A Study on
The Required Physical Infrastructure to attain the Vision of the NSI

NATIONAL ADVISORY COUNCIL ON INNOVATION
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A study conducted by TechnoScene

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This report has been released as a discussion document and does not necessarily represent the viewpoints of the National Advisory Council on Innovation

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Executive Summary

The National Advisory Council on Innovation (NACI) commissioned a Study to Determine the Competitive Aspects of the Required Physical Infrastructure to attain the Vision of the National System for Innovation (NSI). Infrastructure in the context of the NSI refers to the combination, in a special context, of all the facilities to provide the base for education or research in a nation. It includes knowledge, people, facilities, equipment, buildings and laboratories, with emphasis of accessibility and state-of-the-art condition in relation to a set of national strategies, aligned to achieve certain visionary outcomes. Infrastructure is contextual and applies to the global, national and regional aspect of the disciplines, science and technology. Competitiveness can be seen in a dual context: Firstly making the NSI attractive for foreign direct investment in R&D and for international researchers and post-docs to work in South Africa. Secondly, the NSI could be made competitive by spinning out globally competitive knowledge, products and services from R&D and in creating competitive enterprises from the R&D. The study focused on the geographic advantage science missions and the technology missions, frontier science and technology areas and high value industries.

Developments since publication of the National R&D Strategy necessitated reconceptualisation of the *science missions* as follows:

- *Space Science* including Astronomy, Space Physics and Satellite technology, with the latter being dealt with under the technology missions
- *Biodiversity*, both terrestrial and marine including climate change and oceanography
- *Antarctica, Islands and Southern Oceans*
- *Earth Science*
- *Palaeo-sciences* including Palaeontology, palaeoanthropology, archaeology and palaeoclimatology
- *Poverty Reduction and Health*
- *Indigenous Knowledge*
- *Earth Observations*

The *technology missions* that were investigated in terms of competitive infrastructure requirements included:

- ICT
- Biotechnology
- Manufacturing Technology
- Resource-based Industries

Attention was also given to the following *frontier science and technology areas*:

- Nanotechnology
- Hydrogen economy

- Energy technologies, especially renewable energies
- Micro-satellite engineering
- Vaccine technologies

The following are *high value industries* (as defined by *the dti*) and have been investigated in terms of competitive infrastructure.

- Defence
- Aerospace
- Nuclear

The infrastructure required for the science emissions is summarised as:

Science Mission	Sub-mission	Infrastructure
Space Science	Astronomy	2nd Generation Instrumentation
		Upgrades at Sutherland and in Cape Town
	Radio-astronomy	Additional KAT dishes
	HESS 2	Contribution to demonstrator
		Participation cost
	Space Geodesy	New generation VLBI antennas
		NASA SLR2000
		Lunar Laser Ranging
		Dual Frequency GPS Receivers
		New Geodesy Station
	Space Physics	Low Altitude HR Radar
		Ionosonde
		Dual Frequency GPS Receivers
		Smaller instruments and HMO infrastructure
	Satellite Applications Centre (SAC)	New generation smart dishes at SAC on Hartebeesthoek
		Data storage facility
		Operation as a National Facility
Biodiversity	Marine	Near-shore Research Vessel
	Biodiversity	50% contribution to Research vessel for Regional GEF programmes
		Manned Submersible
		Remotely Operated Support Vehicle (ROV)
		Research Instrumentation
		Marine Aquaculture research facility
	Terrestrial Biodiversity	SAEON/LTER sites including instrumentation
		FACE-type instrumented experimental field sites
		"Ecotron"-type national research facility
		NZG Research infrastructure
		Airborne survey
		National BioBank facility
		Natural History Collections
		Specialised Analytical Equipment

Science Mission	Sub-mission	Infrastructure
Antarctica and Southern Oceans		Research Vessel, replacement of SA Agulhas
		Instrumentation
		Operation
		H F Radar Connectivity
		Marion Base (Equipment & Staff)
		Landscape Dynamics
		Oceanography HR capacity: 2 Research Chairs
Earth Science		Geodata storage and Retrieval
		Analytical and characterisation
		SHRIMP
		Infrastructure access
Palaeo-sciences		National Collections
		Characterisation: Imaging
		AMS at iThemba (Gauteng)
		QUADRU: Luminescence
		Stable Isotopes
Poverty Reduction and Health		Surveillance Sites
Indigenous Knowledge		IK Centres
Earth Observations		South African Earth Observation System

