch	375	8.3%	2173	12.6%	5.8	341	10.1%	0.9
Western Cape	166	3.7%	242	1.4%	1.5	34	1.0%	0.2
Witwatersrand	488	10.0%	2093	12.1%	4.3	380	11.3%	0.8
Transkei	82	1.8%	24	0.1%	0.3	2	0.1%	0.02
North-West	42	0.9%	18	0.1%	0.4	7	0.2	0.2
Zululand	66	1.5%	54	0.3%	0.8	13	0.4%	0.2
Vista	93	2.1%	89	0.5%	1.0	35	1.0%	0.4
TOTAL	**4531**	**99.2%**	**17261**	**99.8%**		**3371**	**99.4%**	

* Numbers of doctoral academics are for 1996 or are the latest available figures.

3.3.6 Research and development human resource capacity

Based on headcount, and excluding the business sector, there are approximately 19 000 scientists working on research and development, of which the largest portion (63%) are employed at the universities. However, if calculations are based on full-time equivalent researchers (FTE),[9] the universities contribute only 46% of the total time spent on research and development in South Africa (excluding the business sector).

[9] For higher education institutions, the concept of *full-time equivalent researchers* was applied to determine the percentage of their time that the instructional/research staff spend on research. For example, four researchers that each devote 25% of their time to research constitute one full-time equivalent researcher.

The distribution of research and development capacity among the broad scientific fields shows that 40% of researchers are in the natural science and engineering fields (based on headcount), while based on full-time equivalents, researchers in these fields represent 55% of the capacity.

The analysis of performance sectors shows that in the natural sciences and engineering, the research capacity of the science councils exceeds that of the universities. This supports the case for closer cooperation among these sectors with a view to building research capacity, especially in the fields already experiencing shortages of capacity, for example, engineering and the medical and health sciences.

3.3.7 Mobility of skilled staff

The occupational mobility of research and development staff between the different sectors is largely in one direction – from higher education institutions to the business sector. This leaves the former very vulnerable in terms of its own human resource base. The lack of movement in the opposite direction could impact negatively on the relevance of the training offered and the research done by the higher education sector.

3.3.8 Conclusions

The output of secondary education in mathematics, physical science and technology needs to be improved as a matter of urgency. The composition of the output from higher education needs to be aligned according to demands. Special provision needs to be made to increase the pool of research scientists and to draw from a larger base of graduates. The latter should be possible through planned cooperation among the different role players available to the science and technology system.

3.4 RESEARCH AND DEVELOPMENT OUTPUTS

Survey of Scholarship, Research and Development

J. Mouton and H. Hackmann
Centre for Interdisciplinary Studies
University of Stellenbosch

Terms of reference

The brief for the survey was to collect and analyse data on research projects and their resourcing. A closer specification of this brief required the following:

?? a description of the nation's research projects in terms of key variables, such as objectives, researchers and financial value
?? a classification of those projects in terms of dimensions such as socio-economic sector and discipline, as well as by main performance sector

Research design

The research design consisted of four components, namely:

?? personal interviews on research policy with key persons in surveyed organisations
?? the collection of documentation on the research policies of surveyed organisations for qualitative analyses at a later stage
?? mail questionnaires for individual researchers at higher education institutions (15 333 mailed, 3 337 returned)
?? mail questionnaires as above to science councils and 14 government departments, modified for data collection at the level of programme or main research field

3.4.1 Type of research and development

The classification of the research being done on the basis of the three types of research – basic, applied and development – revealed that about the same amount of effort goes into basic and applied (39% and 38% respectively), while the least amount goes into development (23%). As expected, the higher education sector spends the largest portion (48%) of research time on basic research. The science council sector recorded the highest proportion of time (38%) spent on development, which is mainly due to the focus on technology development by three major institutions.

When basic research is further analysed to fundamental and strategic research, it is revealed that the higher education sector spends a significant portion of its total research effort (23%) on fundamental research, while all the other sectors allocate very little to this area.

The trends in research make-up reveal a decline in the portion of the total basic research undertaken by the higher education sector, from 75% in 1991 to 55% in 1995/96. There has been no significant change in the portion of applied research being done in the higher education sector, while there has been a growth in the development work.

All performers in the public sector devote more than a third of their expenditure to applied research.

The activities of each of the broad scientific fields was analysed by type of research (Table 3.4.1).

Table 3.4.1 Type of research and development in the higher education sector by broad scientific field: 1996

Broad scientific field	Type of research & development			Number of research projects
	Basic %	Applied %	Development %	
Arts	64	24	12	87
Economic and business sciences	43	39	18	369
Engineering sciences	29	44	27	473
Humanities	67	25	8	1256
Medical & health sciences	34	50	16	696
Natural sciences	53	37	10	1746
Social sciences	47	38	15	1502
Average of all research projects	**48**	**37**	**15**	

3.4.2 Expenditure on research and development

Approximately a third (R1.1 billion) of research and development in the country is funded by the government.

More than half of the government expenditure is directed at three sectors – agriculture, the mining and metal industry, and manufacturing. This high proportion is due largely to the levels of expenditure at three of the science councils – the Agricultural Research Council, Mintek and the CSIR. These are all orientated to serving the wealth-generating sectors of the economy.

The analysis of the expenditure by sector creates the impression that the priorities are still those set by the past and do not reflect the national socio-economic concerns of the present government.

While the survey analyses the trends in research and development expenditure and makes some international comparisons, these need to be accepted with caution as they include only estimates of research and development figures for the business sector. The figures for this sector probably include a large portion of expenditure on industrialisation and other areas that should not be included in the classical research and development analysis.

The data indicate that there is probably a need for greater capacity for basic research in the natural sciences and engineering within the higher education sector in order to prepare the country better for the challenges ahead. The consequences of eroding the basic research capacity in these areas at this stage of the country's development would be severe.

3.4.3 Research collaboration

The report also analyses patterns of research collaboration within the higher education sector based on the authorship of research papers published. It found that 29% of publications had multiple authorship, 28% of the funds obtained were in the form of joint funding, 27% of publications had interdisciplinary collaboration, and only 21% involved collaboration with a non-educational institution. However, 13% of the works were multi-sector, meaning that co-workers were from various sectors, including business and institutions abroad.

Most inter-institutional collaboration is in the field of basic medical science, based on the authorship of joint publications.

3.4.4 Conclusions

The survey generated a wealth of information about scholarship and research and development within the South African science and technology system. The picture that emerges is of a system that comprises a diversity of research cultures and practices. It demonstrates strong capacity in a number of sectors and fields, clear divisions of labour with regard to type of research and research output across scientific fields and institutions, definite patterns of research collaboration, and established strengths in certain niche areas. It is also a picture of 'imbalances' in capacity and output, and weak inter-institutional and inter-sectoral collaboration.

There are a number of warning signals: a decline in expenditure on basic research over the last five years, weak inter-sectoral collaboration, and non-alignment of expenditure with socio-economic priorities as far as application is concerned.

3.5 TECHNOLOGY BASE OF THE BUSINESS SECTOR

Survey of the Technology Base of the South African Business Sector

Access Market International (Pty) Ltd and MTA Consulting (Pty) Ltd

Terms of reference

The survey was carried out to determine the extent to which private firms and public corporations within 17 technology-driven business sectors of South Africa invest in research and development and rely on, or benefit from, external funding. It also set out to identify the extent to which these companies were competing internationally.

Research design

There were several stages in the research design:

?? The Standard Industrial Classification (SIC) was used to highlight the sectors of the economy that utilise technology to produce products.

?? Representative sampling established that some 1 260 companies would constitute the broad sample for a fully representative picture to be obtained of the technology base of the South African business sector. Since only significant companies were to be considered, some 313 companies were selected for interviews.

?? A business survey questionnaire was developed by a specialist technology task group, pilot-tested and analysed prior to being used on the sample of companies selected for interviews.

?? A series of buy-in interviews was conducted in conjunction with the audit management and consultants.

The activities of the business sector can be categorised in terms of the following four areas of activity:

?? continuous process industry (typical of processing and resource-intensive industries)

?? discrete product industry (typical of assembly and complex factor industries)

?? information industry

?? service industry

The first two are the major drivers of the South African economy, while the last two are primarily dependent on the successful and active outputs of the first two. The information and service industries are not further discussed as the survey concentrated on the agriculture, mining, manufacturing, construction and energy sectors of the business sector.