The infrastructure required for the technology missions, frontier science and technology and high value industries is summarised as:

Technology Mission	Sub-focus	Infrastructure
ICT	HLT	Centre for Human Language Technology
	HPC	Centre for High Performance Computing
	Wireless & satellite	Wireless test bed
	Networks	SANREN
		TENET
		UbuntuNet
	Generic ICT	Centre for Monitoring and Evaluation
Biotechnology	BRICs	Biotechnology Hubs
	Networks	National Bio-informatics Network
		Biobank
	Clinical testing	National Preclinical Institute

Technology Mission	Sub-focus	Infrastructure
Manufacturing Technology	Advanced Materials	Centralised Advanced Characterisation Facility
		Micro- and Nano-processing Facility
	Generic Manufacturing	National Centre for Systems Engineering
	Precious Metals (including PGMs and Gold)	National Centre for Precious Metals Research
	Light Metals and New Metals	Centre for Light Metals and New Metals Research
Frontier Science and Technology Theme	Nanotechnology	Regional Nanotechnology Characterisation Facilities
	Hydrogen	Specialised (Regional) Hydrogen Energy and Fuel Cell R&D Centres
	Energy Coal & Renewable	SANERI
	Microsatellite Engineering	Flagship satellite projects
		Space optics testing facility
	Vaccine technologies	Vaccine/Bio- Manufacturing Facility
High Value Industry Sector	Aerospace	Wind Tunnels
	Nuclear	South African Nuclear Research Institute
		Synchrotron
		Radioactive Beam Facility
		Nuclear Manufacturing Centre of Excellence
		National Nuclear Science Centre
Cross-cutters	Systems Engineering	National Systems Engineering Initiative
	Foresighting, Road Mapping and Demonstration	Foresighting and Road Mapping Institute
	Innovation Space	Innovation Laboratories on The Innovation Hub

The combined financial implication for the science and technology missions, including running costs and start-up costs is as follows:

Mission	Capital Cost (R million)	Running Cost (R million)	Start-up Cost (R million)	Total Cost (R million)
Science Missions	1 955	238	92	2 285
Technology Missions	2 870	287	187	3 344
Total	4 825	525	279	5 628

Running or recurring costs include:

- Technical support
- Maintenance costs
- Management support

Start-up cost includes:

- Feasibility studies
- Strategy planning
- Training of people in new fields of science and infrastructure management

If only the impact on multiple missions is considered, the required infrastructure identified could be prioritised in groups and strata as shown in the table below, where 7 to 1 under column A reflect increasing impact. Numbers under column B reflect the perceived prioritisation in terms of short (1 – 3 years), medium (4 – 6 years) and longer (7 - 9 years) term, where 1-2, 2-3 and 1-3 reflect annual investment requirements over the respective periods indicated. The table below

A	B	Science Missions
7		Additional KAT dishes
	1-2	Dual Frequency GPS Receivers
	1	Contribution to HESS demonstrator
	1	Manned Submersible and ROV
	1	Upgrades at Sutherland and in Cape Town
	1	2nd Generation Instrumentation
	1-2	CT Scanner and Tomography
	2-3	New Geodesy Station
	2-3	Marine Aquaculture research facility
	1-3	Research Instrumentation
	1-3	Near-shore Research Vessels
6	1	SAC Databank
	1	IK Centres
	1-3	NZG Research infrastructure
	1	Lunar Laser Ranging
	1-2	FACE-type instrumented field sites and Special Analytical Equipment
	1-3	New generation VLBI antennas
	2-3	Dating & National Collections
	2-3	Satellite dishes
	2-3	Geo-analytical and characterisation
	3	"Ecotron"-type facility
5	1	Marion, SANAP, Oceanography
	1-2	Surveillance Sites
	1	Natural History Collections
	1-3	BioBank facility
4	1	Airborne survey facility
	1-2	SAEON/LTER sites
3	1-2	Instrumented anchored buoys
2	1	Accelerator Mass Spectrometer (AMS)
	1-2	Replacement of SA Agulhas
1	1-3	Modelling Capacity & Earth Observation Systems

A	B	Technology Missions
9	1	National Nuclear Science Centre
	1	Synchrotron
	1	Centre for Monitoring and Evaluation
	1	Space optics testing facility
	2-3	Biobank linked to Biotech Hubs
	2	National Preclinical Institute
	3	Radioactive Beam Facility
8	1	Nuclear Manufacturing Centre of Excellence
		National Bio-informatics Network
	2-3	Centre for Light Metals and New Metals Research
	1	Centre for Human Language Technology
	2-3	Biotechnology Hubs
7	1	South African Nuclear Research Institute
		SANERI
	1	Wireless test bed
	2	Vaccine/Bio- Manufacturing Facility
6	3	Wind Tunnels
	1	Regional Nanotechnology Characterisation Facilities
5	2-3	National Centre for Precious Metals Research
	1-3	Flagship satellite projects
4	1	UbuntuNet
		TENET
	2-3	Specialised (Regional) H2 Energy & HFC R&D Centres
3	1	National Systems Engineering Initiative
2	1-2	Centralised Advanced Characterisation Facility
1	1	Foresighting and Road Mapping Institute
	1-2	Micro- and Nano-processing Facility
	1	Innovation laboratories on The Innovation Hub
	1-3	Centre for High Performance Computing SANREN

should be read in conjunction with Table 24 and Table 25 of the main text which provide more details regarding costs, responsible Government Departments and possible linkages for leading the roll-out of the infrastructure.

The roll-out of the competitive infrastructure required is suggested to take place over three MTEF periods of three years each. The cost implications per MTEF period are:

Mission	**MTEF Period**		
	1	**2**	**3**
Science Missions (R million)	968	841	475
Technology Missions (R million)	995	1 159	1 189
Total (R million)	1 963	2 000	1 664
Average per annum (R million)	654	667	555

It should be kept in mind that not all the required costs are new and some are already catered for in other strategies such as the ICT R&D Strategy, the Energy R&D Strategy, Nanotechnology Strategy, etc. The shared responsibility of the different departments should also lower the burden on the DST budget.

It is proposed that the following interventions are initiated to enable the DST to have a competitive advantage in motivating for infrastructure funding from National Treasury:

- That the entire infrastructure landscape and cost estimates as revealed by this study are considered.
- Priority is given to infrastructure that:
  i. Maximises benefit to as many missions as possible,
  ii. Those that are under threat if not given immediate attention, and
  iii. Those with potential to facilitate foreign direct investment, including in R&D.

  No single methodology for prioritisation should be used, and a combination of the three priority considerations is required.
- Successful allocation for competitive strategic infrastructure funding from National Treasury be followed by commissioning of detailed business plans for infrastructure, with due cognisance of recommendations regarding planning and governance of expensive research equipment as outlined in the National Key Research and Technology Infrastructure Strategy.
- Implementation of infrastructure development plans by establishing appropriate governance and management systems, and instruments that optimise their use and benefits to the NSI.

Prioritised infrastructure according to the first criterion include (by example) additional resources to accelerate implementation of SANReN and the High Performance Computing Facility, centralised facilities for Advanced Characterisation and for Micro- and Nano-processing, a national facility for Marine and Antarctic Research, and Accelerator Mass Spectroscopy. Those in the second category include the natural history collections and the second generation SALT instrumentation, whereas the third includes the HESS 2 prototype and the creation of an Innovation Space on The Innovation Hub.

In addition to the above the study has identified aspects that require urgent attention in order to ensure competitiveness and optimal utilisation of research infrastructure. These include:

- The development of strategies, particularly for the science missions, but also for some of the technology missions where existing strategies do not adequately address infrastructure requirements. Ideally, the development of such strategies should include the conceptualisation of flagship programmes, as these will dictate the infrastructure requirements to meet the objectives of such programmes.
- Clarification of roles amongst government departments where R&D priorities straddle their respective responsibilities. This relates particularly to the DST (Department of Science and Technology) and DEAT (Department of Environmental Affairs and Tourism)/SANBI (South African National Biodiversity Institute) in the case of biodiversity, and the DST, DEAT and DAC (Department of Arts and Culture) in case of the natural history collections in museums.