The sample sizes per SIC sector used in the survey were small. The analytical task team for the audit therefore grouped the SIC sectors into broader sectors – namely, the continuous process and the discrete products sectors – to create a larger database for analysis. These groups were broadly classified into discrete product and continuous process sectors according to Table 3.5.1. While it is recognised that these allocations are not pure, they do give sufficient information to understand the research and technology thinking and strategies in the two major sectors.

Table 3.5.1 Industry sectors

INDUSTRY SECTORS	
Continuous process	**Discrete product**
Agriculture	Rubber and plastics
Mining	Civil construction
Base metals	Textiles and footwear
Pulp and paper	Electrical and electronic
Power generation	Medical and pharmaceutical
Petrochemicals	Automative and transport
Glass and non-metallic	Metal products and machinery
Food and beverage	Defence
Water	

3.5.1 Discrete product industries

The nature and context of discrete product industries

Discrete product industries are those which produce outputs that are usually sold as individual items, such as a motor car or a television set. The products are usually complex manufactures, produced as an assembly of many different components and frequently made from many different materials. They are therefore sometimes referred to as complex manufactures.

Competitiveness in the discrete products industry comes from product design, process technologies, industrial engineering and marketing. The international trend is away from inflexible mass production of standard products (for example, the Model T Ford) to an optimum batch quantity of one (for example, the customer-specified options for a motor car).

Computerisation and mechanisation of the manufacturing and assembly processes is leading the drive in competitiveness, except in those products where there is a high engineering content. Products that are material intensive and produced in South Africa to international standard specifications do not seem to be competitive. An example is the standard low-voltage electric motor which needs import protection and is not exported. However, high-voltage electric motors, which are usually engineered to meet a customer's specific requirements, are competitive and are being exported.

Where investment in design and technology has been significant, internationally competitive products have been achieved, for example, systems in the defence industry such as the G5 and G6 artillery.

The countries that have recently become economically successful tend to be those which have few natural resources and which have been able to achieve success through the application of science and technology to the discrete product industries to convert materials into competitive complex manufactures.

Performance of discrete product industries

Table 3.5.2 Relationship in discrete product industries between research & development and exports to sales: 1996/97 (indicative)

Industry	Rubber & plastics	Civil con-struction	Textile & footwear	Electrical & electronic	Medical & pharma-ceutical	Automotive & transport	Metal products & machinery	Defence
R&D to sales (%)	0.26	0.20	2.00	0.73	10.20	2.11	1.90	18.00
Exports to sales (%)	3	4	10	1	4	12	12	18

In the level of research and development spend to sales, as well as in the portion of output exported (Table 3.5.2), the discrete product industries are dominated by the defence industry. This industry has an extremely high product focus and has been through the experience of being denied access to imported technologies.

It is significant that the area with the highest tariff protection – electrical and electronics – has the lowest export achievement. The metal products and machinery sector also uses a protectionist strategy, but achieves a good level of exports by means of a reasonably high investment in research and development.

Technology strategy

Research and technology strategies within the various discrete product industries differ, depending on the type of ownership, the source of technology, and the individual company strategies for research and development.

As shown in Table 3.5.3, however, discrete product industries show a strong orientation towards investing research and development resources in product technologies. Two sectors, rubber and plastic and textile and footwear, focus to a significant extent also on process technology; this may be because significant portions of both these sectors are actually continuous process industries.

Table 3.5.3 Technology strategy of discrete product industries: 1996/97

Industry	Rubber & plastic	Civil con-struction	Textile & footwear	Electrical & electronic	Medical & pharma-ceutical	Automotive & transport	Metal products & machinery	Defence
Direction of R&D investment								
Product (%)	37	60	45	74	75	61	80	94
Process (%)	41	25	42	11	18	18	8	3
Support (%)	13	0	1	10	0	8	6	2
Information (%)	9	15	12	5	7	13	6	1
Technology outsourced (%)	49	5	67	45	89	62	54	11
Local (%)	14	0	5	2	1	6	4	4
International (%)	35	5	62	43	88	56	50	1
R&D externally sourced (%)	7	0	11	14	0	17	10	16
Local (%)	3	0	2	14	0	17	8	16
International (%)	4	0	9	0	0	0	2	0

There is an overall lack of investment by discrete product industries in process technology and research and development, which is probably the result of South Africa’s being an industrial colony (importing product and process technologies under restrictive licensing conditions). There is a great need for more industrial engineering and production technology application and research to offset this feature of the discrete product industries. This gap is exacerbated by a lack of international competition and a shortage of skilled human resources with practical experience. More will have to be invested in this area if the industries are to retain their position in an increasingly open market-place.

In most sectors, there is a strong practice of outsourcing technology,[10] with the medical and pharmaceutical sector outsourcing 89% of its technology requirements and most of the other sectors outsourcing between 40% and 70%. The exceptions are the civil and construction industry at 5% and the defence industry at 11%. In all cases, most of the technology is outsourced internationally. The high imported content of outsourced technology is probably due to the importation of production machinery, the local machine tool industry being very underdeveloped. This represents a massive challenge for a long-term sustainable manufacturing technology base.

In all the sectors, the amount of research and development that is externally sourced[11] is small. Two sectors – civil and construction and medical and pharmaceutical – outsource no research and development locally, while the automotive and transport sector externally sources 17% of its research and development capacity.

In the discrete product industries, the research and development is often in-house because of the competitive nature of the products. Product technologies are essential to retain market position in the market-place. However, there must be room for more external sourcing of research and development by these sectors in the pre-competitive arena and in the face of increasing international competition.

Most of the externally sourced research and development is placed locally, with a very small amount going abroad, except in the case of the textile and footwear sector, where 9% of research and development effort is sourced from abroad.

Three of the sectors – the electrical and electronic, the medical and pharmaceutical and the metal products and machinery sectors – show a tendency to patent their research and development outputs, stressing the reliance on technology to create product differentiation in the market. The production and publication of trade articles are extensive in the electronic and electrical and in the metal products and machinery sectors, where the market tends to comprise technical customers.

[10] *Outsourcing technology* occurs when companies purchase technology from another source and do not have ownership of it.
[11] *Externally sourced research and development* occurs when a source outside the company performs the research and development and the company obtains ownership of the outcomes.

With regard to the limitations on more research and development commitment, the most common reason given is the lack of available funding to do more.

3.5.2 Continuous process industries

The nature and context of continuous process industries

Continuous process industries are those that produce commodities which are measured in units of volume, mass, length and area. Often the prices have well-established international benchmarks against which these industries compete globally, and they thus have to ensure ongoing process innovation against very clear product specifications. Product development is driven by local conditions of raw material supply. A significant South African example was the development of a low-chromium stainless steel (3CR12) in the late 1970s and early 1980s by the then Middelburg Steel and Alloys (now Columbus), with the assistance of universities and science councils. This product has become a replacement product for mild steel in a number of applications locally and globally.

Continuous process industries globally are making increased use of integrated modelling and simulation to optimise plant and market performance. Complex models have become more tractable with advances in computing power, and data have become available on-line from computer-based control systems. At the leading edge, real-time simulation models are used to dynamically improve plant performance.

These industries are still dominated largely by economies of scale, although there are notable exceptions (for example, mini-mills for steel-making). The underlying economics of commodity markets have led to forward integration in firms in this sector, with an increasing emphasis on speciality products. Plant-life extension, integrated asset management and optimisation of plant operational and maintenance cycles are sources of competitive advantage in continuous process industries.

Performance of continuous process industries

The continuous process industries generally perform much better in export markets, with lower investment in research and development. In fact, the sector with the highest research and development to sales ratio – agriculture – performs the worst in export markets. However, all these figures need to be read with an understanding of how they were derived. For example, South Africa has a policy of beneficiation, which should serve to reduce the exportation of the outputs of the mining sector and increase the exports of downstream industrial sectors.