It is furthermore proposed that the home of the South African National Antarctic Programme (SANAP) be reconsidered, as part of the creation of a National Facility for Marine and Antarctic Research. Such a facility should be tasked to manage all the research vessels, the research bases in Antarctica and on Marion Island as well as the submersibles. This proposal is made in view of the present unsatisfactory arrangements whereby the DST is responsible for the science of SANAP and the DEAT for logistic and infrastructure. In addition there is an urgent need to grow capacity for oceanographic research, given among others the substantially increased area of ocean over which South Africa will obtain jurisdiction in terms of the United Nations Law of the Sea Convention.

This study into R&D infrastructure has revealed that significant investment will be required to elevate the NSI to the state of competitiveness that is required to be a global player in R&D and innovation. It has taken a holistic view of the NSI from both a science and a technology perspective and shown that although many strategies that are in place are facilitating a move towards competitive R&D, in some cases strategy vacuums exist and in general very little synergy exists between science and technology areas. This may partly be caused by the fact that academic research still takes place in the silos of disciplines, whereas people, markets and the environment benefit from a multidisciplinary approach. It became clear in the study that much of the infrastructure requirements could be deployed in such a way that will foster multidisciplinary research and development and thereby beneficiate strong innovation behaviour. This supports the notion that most innovation takes place at the interfaces and boundaries of disciplines.

A systematic implementation of the infrastructure requirements identified in this study will enable government to elevate science, engineering and technology in the identified priority areas, and hence also the NSI to the level of international competitiveness as envisaged. This will undoubtedly have numerous positive impacts such as making the country globally competitive as a player in R&D, in developing products and services based on science and technology that are attractive for the world markets, and in making South Africa a place of choice to do business, effecting the incubation of many small and medium sized enterprises that can grow to successful, sustainable business entities.

1 Introduction

TechnoScene (Pty) Ltd was assigned by the National Advisory Council on Innovation (NACI) to conduct *A Study to Determine the Competitive Aspects of the Required Physical Infrastructure to attain the Vision of the National System for Innovation (NSI)*. This document reports on this study. According to the White Paper on Science and Technology[1] and the NACI Act[2], a national system of innovation can be thought of as a set of functioning institutions, organisations and policies which interact constructively in the pursuit of a common set of social and economic goals and objectives through innovation. A prime objective of the NSI is to enhance the rate and quality of technology transfer and diffusion from the science, engineering and technology (SET) sector by the provision of quality human resources, effective hard technology transfer mechanisms and the creation of more effective and efficient users of technology in the business and governmental sectors.

The vision[3] of NACI states that: "NACI, as the key source of science and technology advice to government, will successfully promote S&T [Science and Technology] as the primary driver behind South Africa's economic and social development". NACI is appointed by the Minister of Science and Technology to advise him (and through him Cabinet) on the role and contribution of innovation (including science and technology) in promoting and achieving national objectives[4], namely to:

1. improve and sustain the quality of life of all South Africans
2. develop human resources for science and technology
3. build the economy
4. strengthen the country's competitiveness in the international sphere

NACI bases its advice to the Minister and Cabinet on evidence-based policy research and to this end it has commissioned this study.

[1] http://www.naci.org.za/pdfs/whitepaper_st.pdf
[2]: National Advisory Council on Innovation Act. No 55 of 1997
[3] http://www.naci.org.za/about/mission.html
[4] http://www.naci.org.za/about/whatis.html

2 Background

Events leading to this investigation of the "Competitive Aspects of the Required Physical Infrastructure to attain the Vision of the National System for Innovation" commenced with the National Research and Technology Audit, which produced a database of research equipment and generated a scenario of the status of that equipment in 1998. The equipment infrastructure for research was characterised as old, not enabling South African researchers to compete effectively internationally. The recommendation from the audit called for a major injection of funds to replace, renew and introduce state of the art equipment, which was to improve the quality of both the research outputs and research skills. Yet, the audit recommendations were based more on research environments and replacement of the research equipment base in the highly industrialised nations of the north, and not on a firm strategy to plan for the future of research support through capital infrastructure based on national priorities.

The National Research and Technology Foresight project (2000) followed the Audit and identified a few areas where South Africa should excel, also in research leadership. These areas were explored further in so-called road mapping exercises and some have led to the development of national strategies, such as the Biotechnology Strategy, Advanced Manufacturing Technology Strategy and Nanotechnology Strategy. These areas, and others have been taken up in the National Research and Development (R&D) Strategy, which in turn constituted the strategic framework within which a National Key Research and Technology Infrastructure Strategy[5] was developed by the NRF in 2004. This strategy mainly addresses equipment at world class level and well-found laboratory level, provides for the preferential acquisition and replacement of equipment in accordance with national priorities and for the funding, management, utilisation and access of such equipment. It does not specify the nature and types of equipment required for the various national priorities.

Despite these strategies and the foresight process, lack of sufficient capital investment caused the research infrastructure base to age at an alarming pace in most disciplines, with the result that researchers find it extremely difficult to stay internationally competitive. Training of human resource capacity with adequate skills, particularly in the natural sciences, engineering and technology has been suffering under the lack of adequate and state-of-the-art equipment, laboratories, facilities and infrastructure (clarity of these terms is given in section 4) for some time now.

This investigation into the research infrastructure needs linked to the national research and development priorities is therefore not only a logical next step following on the above, but also a very timely exercise in view of government's resolve to make substantive investments in the renewal of essential infrastructure of the country.

The purpose of this infrastructure study as defined in the terms of reference compiled by NACI includes:

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[5] http://www.nrf.ac.za/equipment?EquipmentStrategyFinal.pdf

i. To identify the ideal public technology infrastructure (equipment, laboratories and facilities) to support the *technology missions* (information technology, biotechnology, manufacturing technology, beneficiation of natural resources, technologies to enable poverty reduction) identified in the National Research and Development Strategy (NRDS). Important to note is that since 2002 these missions have been sharpened to include subsidiary areas such as energy technologies and nanotechnology. Such identification should be presented as a matrix of infrastructure *vs.* technology missions and indicate the current state and the required state by doing a gap analysis.

ii. To identify the ideal public technology infrastructure to support globally competitive large-scale research in the five areas identified in the NRDS as being well-placed to exploit the principle of 'South Africa's *geographic advantage*', i.e. astronomy and earth observation, indigenous knowledge, biodiversity, palaeontology, and Antarctica and the Southern Ocean and to represent it as a matrix of infrastructure *vs.* geographic advantage missions and indicate the current state and the required state by doing a gap analysis.

iii. To clearly establish how the 'ideal-type' scientific and technological infrastructure should be deployed in order to ensure that all strategically prioritised research has the necessary infrastructure support and that the infrastructure is optimally used. This requires an assessment of current and desired deployment patterns, locations and management systems.

iv. To specify the capacity requirements needed to deploy and productively use the technologies identified. The quality and size of the knowledge base required as well as the capital layout needed over time is addressed in this regard.

v. To indicate how the technological infrastructure will be deployed and managed in order to ensure optimal utilisation of facilities and equipment and the widespread availability of the infrastructure to all potential users. – Refer to (iii)

vi. To determine the gap between the existing scientific and technological infrastructure in South Africa and the 'ideal-type' which is urgently required for crafting a more productive and sustainable NSI in South Africa. This gap is described in terms of: availability of infrastructure; age and state of infrastructure; usage and capacity shortfalls; deployment and geographic spread, relating to access and competitiveness; networking and using the Internet and modern networking technologies for access; level of sharing and national access as well as regional access.

vii. From a technological infrastructure perspective, the raft of government interventions are spelt out that are required to reposition the NSI on a higher, sustainable growth trajectory. This is based on required strategic interventions by the state; phasing of redress of the infrastructure environment; budgets required and promotion of the infrastructure for local and international users.

The outcome of the project should enable NACI to advise government, the Minister of Science and Technology and Cabinet on interventions required to redress the state of physical infrastructure at research institutions that provide R&D for national competitiveness.