Table 3.5.4 Relationship in continuous process industries between research & development and exports to sales: 1996/97 (indicative)

Industry	Agriculture	Mining	Base metals	Pulp & paper	Power Generation	Petro-chemicals	Glass & non-metallic	Food & beverage	Water
R&D to sales (%)	1.5	1.3	0.5	0.6	0.2	0.6	O.6	0.2	0.1
Exports to sales (%)	<1	27	54	27	2	15	4	19	0

Technology strategy

The continuous process sector shows evidence of very sound capacities for sourcing and adopting process technologies. With some exceptions, process technologies in South Africa have been largely imported, but there have been notable innovations at the level of specific unit operations in some industries. There is a strong focus on products in the research conducted by sectors with strong forward integration. Sectors facing environmental constraints focus appropriately on support technologies to address environmental impacts.

In a number of sectors, the research and development and technology strategies are disconnected from the national science and technology system and, ironically, intimately linked to international sources (Table 3.5.5). Local institutions are therefore not generating the capacity to support innovation in continuous process industries, and their research needs are not being directly addressed. Although this is evidence of the internationalisation of technology in the process sectors, it also indicates the development of a dependence on suppliers from abroad as a result of the science and technology system's lack of strategic focus on their needs.

Table 3.5.5 Technology strategies of continuous process industries: 1996/97

Industry	Agri-culture	Mining	Base metals	Pulp & paper	Power gener-ation	Petro-chemicals	Glass & non-metallic	Food & beverage	Water
Direction of R&D investment									
Product (%)	100	9	9	38	8	46	82	49	75
Process (%)	0	72	55	26	65	35	8	50	18
Support (%)	0	5	28	35	0	17	7	2	0
Information (%)	0	14	8	0	0	2	3	4	7
Other (%)				1	27				
Technology outsourced (%)	77	56	62	50	65	59	57	46	100
Local (%)	41	32	2	4	15	3	0	22	100
International (%)	36	24	60	46	50	56	57	24	0
R&D externally sourced (%)	39	30	36	0	20	7	16	11	–
Local (%)	37	29	11	0	12	5	16	4	–
International (%)	2	1	25	0	8	2	0	7	–

Considerable resources are available to the agriculture sector in terms of both technology and research and development. The research function tends to be academically rather than market orientated, and it appears that research and development and technology sourcing are mostly not viewed as prime bases of competitive advantage in this sector.

Capacity and productivity

Most export-oriented sectors show indications of the effective utilisation of science and technology in support of core process technologies. Those that have strong export markets have the clearest strategic intent with respect to technology and research and development.

The petrochemical, base metal and pulp and paper industries show a strong commitment to protecting intellectual property rights, which represents a measure of the utility of research, both in terms of the relevance of the work and its quality.

Given the level of research and development spending in most sectors, there is evidence of good appropriation of benefits in the sectors with export markets. These sectors face global competition in commodity markets and utilise science and technology inputs well. It is interesting to note that these sectors regard insufficient funding as the primary constraint to doing more research and development, rather that the unavailability of suitable personnel or the lack of a research culture. In the agricultural sector, by contrast, the lack of a mission-orientated research culture and the unavailability of skilled people are as important deterrents as the lack of funding. (As indicated, the research culture in the agricultural sector is driven essentially by academic values.)

3.5.3 Technology management

The following points raised in the report reflect on the management of technology in the business sector:

?? The business sector generally employs informal technology management. Poor strategic management of technology is evident at all levels of the science and technology system, including the business sector.

?? People represent a constraint (although never a primary constraint) in a number of sectors, suggesting limitations in the type or number of science, engineering and technology personnel available to the business sector.

?? There is no clear strategic technology focus in information technologies, and this represents either serious undercounting in the review process or (more likely) an underestimation of the influence and impact of information technology on traditional science and technology activities.

?? The most frequently quoted barriers to increasing expenditure on research and development were the following:

?? lack of funding

?? lack of ideas

?? "no specific barriers"

Given that funding levels are already low in the majority of sectors, these sentiments indicate a very low commitment by business management to innovation. This could well be due to the lack of strategic management of technology in most of the business sector.

?? There does not appear to be any significant relationship between research and development commitment and export performance, but it is clear that the product focus in research and development investment by the defence industry has produced internationally competitive products. It has at the very least proved that research and development commitment locally can yield results equal to the best in the world. The notable lack of exports from the electronics and electrical sector may be due to the sample of companies included in the survey, but the results are nonetheless very disappointing.

?? On the whole, South African firms invest limited resources in research and development compared with their competitors internationally and tend not to externally source their research and development. These features are probably characteristic of the culture of local industry. They need to be addressed as they are not conducive to creating a more internationally competitive industrial sector.

3.5.4 Characteristics of and trends in industry

The audit was able to collect a significant number of data on the technological activities of the business sector. The surveys allow the development of new insights into the technological activities of the nation and the effectiveness of research and development output nationally and internationally.

Although most of the data collected were of a snapshot nature, some significant trends were identified by correlation with previous studies commissioned. The significant trends include:

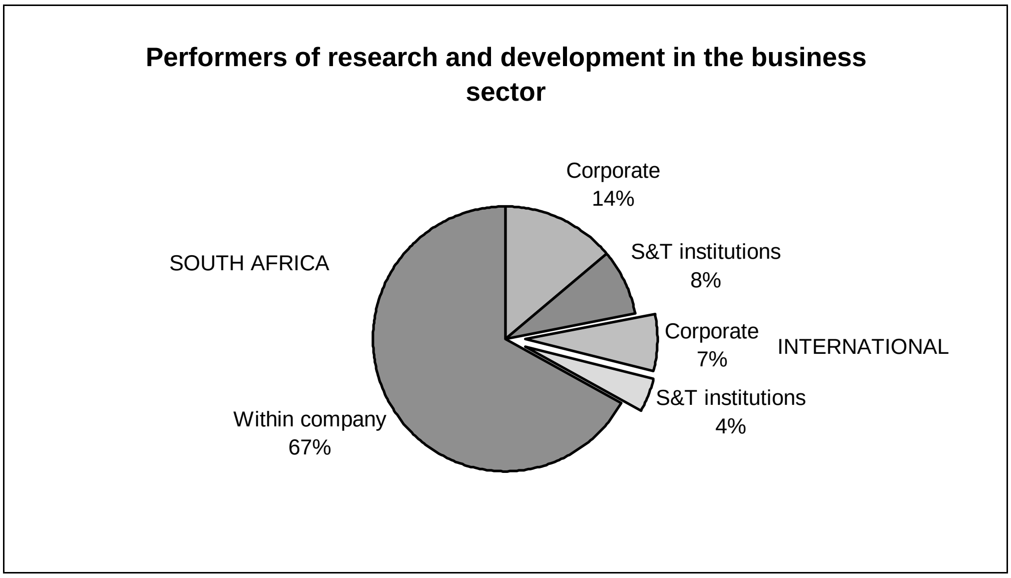
?? ***Technology orientation***

A persistent divergence between the research and development outputs and the technology inputs of companies suggests that in many cases, the management of technology is not a priority.

?? ***Poor linkages and networks***

A focus on in-house capability to perform research is developing at present in most sectors. (Fig. 3.5.1 indicates that 67% of research and development expenditure is performed in-house by companies.) The global trend is towards the formation of joint ventures and the external sourcing of certain types of research. There is only a limited level of collaboration between the science and technology infrastructure and business entities in the continuous process industrial sectors. The low levels of collaboration limit the possible benefits of technology transfer and innovation and inhibit competitiveness. In certain industries (for example, sugar), regional clusters have developed through the integration of the science and technology infrastructure with local industries. The result has been that industry has attained a strong, globally competitive position facilitated and sustained by innovation-based technology transfer.

Fig. 3.5.1 Destination of research and development expenditure: 1996/97



While there is a good variety of institutions in the science and technology system, there are few linkages across sectors and little evidence of significant levels of shared objectives among higher education institutions, science councils and the business sector.

Business sector research institutes – where they exist (all these research institutes serve continuous process industries) – are too small to tackle the challenges presented by the information age, the transdisciplinary approach to science and technology and the continuous renewal and transformation of the science, engineering and technology human resource base. However, business sector research institutes do have excellent domain-specific knowledge.