3 Methodology and Approach

TechnoScene adopted the following methodology and approach for this investigation :

i. Studied existing strategies, white papers and policies regarding infrastructure issues.
ii. Conducted desk studies, using available literature and the Internet on the situation in other National Systems of Innovation to determine benchmarks for South Africa within context of its policy environment, knowledge resource and economic challenges.
iii. Interviewed selected key individual and groups of stakeholders in the NSI to provide the latest inputs into the infrastructure debate (See section 12.1 – Appendix A)
iv. Did selected site visits to determine which models of infrastructure deployment and usage work and why and which do not.
v. Drew up a scenario of the current state of the physical infrastructure and the desired state.
vi. Compiled a draft report on the required physical infrastructure.
vii. Presented this model in stakeholder workshops in Gauteng and the Western Cape and tested the conclusions and recommendations.
viii. Prepared this report for NACI stating the outcome of the study and recommendations on interventions to address the state of the physical infrastructure for competitive research and development.

The methodology of interviewing experts in the various science and technology missions includes processes of extracting expert opinion in a modified Delphi approach, as well as doing "triangulation" of opinions. In such "triangulation" more than three views are obtained on a similar issue from users approaching the issue from different perspectives and even, in the case of this study, different missions. The synergies and cross sections were then explored. The interviewing process was enriched by model development based on these triangulated opinions and then tested with subsequent interviewees to reinforce or deconstruct the model. Through experience it is found that this approach is much more informative and productive than doing statistical questionnaire based research. Once the preliminary feedback was received from the about 130 individuals interviewed plus another 70 who contributed in mini-workshop style and this information was analysed, the findings were tested again in stakeholder workshops. In the case of this study about 33% of the respondents directly interviewed attended the workshops, as well as a few others who, for various reasons could not be reached during the interview stage.

The information mining via interviews was reinforced by studies that included:

i. Interrogation of current science, technology and innovation policy and strategy documents and the extraction of the parameters of an ideal-type NSI based on international best practice and in context of the National R&D strategy as well as policy and strategy developments since publication of the National R&D Strategy in 2002. This work included apart of the energy and nanotechnologies already referred to above, also the implications for South Africa of the Johannesburg declaration on sustainable development of 2002, the Consolidated Science and Technology Plan of Action approved by the African Ministerial Council on Science and Technology on 30 September 2005, the Millennium Development Goals as well as any other obligations under international treaties and agreements that may impact on the outcome of this investigation. The work further included a study of the Accelerated and Shared Growth Initiative – South Africa (ASGISA).[6] ASGISA refers to the R&D infrastructure in the following way: "Other strategic interventions in the infrastructure arena include further development of the country's research and development infrastructure …" Since R&D infrastructure is also largely applied to the development of skills, the ASGISA reference to skills development is valid: "For both the public infrastructure and the private investment programmes, the single greatest impediment is shortage of skills – including professional skills such as engineers and scientists; managers such as financial, personnel and project managers; and skilled technical employees such as artisans and IT technicians".

ii. In the light of (i) above, the high priority sectors were identified as highlighted in existing policy and strategy documents and focus on the particular infrastructure requirements of these sectors.

iii. Recent national and international equipment and systems surveys were critically analysed, as well as the National Key Research and Technology Infrastructure Strategy developed by the NRF. Competitive research infrastructure was viewed in the broadest possible sense, including research equipment, national and regional facilities, research vessels and stations, collections, databases and knowledge bases, as well as developments in supporting infrastructure such as broadband Internet connectivity in context of National Research and Education networks (NRENs).

In the recommendations made in this report, a general principle was applied of not stating who should own any infrastructural components or where it should be placed. Many of the infrastructural components discussed exist in some form or another and may be affected by reorganising, relocating or restructuring. In some cases it may make sense to add new infrastructural components to existing ones, or to create them in entirely new places. The emphasis is on what the country needs and not the interest of individual institutions or people. In the few cases where deviations occur from this rule, it is because it would be most appropriate in terms of supporting infrastructure that may already exist, or because of the complementary nature of the existing infrastructure at the existing facility.