The lack of good networking inhibits the development at programme and project level of the intellectual critical mass required to solve the challenges presented by the information age and to recognise the reality of the new modes of knowledge generation and management. This situation indicates the limited ability of the science and technology system to be fully productive and relevant in terms of outputs.

?? ***Market alliances with the science councils***

In contrast with the business sector research institutes, the science councils often have the capacity to provide technology and specialised services but lack market- and/or sector-specific linkages and legitimacy. This hinders the effective transfer of technology and research outputs. Improved linkages between science councils and business sector research institutes and between science councils and industry in general are essential and should be actively fostered to their mutual benefit.

?? ***Systemic issues that impact on the business sector***

The higher education sector is developing linkages to the business sector through the Technology and Human Resources for Industry Programme (THRIP)[12] and the Foundation for Research Development's directed programmes, but these initiatives should still be considered embryonic in relation to the scale of the challenges. The potential benefits of such linkages, such as more relevant programme and project outcomes and more productive human resources for the market, can only be obtained once the system embraces the linkages in a positive manner.

Some sectors have no local research or technology capacity. This points to a lack of technology development, fusion and deployment capacity in these industries, leaving less potential for innovation-led economic growth. Poor industrial and production engineering research, technology and innovation are evident in the discrete industries, but there is a positive level of industrial spending overall on product development initiatives.

[12] The THRIP partnership scheme provides research funding to higher education institutions on a matching grant basis by industry and the Department of Trade and Industry. The THRIP programme is managed by the Foundation for Research Development.

3.5.5 Conclusion

?? The survey used the following eight stages of a product life cycle development process to provide an indication of where the effort of the business sector was concentrated:

i)	idea generation	Innovation (i–v)
ii)	research and development	
iii)	prototype development	
iv)	design	
v)	industrialisation[13]	
vi)	manufacture	
vii)	sales and marketing	
viii)	maintenance and service	

In the business sector, only one third of the total innovation activity is in research and development. Twice as much effort is put into the other stages of innovation – activities (iii), (iv) and (v) – as is put into research and development.

?? Direct spending on innovation was R1.6 billion for the 177 firms that provided information on spending. For every rand spent by business on research and development, two rands are spent on the other stages of innovation.

?? Notwithstanding this activity, industrialisation is rated lower than research and development, prototype development and design, suggesting that product development is incremental rather than quantum in nature and that there is limited attention to new production processes. This confirms the view often stated that South Africa is still dependent on embodied technology importation to establish manufacturing capacity.

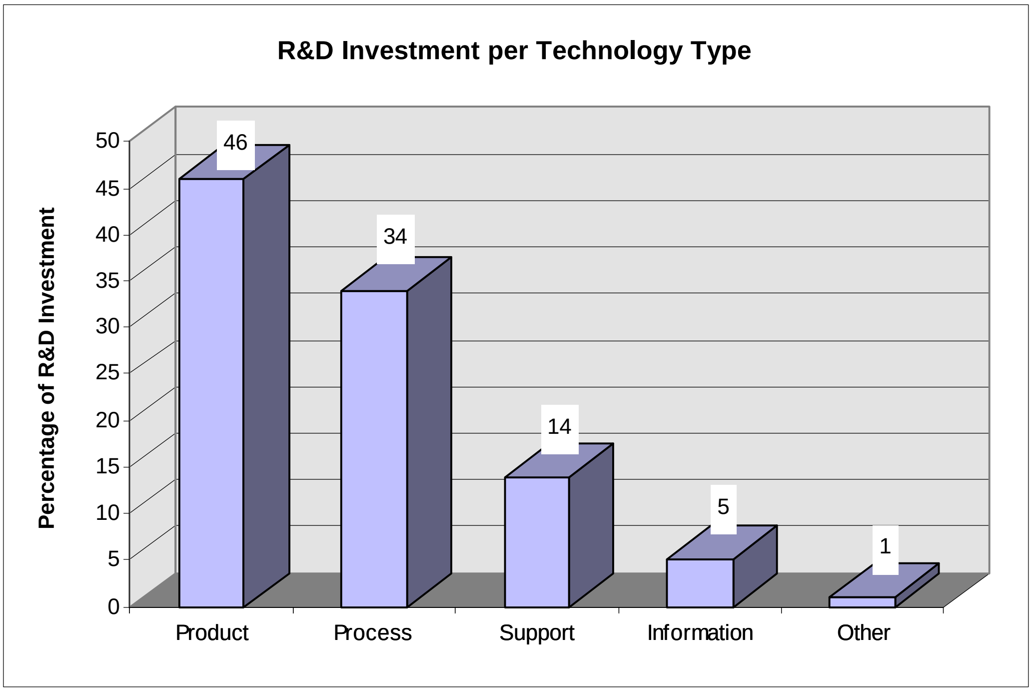
?? There are indications of a need to strengthen technology management, as a disparity of approaches and levels of sensitivity to technology was found.

?? Sectoral, inter-sectoral and cluster technology networking is weak.

[13] *Industrialisation* is the process of converting a development of a new product or process into the production activity.

?? The need for greater process focus in research and development and technology activities in the face of international competition will require new spending by industry rather than substitution of current spending. This provides an opportunity for research and technology consortia to contribute to important process technology issues and information technology. Fig. 3.5.2 shows that only 34% of research and development investment is currently spent on process technologies.

Fig. 3.5.2 Research and development investment per technology type: 1996/97



3.6 RESEARCH AND TRAINING EQUIPMENT

Survey of Research and Training Equipment in South Africa

Dr A. Pouris

Science Consultancy Enterprises

Terms of reference

The investigation was aimed at obtaining, organising and analysing data related to training and research equipment in South Africa.

The exercise had two components:

- to collect the necessary data for the National Research and Technology Database
- to cast light on policy and management issues related to research and training equipment at a national level in the country

Research design

- Higher education institutions, research councils and other government research establishments were surveyed using a census approach. Businesses were approached on a sample basis by another consultant.

- A questionnaire was piloted with a number of institutions, approved by the management of the audit and distributed to higher education institutions, research councils and government departments (2 700 were distributed). Each institution was surveyed individually. The questionnaire was divided into two parts:
    - the adequacy and need for research and training equipment
    - an inventory of the available items of equipment

- A number of institutions were visited to improve response rates and to gain first-hand experience of issues related to research and training equipment.

3.6.1 Main findings

The main findings of the investigation were:

1. There are 2 168 items of research and training equipment, with a value in excess of R80 000 per item, recorded in the database, of which:

?? 966 items valued at R1.12 billion were at science councils
?? 884 items valued at R376 million were at universities
?? 202 items valued at R40 million were at technikons
?? museums and government departments declared 118 items of equipment valued at R256 million
?? the two most expensive items are the National Accelerator Centre (R500 million) and the medium-speed wind tunnel at the CSIR (R125 million)

2. The age profile of the equipment (Table 3.6.1) shows that, while 33% of the equipment is more than ten years old, 838 items of equipment, with a value of nearly R1 billion, were added to the national stock between 1991 and 1996.

Table 3.6.1 Age profile of equipment in South African higher education institutions, science councils and government departments

Year of purchase	Number of items of equipment	Replacement value R (million)
1991–1996	838	895.4
1986–1990	432	322.1
1981–1985	273	211.1
1976–1980	175	166.2
before 1975	183	115.8

3. There appears to be a need to give attention to the renewal of parts of the equipment base. The Analytical Task Team for the National Research and Technology Audit recommends that, where necessary, the replacement of equipment should be incorporated as part of the budget of research programmes and funding agencies.

3.6.2 Collaboration

The survey identified that a reasonable amount of equipment was used by outside parties. This practice could be expanded by requiring institutions to collaborate in the acquisition of large-scale equipment in the future.

3.6.3 Planning and management

Planning and management of research and training equipment are essential on a life-cycle basis. The science councils have good financial practices in this regard, but higher education institutions do not have any central systems in place to assist planning or the generation of reserves for future purchases. The remaining organisations should consider introducing such systems.

3.6.4 Business sector

The information gathered from the sample of the business sector on its research equipment shows signs that the sector is very dependent on suppliers of equipment from abroad. However, the survey data could be complemented by enlarging the database to include equipment in all the major research-performing organisations in the business sector.

3.6.5 Conclusion

South Africa needs better strategic integrative management of research equipment.

CHAPTER 4

IMPLICATIONS OF THE FINDINGS OF THE NATIONAL RESEARCH AND TECHNOLOGY AUDIT

4.1 TECHNOLOGY AND THE FUTURE

This section is based on the study *Scoping Socio-economic Trends in South Africa: a Technological Perspective.*

Scoping Socio-economic Trends in South Africa: a Technological Perspective

P.H. Spies
Institute for Futures Research
University of Stellenbosch

Purpose and subject of the study

A reconnaissance of the general societal conditions under which, and for which, technology development in South Africa must be planned.

The focus is on the economic, social and environmental trends that are shaping South Africa's future, on the stakeholders in technology development and on how technologising the society should be managed as a means of human upliftment.

4.1.1. Technology

Technological change has been a major driver of growth in the global context and should be in the South African context. Technological development is a key to social and economic development. One cannot successfully have any one without the others. Research has confirmed that technological change has been one of the more important components of productivity increase and of the growth of modern economies.

In the global market, the most successful nations are those that have a culture of and infrastructure for technology learning and innovation. The nations that are least successful are those that rely solely on exploiting natural resources to survive in the highly competitive global market-place.

Any country, and particularly South Africa, needs a strategy to create science and technology awareness, science and technology literacy and a work ethic that places an important emphasis on competing in the high technology sectors globally. At present, the focus of the S&T policy debate is on the structure of science and technology-related institutions, but it should be moved rapidly into plans of action for the nation as a whole.

There is a close link between national competencies and national development, and that is the growing importance of technological innovation as a strategic resource. Unless a country makes a determined effort to become innovation-driven, it will not be able to compete effectively in global markets, and will not be able to generate wealth and raise the standard of living of its citizens.

The barriers to innovation are almost never technological in nature – rather social, political, financial and economic. The primary barriers are considered to be:

?? the structure of society itself, the state of human development and the inequality of the institutions
?? the reward system of society
?? the attitudes and concepts of the labour force
?? the political forces that influence the overall economy
?? the lack of demand for quality products and services

It is noted that taxation, finance and competition also affect innovation. The political forces that create an innovative climate include the presence of scientific and technological know-how as manifested in research and development institutions and educational institutions. Obviously, an additional factor is the presence of investors with money for investment, as well as with technical understanding and expertise.

The major competitive advantage today is the ability to learn and to apply knowledge faster than competitors are able to. Knowledge and information are resource flows that are embodied in human potential. This creates powerful regenerative capacities within society. In today's world, 'achieved' (created) competitive advantage is more critical than 'given' (natural) comparative advantage. It is generally accepted that a modern economy is primarily dependent on its executive, professional and highly skilled classes for continued innovation, long-term competitiveness, sustained economic growth and development. The knowledge and skill of the South African population are altogether inappropriate for a country that aspires to becoming an industrialised nation.

4.1.2 The future

The main drivers of the current and future scenarios are firstly the global patterns of change, secondly the regional patterns of change in southern Africa, and thirdly the forces within South Africa that are driving current trends.

South Africa’s long-term economic prospects in a post-industrial technological world are decidedly bleak unless the vexing problem of the poor status of human development can be solved sufficiently and rapidly. The major areas are population growth, housing, health care and education. The additional pressure of urbanisation creates problems of housing and squatting, water and sanitation, waste disposal, pollution and transport. These are all areas that do have, *inter alia*, technological solutions.

The pressures on the natural resource base are great, as there are much deeper problems, requiring greater commitment of resources of research and technology for their resolution. Some of these are:

?? the sharp decline in South Africa’s per capita food production since 1980, with the likelihood of deficits in food production by about 2010
?? the anticipated per capita decline in cropland from 0.31 ha in 1996 to 0.20 ha in 2026
?? the anticipated per capita decline in the availability of fresh water from 1 140 m^3 at present to 760 m^3 in 2025

South Africa is a water-scarce country, and the pressure from the population and industrial growth is mounting. The challenge will be to use creative strategies for both agricultural development and water resource optimisation. South Africa’s capacity for food and fibre production has already reached a ceiling with present-day technology. There is a need for a food policy to address the emerging food crisis. It is claimed that for sustained improvements in agricultural technology, and thus also for technology-based increases in agricultural production, the operating environment of a developed economy is a necessary condition.

The long-term viability of mining in this country will be partly dependent on continuous technological innovation in the industry and the development of the general competitiveness of the South African economy.

These are some of the economic problems facing South Africa in the future. The science and technology system can and will have to make a significant contribution to their resolution. This will require a more efficient, effective and relevant science and technology system working within the framework of a national system of innovation, and directed primarily at contributing to solving the problems facing us.

More importantly, the policy aim of the development of a science and technology system for South Africa will have to be a ‘human plus’ approach, which means that technology is embodied in the competencies of the South African population. Technology is an inclusive process; it is human development. A developing society in today’s world is a ‘technologising’ society. Technologising therefore implies the upliftment of people – a process of capacity generation in which people are developed in order that they can benefit in full from the fruits of modern technology.

The future is not predetermined; it is out there for the making.

4.2 EXAMINATION OF THE REALITIES OF THE SCIENCE AND TECHNOLOGY SYSTEM

The primary function of the science and technology system of South Africa is to make a contribution to the future of the country in dealing with the problems facing us and the need to grow the economy. Any examination of the system must be against this background, and all activities within the system need to be judged for:

?? relevance

?? quality

?? effectiveness

?? efficiency

These criteria apply to all outputs (that is, skills, knowledge, technology and developments), which should be judged against the needs and requirements of the business sector and the social development sector, as indicated in Fig. 2.1 on page 8.

4.2.1 Relevance

The relevance of research can be considered in two separate but related ways. The first is the extent to which research addresses the most pressing issues in a particular field, irrespective of the type of research, and the second concerns the type of research.

The data in the audit seem to indicate that the science and technology system is moving increasingly towards relevant types of research, or application-driven research. In this regard, the most noticeable indicator is the increasing level of expenditure on development work and the concomitant decrease in basic research.

While the above observation could be seen as a positive indication, caution against over-optimism is needed. An analysis at project level remains to be undertaken to ascertain whether projects are actually relevant in value and in terms of the national objectives and the consequent demands on the science and technology system. Such an analysis can only be undertaken once all the aspects of programme and project relevance have been established. This would have to come from the breakdown of the national objectives into relevant programmes. It is apparent from the findings that research projects conducted at higher education institutions indicate that a sizeable proportion are classified as applied research (up to 30 %). However, many of these would be discipline-bound or generic in nature, and in all probability they do not directly address the technological and information needs of national priorities or resolve salient problems.

The audit surveys were not really designed to answer these questions in any comprehensive way, but the information presented would seem to indicate that the science and technology system is not coherently geared to address the critical problems confronting South African society.

A fundamental shift in the relevance of research is thus required.

4.2.2 Quality of human resources

The discussion of the issue of quality is based on the understanding that quality implies that the output is fit for the purpose intended. In the findings of the survey of human resources, one of the most important questions the audit answers is how appropriately trained the human resource base is. While it is difficult to separate the roles of the respective main contributors to the focus of training and research priorities, the following observations can be made:

?? The relatively small proportion of graduates in fields such as engineering and related sciences calls into question the appropriateness of the human resources delivery system, given world-wide trends and the unique problems confronting South Africa.

?? Qualitative findings concerning the induction time required before graduates become fully functional in the workplace reinforce the impression that too many new entrants to the job market may not be optimally prepared for their new careers.

?? The asymmetric mobility of people between higher education institutions and the business sector would seem to indicate that the likelihood of making training more relevant to the needs of business is not favourable. The Technology and Human Resources for Industry Programme (THRIP) and similar initiatives that encourage cross-sectoral and institutional collaboration therefore become all the more important. Functional systems of innovation are characterised by the mobility and 'multiplexity' of skilled resources between the government, business, science councils and higher education sectors.

?? There is still a significant racial skewness in the human resources outputs of engineering and related sciences.

A better match is needed between the needs of the economy and the training and development of human resources.

4.2.3 Effectiveness

In the present context, the criterion of effectiveness refers to whether the science and technology system succeeds in attaining the goals of generating new and relevant knowledge, developing technology and ensuring the continuity of the system by providing research capacity. The audit suggests the following conclusions:

?? The system has produced a substantial volume of research outputs, although international comparisons would seem to indicate that there is significant room for improvement, while other functions, such as teaching in the case of higher education institutions and marketing in the case of science councils, appear to consume a disproportionate share of capacity.

?? If technology production is defined as one of the ultimate objectives of research and development, the effectiveness of the science and technology system must be rated as relatively low, both in terms of the absolute and relative number of technologies reported in the surveys.

?? With regard to ensuring continuity through the provision of adequate research capacity, the situation is complicated by the following considerations:

    ?? The higher education system provides an adequate number of graduates, but the mix of expertise needs to be changed so that more people are trained in engineering and related sciences. This would, however, require a fundamental reform of the education system, especially at secondary level.

    ?? The prominent role played by the science councils in their present form raises questions with regard to the optimal use of institutional infrastructure in their contribution to the development of research capacity.

    ?? There seems to be a one-way flow of human resources from the higher education institutions to the business sector. In the absence of proper strategic management, the present somewhat impermeable boundaries between these two sectors could mean that higher education institutions will find it increasingly difficult to keep their research and development capabilities.

    ?? The inadequacy and uneven availability of research equipment at higher education institutions gives rise to serious questions about the effectiveness and continuity of the research effort.

There needs to be a fundamental shift in the effectiveness of the whole science and technology system.

4.2.4 Efficiency

The efficiency of the science and technology system is the measure of the outputs in relation to the resource inputs, such as staff, finance and equipment. While the surveys were not specifically designed to measure efficiency, the information allows the following tentative conclusions to be drawn:

?? The system is not operating efficiently if the relatively unfavourable ratio of research output to resource input is considered.
?? There is a lack of research focus within higher education institutions.
?? The low degree of inter-sectoral collaboration, which is not a newly identified weakness, can be regarded as a form of inefficiency in the collaborative use of resources.
?? The apparent lack of success in significantly increasing the number of science and engineering graduates points towards an inefficiency (probably multidimensional) in the system.
?? The apparent success with which scientific and technological breakthroughs have been achieved in certain fields (such as defence, mining, metallurgy and the conversion of coal to liquid fuels and chemicals) indicates that mission-orientated research leads to higher levels of efficiency.

The science and technology system as a whole does not appear to be functioning at optimal levels, and the success that South Africa has achieved in certain fields suggests that higher levels of efficiency could be achieved, particularly through more mission-orientated application of resources.

4.2.5 Status of the science and technology system

The following conclusions can be drawn:

?? In general, the training of researchers by higher education institutions is of a high standard. There is concern, however, that the general massification of the higher education sector, which is required to correct imbalances created by the previous political dispensation, and the funding limitations could jeopardise research training in future and not provide sufficient incentives for entrants into the science and technology disciplines.

?? South Africa has achieved international recognition in some science and technology fields, but it is equally true that it is lagging far behind in others that may be important for economic or social development (especially new interdisciplinary fields).

?? The normalisation of international scientific relations affords South Africa excellent opportunities for research partnerships. However, the normalisation of relations is already exposing the strengths and weaknesses of the system, and this is likely to intensify in the future.

Despite the weaknesses of the science and technology system, there are a number of areas of strength on which South Africa should draw if the system is to make a full contribution to the economic and social growth of the country.

4.3 RESOURCING OF THE SCIENCE AND TECHNOLOGY SYSTEM

4.3.1 Funding the system

The prime resource of the science and technology system is funds. The funding for the system comes from three major sources – the government, the business sector and the public. The total funding of the system is estimated at R15.4 billion, and is tabulated in Table 4.3.1. The values in this table, particularly for the business sector, are the best estimates possible at present, using the audit survey reports as well as other research and survey documentation.[14]

[14] Department of Arts, Culture, Science and Technology (1994). *Resources for R&D 1993/94.* Pretoria: DACST; Foundation for Research Development (1996). *South African Science and Technology Indicators. Pretoria: FRD;* Industrial Strategy Project/Foundation for Research Development (1997). *Innovation Patterns in South African Manufacturing Firms.* Cape Town: ISP and Pretoria: FRD; LHA Management Consultants (May 1997). *The South African Science Budget Survey*, Pretoria: LHA.

Table 4.3.1 Funding of the South African science and technology system: 1995/96

			R (million)
State			**7370**
	Transfers	6240	
	Contract	480	
	In-house	650	
Business sector			**5550***
	Contracts	250*	
	In-house	4300*	
	International (including royalties and purchase of technology)	1000*	
Other			**3536**
	Higher education institution's own income	3182	
	Non-government organisations	354	
Less funds sent out of South Africa			**(1000)***
TOTAL			**15456**

* Estimates

The government commitment – which was R7.37 billion for 1995/96 – was made by way of transfers (R6.24 billion), contracted work (R0.48 billion) and internal departmental expenditure (R0.65 billion) by a number of departments; the major ones are listed in Table 4.3.2.

Table 4.3.2 The science and technology budgets of major government departments: 1995/96

Government department	Total R (million)	Transfer R (million)	Contract R (million)	In-house R (million)
Education	4273	4273	–	–
SA National Defence Force	529	135	365	29
Mineral & Energy Affairs	437	371	22	44
Arts, Culture, Science & Technology	409	392	6	11
Agriculture	324	292	2	30
Trade & Industry	312	298	–	14
Environment Affairs & Tourism	145	42	9	94
Health	115	51	36	29
Labour	113	107	2	4
Central Statistical Service	109	–	7	102
Other departments	604	279	31	293

Source: LHA Management Consultants, The South African Science Budget Survey, May 1997.

The business sector funding had to be estimated for several reasons, the main two being that only a sample of businesses supplied data on their funding commitment, and it is not always clear what a business has spent on science and technology. However, based on the results of 177 firms that revealed an expenditure of R1.56 billion and on other research and survey inputs, the business sector expenditure on science and technology is estimated at R5.55 billion per annum. Most of this sum is expended within the business operations, for the most part for the implementation of new technologies. It is estimated that R250 million is paid to other institutions in the system – notably the science councils and the higher education system – and R1 billion is paid out of the country by way of technology licence fees and royalties and the purchase of technology.[15]

The remainder of the funding is the higher education institutions' own income from student fees and other income, totalling R3.2 billion, and non-government organisation funds of R354 million.

[15] Reserve Bank, pers. comm.

4.3.2 Activities of the science and technology system

The funds that enter the system are used in performing various activities dealing with knowledge. These activities can be grouped into those that deal primarily with ‘known knowledge’ and those that deal primarily with ‘new knowledge’. The groups would be:

A. Known knowledge
?? education and training
?? application and diffusion (for example, standards)

B. New knowledge
?? developing or creating (research and development)
?? applying (industrialisation)

The activities of A focus primarily on preparing people and other resources either to be able to create or apply new knowledge, or maintaining known knowledge for societal systems and structures. The activities of B, dealing with new knowledge, constitute what is regarded as innovation.

The activities of the science and technology system are performed by various institutions, some of which deal with all the different activities of the system. The quantum of funds used for each of the activities by each of the performers is shown in Table 4.3.3.

This table is to be used as a guide only as there are a number of assumptions and estimates in the allocations, particularly in the business sector. The audit was not designed to account for all expenditure in the science and technology system, and notable exceptions would be the spend by the business sector on education (by education and training companies) and the application of known knowledge (by consultants, for example). The table does indicate that of the approximately R15 billion spent on knowledge, about 55% is spent dealing with known knowledge and 45% with establishing and applying new knowledge.

An analysis of these figures indicates that about 75% of the innovation spend is by the business sector. If the business sector funding of research and development in higher education institutions and science councils – estimated to be R250 million – is taken into account, it confirms previous findings that the business sector funds more than half of the total research and development activities in the country.

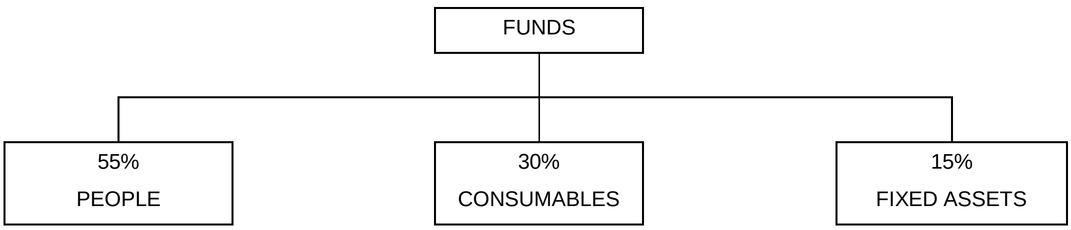
Table 4.3.3 Activities of the science and technology system by performer, in rand (million): 1995/96

Performer	Known knowledge		New knowledge (Innovation)		Total spend
	Education	Diffusion	R&D	Implementation	
Higher education institutions	7227		575		7802
Science councils	38	352*	728	352*	1470
Government	54	545	55		654
Other	39	668	141		848
Business			1551*	3100*	4651*
TOTAL	**7358**	**1565**	**3050**	**3452**	**15425**

* Estimates

4.3.3 Resources used in the non-business sector

Information gathered indicates that the funds spent for science and technology are allocated as in the following diagram.



The ‘people’ group would be the actual performers of the knowledge generation or application, together with the support staff of the institutions. The ‘consumables’ would be consumed during the process, and the ‘fixed assets’ would be what are used by, or purchased for, the system and remain after the completion of any activity.

The audit has identified that in the science and technology system (excluding the business sector), over 70 000 people are employed. These people perform about 72% of the activity of the system, the remaining 28% being performed by the business sector.

About 55% of the total funds of the system are used to pay for the people resource, while 15% of the funds are used as expenditure on fixed assets and about 30% on consumables.

The value of the assets used by the performers in the public sector is R8.7 billion. Comparable figures for the business sector are not available from the audit.

4.4 CHARACTERISTICS OF THE SOUTH AFRICAN SCIENCE AND TECHNOLOGY SYSTEM

This section discusses the characteristics of South Africa's science and technology system as inferred from the surveys conducted for the audit. While some of them may at first appear to be somewhat self-evident, that should not detract from their fundamental importance. These findings could inform policies designed to revise the science and technology system.

4.4.1 The science and technology system is an open system

Science and technology constitute an open social system of interdependent subsystems, which complies with Gibbons's "socially distributed knowledge system".[16]

4.4.2 Science and technology represent an important part of the national economic system

The science and technology system, in terms of the number of human resources, annual turnover and capital investment, represents an important part of this country's economic system.

[16] Gibbons M. et al. (1994). *The New Production of Knowledge: the Dynamics of Science and Research in Contemporary Societies*. Thousand Oaks: Sage.

4.4.3 The human resource base as primary condition for an effective science and technology system

Given that a competent human resource base remains the primary necessary condition for an effective science and technology system, mathematics, technology, physical science and language abilities at secondary school level represent the Achilles' heel of the preparation of future generations of science, engineering and technology workers in general, and researchers in particular.

4.4.4 Institutions

One of the main findings of the audit is that in comparison with other countries, South Africa has a sufficient variety of institutions within the science and technology system; a possible exception is a technical university. The implication of this finding is that there is no need for dramatic interventions at the institutional level in terms of closing down institutions or funding the development of new major types of institutions.

4.4.5 Gaps in the system

Within the science and technology system, 'gaps' exist because of the differing dynamics of the business environment and other research and higher education institutions that comprise the science and technology system.

Evidence from the audit suggests that the transfer sciences that enable bridging such gaps are at an embryonic stage in South Africa, and to a certain extent declining in spite of a very low base. This is due to a culture which encourages learning based on individually driven interest at the expense of collaboration and network-driven knowledge generation. An example of such a gap is the limited productive capability of science, engineering and technology graduates on exit from higher education institutions.

4.5 SUITABILITY TO MEET FUTURE NEEDS

4.5.1 The role of government within the science and technology system

It is important to recognise that the role of government should be congruent with internationally accepted practice and should take into account the peculiarities of the current realities in South Africa.

Based on this understanding, the government has the generic role of:

?? establishing the structures to run the system
?? allocating funds at the macro level in line with priorities
?? designing instruments, such as special programmes, for achieving its objectives
?? strategically measuring and reviewing the impacts and outcomes of science and technology programmes
?? establishing a regulatory regime for the system

A review of the findings of the audit suggests that the South African government is adopting a low intervention approach. The key role which government should take is to set priorities for the outcomes of the science and technology system, undeterred by the possibility that its interventions may sometimes not be fully achieved. Such priorities are normally aligned to a significant extent with the current national priorities published in various policy documents, as well as medium- to long-term priorities associated with economic and industrial competitiveness. In this way, the government uses the science and technology system strategically in achieving its policy objectives.

Another necessary function for government is to measure the effectiveness and efficiency of the science and technology system on a continuous basis. It was found that the government is not playing this role in the South African science and technology system. In an ideal situation, the framework for measuring the system is derived from the demands on the system, and an agreed, integrated, transparent system of measurement is implemented. Such a measurement system does not exist at present. The evaluation of components of the system can never substitute for an evaluation of the system as a whole.

The policy implication of both these findings is that the government, in partnership with the stakeholders of the science and technology system, should strategically manage the science and technology system in order to leverage the assets of the system to achieve medium- to long-term national priorities.

Examples of such alignment and management of the science and technology system can be found in developed and developing countries alike. The mechanisms that can be employed include:

?? partnerships in acquiring, designing, constructing and equipping new manufacturing industries
?? technology upgrading in the business sector (in other words, moving away from import substitution to export generation or from labour-intensive to technology-intensive products)
?? creating an educational system and an environment that foster the adoption and diffusion of technology in order to facilitate technological leap-frogging

Numerous studies show that it is more important for governments to focus on implementing innovation structures and linkage programmes than on absorbing state-of-the-art technology (which the business sector will do more efficiently).

4.5.2 The science and technology system should be a demand-led system

One of the key findings of the audit is that it is claimed that the priorities of the science and technology system (as derived from institutional programme activities and the allocation of funds) are in line with national priorities as described within the policy environment. The policy environment is so broad, however, that almost any activity within the system could be claimed as meeting the national priorities. The national priorities need to be distilled into more precise objectives against which the relevance of the outcomes and outputs can be measured.

Government policy focuses on achieving major socio-economic and political objectives, and policy documents cannot spell out any explicit priorities for the science and technology system. For this system to be demand-led, there needs to be a linkage between the system and the national policy objectives. This linkage has to be strategically managed in order to establish the priorities for the system, translate them into actions and monitor the outcomes and outputs in relation to their relevance.

4.5.3 Dynamic change in knowledge production

One of the central implications for policy is that in the future, industrial competitiveness will be dominated by the new value chain formed by data, information and knowledge.

This value chain offers South Africans the means of developing global competitiveness in technological areas selected as national areas of specialisation. Another important reality of this value chain is that the costs of technological development and transfer are considerably lower than the cost of the traditional research and development that characterise the current science and technology system.

Two of the six pillars of the South African policy environment are the creation of an information society and the generation of knowledge, and there are significant weaknesses in the current science and technology system associated with these two pillars at institutional and systemic levels.

The policy implications of this major finding are that the science and technology system should recognise the value of knowledge management and incorporate it into the activities of the system in order to facilitate national technological development. Some weaknesses of the science and technology system can be eliminated primarily by means of focused knowledge management and transfer at programme and project level. The ways in which this can be encouraged at various different levels include:

?? encouraging outcome-based transdisciplinary cooperation involving higher education institutions, science councils and business
?? developing special technological programmes focused on the transfer of technology in order to solve problems of national priority
?? linking funding allocation mechanisms to encourage new knowledge-intensive activities relating to the information society
?? encouraging activities at the innovation interface, such as technology platforms, technology demonstration programmes and technology diffusion projects (which are very poorly developed in South Africa at present)

4.5.4 Scale and scope of the system

A review of the findings of the audit consistently indicates that the level of investment in the South African science and technology system has been declining in real terms and that there is significant under-investment in view of current and future demands on the system.

Although it is recognised that some improvements in the efficiency and productivity of the science and technology system can be achieved by maintaining current levels of investment and improving the management of the system, such improvements would not necessarily be sufficient to meet the increasing demands.

The policy implication of the findings is that there is a need for a quantum increase in the level of investment in the South African science and technology system. In order to ensure congruence with the other findings of the audit, any increase in investment should be applied strategically by:

?? contributing to a restructuring of the science and technology system so as to improve the management and productivity of the system and align it with national priorities (especially its linkages)

?? optimally utilising potential expertise

?? developing a national infrastructure for the management of knowledge

?? increasing the number of relevant human resources developed and trained by the science and technology system

?? focusing new resources on technology platforms, and the demonstration and diffusion of technology

4.5.5 Summary

This chapter has outlined the findings of the audit that have the most important implications for policies designed to leverage the science and technology system to achieve national priorities. The review indicates that the current science and technology system, although institutionally complete, does not achieve its maximum potential because of the lack of internal linkages.

4.6 STRENGTHS AND WEAKNESS OF THE SCIENCE AND TECHNOLOGY SYSTEM

4.6.1 Strengths and weaknesses

One of the primary objectives of the audit was to identify the strengths and weaknesses of the South African science and technology system. When measured against the reasons for having the system, the following tables present a list of the identified strengths and weaknesses.

STRENGTHS
1. There is a well-developed infrastructure of institutions.
2. The existing science councils and the higher education sector have the potential to be strong participants in the national system of innovation.
3. There is a core of skilled and knowledgeable people.
4. There is capacity within the science and technology sector to contribute successfully to national priorities.
5. There are pockets of international achievement in science and technology, which indicates the capability of the nation's human resources to achieve that level.
6. There are examples of successful mission-orientated research and development programmes.
7. The business sector is involved in technology uptake and application.
8. There are examples of technology achievement in the process industries.

WEAKNESSES
1. The system is not led enough by national demands and priorities.
2. The relevance and purpose of the research is not always clear.
3. There is a major mismatch between the needs of the economy and the human resource skills the system is producing.
4. International and inter-institutional collaboration is lacking.
5. The responsiveness of the system is low; there is a lack of information technology familiarity in the system.
6. The system as a whole is not strategically managed.
7. Specialised research equipment is ageing, particularly at the higher education institutions.
8. The uptake of technology from local sources by the business sector appears to be weak.
9. The system lacks packages of locally developed technology due to the high level of technology imports by local subsidiaries of international companies.
WEAKNESSES
10. The business sector generally employs informal technology management. Poor strategic management of

technology is evident.
11. The system as a whole is underfunded to ensure it is making the optimal contribution to the country's socio-economic growth.
12. The system has to operate in a society that is not 'technologised'.
13. In the past, 85% of the population was systematically excluded as a potential source of human resources, knowledge and expertise.

4.6.2 Strengths and weaknesses compared to the characteristics of a functional national system of innovation

In Section 2.3.3 of Chapter 2, the significant characteristics of a functional national system of innovation are listed. Table 4.6.2 relates the strengths and weaknesses listed above to these characteristics. From this comparison, it is clear that most of our strengths are potential rather than in full deployment, mainly because of a lack of strategic management. There are even some empty boxes under strengths, while under weaknesses, one or more is listed in every box. This may serve as a guide to devising a strategy for the development of the South African science and technology system. It provides a basis for the recommendations in the next chapter.

Table 4.6.2 Strengths and weaknesses of the South African science and technology system compared to the innovation

	CHARACTERISTICS OF A FUNCTIONAL NATIONAL SYSTEM OF INNOVATION	SOUTH AFRICA'S STRENGTHS	SOUT
A	Technology of local origin is embodied in packages, reflected in end-user groupings.		9. The techn impor comp
B	Innovation and technology projects are performed by transdisciplinary (often international) teams.		4. Inte lackin
C	All the competencies of strategic technology management are developed and employed to manage the national system of innovation to achieve national objectives.	6. There are examples of successful mission-orientated research and development programmes.	10. Th techn mana
D	The national system of innovation operates within a 'technologising' environment, which enables relevance to communities and develops international competitiveness.		12. Th 'techn 13. In syster huma

	CHARACTERISTICS OF A FUNCTIONAL NATIONAL SYSTEM OF INNOVATION	SOUTH AFRICA'S STRENGTHS	SOUT
E	The system is outcome-oriented and outcome-driven. Outcomes are developed and agreed upon by appropriate stakeholder groups, ensuring long-term sustainability of the national system of innovation. Funding methods are outcome-based.	1. There is a well-developed infrastructure of institutions. 2. The existing science councils and the higher education sector have the potential to be strong participants in the national system of innovation. 3. There is a core of skilled and knowledgeable people.	5. The a lack syster
F	The strong, self-reinforcing linkages among business, government development agencies and higher education institutions are enhanced through collaborative projects, sometimes sponsored by government.	7. The business sector is involved in technology uptake and application. (THRIP is an example).	8. The the bu 11. Tl it is m socio-
G	The national system of innovation is managed as a system with strategic high-level objectives and performance measures based on national priorities aligned with the agendas of government departments.	4. There is capacity within the science and technology sector to contribute successfully to national priorities.	1. The dema 6. The mana

	CHARACTERISTICS OF A FUNCTIONAL NATIONAL SYSTEM OF INNOVATION	SOUTH AFRICA'S STRENGTHS	SOUT
H	The national system of innovation facilitates the technological and sectoral specialisation needed to develop unique competencies and sustain specialised technology.	5. There are pockets of international achievement in science and technology, which indicates the capability of the nation's human resources to achieve that level. 8. There are examples of technology achievement in the process industries.	2. The alway 3. The the ec produ 8. Spe partic

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The audit indicates that the South African science and technology system is endowed with a well-developed infrastructure of institutions with good potential and a core of skilled and knowledgeable people. There are pockets of international achievements in both the business sector and the social development sector.

However, there are some structural, organisational and societal weaknesses:

?? The system as a whole is not strategically managed.
?? The system is not led by national demands and priorities.
?? The relevance of much of the research is not clear.
?? Inter-institutional collaboration and cooperation are poor.
?? Compared to countries with which South Africa has to compete, the science and technology system is under-funded to ensure that it is making an optimal contribution.
?? There is a major mismatch between the human resources outputs and the country's needs, both in terms of demography and discipline.
?? South Africa's people do not currently have the capacity to benefit fully from the fruits of technological advance.
?? In general, the system lacks information technology familiarity.

The net effect is that while the system has capabilities, it is not functioning optimally and is not structured to maximise its contribution to meeting the national objectives in the areas of economic growth and social development.

5.2 Recommendations

Based on the analysis of the audit information as background and recognising the determination of government and its various organs to develop an integrated approach to address the socio-economic needs of the country, the synthesis report makes four recommendations.

Recommendation 1

The strategic planning and strategic management of the national science and technology system require a policy apparatus that will enjoy such a high degree of respect that government, business and civil society, as key stakeholders in the national system of innovation, will "take their cue" from it and adjust their activities to accord with its stated objectives and requirements. This apparatus would then set the basic tone for the strategic planning and strategic management of science and technology by ALL elements comprising the national system of innovation and will inform the collective planning and management of the national system of innovation. Such an apparatus must give purpose to the science and technology system and, through incentives, remove conflicting interests that prevent or inhibit the science and technology system from working coherently.

Recommendation 2

A coherent national human resource and skills development policy and accompanying strategies should be developed urgently. Such a policy should aim to negate all the undesirable features of historical policies, patterns and practices. The policy should ensure that human resources and skills of appropriate quality and in appropriate quantities are developed in accord with macro-economic policies and with a view to improving the human development index.

Recommendation 3

A programme should be developed and implemented to technologise South African society, as a sustainable process of re-creation and renewal that will include improving perspectives and understanding by all its people.

Recommendation 4

The information network, including the human utilisation capacity, should be enhanced to serve the science and technology system and prepare the country for becoming a knowledge society, thereby allowing the people of the country more effectively to communicate, innovate and compete globally.

The synthesis report makes no recommendation for additional funds for the science and technology system. The first priority is to ensure the coherent, effective and efficient use of present and future additional funding.