[6] www.info.gov.za/asgisa/asgisa.pdf

4 Definitions

For the purpose of this study "equipment", "facility," "laboratory" and "infrastructure" are defined as follows:

Equipment: Equipment includes scientific and analytical research and experimental or improvised equipment utilised for education and training, research and development and training through research. Equipment can either be part of a fully integrated system, stand-alone and operationally independent from other equipment, or a component of a stand-alone unit of research equipment. Computerisation of equipment, networking or ICT equipment itself is also included.

Laboratory: A place of learning, experimentation, demonstration or simulation where equipment is used to illustrate or achieve a certain outcome based on knowledge, research or science, technology and engineering practices.

Facility: A conglomerate of equipment, people, skills, knowledge and activities conducting education, training and research that depends closely on equipment, focused on a core aspect of any of the sciences, technology, engineering and humanities. A research facility may thus have a collection of education, training and research equipment of varying nature.

Infrastructure: The combination, in a special context, of all the facilities to provide the base for education or research in a nation. It includes knowledge, people, facilities, equipment, buildings and laboratories, with emphasis of accessibility and state-of-the-art condition in relation to a set of national strategies, aligned to achieve certain visionary outcomes. Infrastructure is contextual and applies to the global, national and regional aspect of the disciplines, science and technology.

Competitiveness: Competitiveness can be seen in a dual context: Firstly making the NSI attractive for foreign direct investment in R&D and for international researchers and post-docs to work in South Africa. Secondly, the NSI could be made competitive by spinning out globally competitive knowledge, products and services from R&D and in creating competitive enterprises from the R&D.

5 International Infrastructure Roadmaps

Several countries have in recent years embarked upon a process of identifying the large infrastructure requirements for the next decade or two. These studies are driven by the recognition of the importance of such facilities for advancements in science and technology, which in turn contribute significantly to economic growth, societal wellbeing and environmental sustainability. Several features are common to all these "roadmap" studies such as:

- The high level prioritisation of infrastructure.
- The recognition that they are snapshots at a given time and that they require regular review because of scientific and technological advances.
- They are based on widely consultative processes.
- They are guidelines to assist governments in planning longer term investments in infrastructure, not commitments. Decisions to invest in any particular infrastructure will be based on detailed motivations and business plans.

5.1 United States - Facilities of the Future of Science[7]

Fully half of the United States (US) economy over the last 50 years is estimated to be due to federal funding of scientific and technological innovation. The US recognises that for researchers to continue making important scientific discoveries that translate into technological spin-offs capable of creating entirely new industries, demands the availability of the most advanced research facilities. This study was therefore conducted by the Department of Energy (DoE) "to ensure that the US retains its primacy in critical areas of science and technology well into the next century."

The study was conducted in consultation with the US scientific community through the Office of Scientific Advisory Committees of the DOE and several other US agencies, including the NSF (National Science Foundation), NIH (National Institute of Health) and NASA (North American Space Agency). It identifies 28 prioritised new scientific facilities and upgrades to existing facilities which scientists will require across all fields of science supported by the DoE. It is a list designed for the planning of future investments in science and selected by the DoE on the basis of two criteria, viz. the scientific significance and their support of the DoE missions. Facilities have furthermore been grouped into near-term, mid-term and far-term categories.

5.2 Research Councils United Kingdom: Large Facilities Roadmap 2005

The United Kingdom (UK) Science and Innovation Framework 2004-2014 provides a framework to ensure that UK researchers have access to world leading scientific facilities. Facilities include national infrastructure and infrastructure shared with other nations, primarily within the European Union (see European Strategy Forum on Research Infrastructures (ESFRI) below). The UK recognises that science is increasingly an international endeavour largely because

[7] Facilities for the Future of Science: A Twenty Year outlook. Office of Science, US Department of Energy, 2003

nations can ill afford to support many advances and technologically complex facilities on their own.

The Large Facilities Roadmap sets out how to maintain access to world class facilities and its priorities in this regard. It contains detail of several large facility and equipment projects to which UK scientists should have access to over the next 20 years and the anticipated requirements to access such facilities. The roadmap will also be used by the Office of Science and Technology and the Research Councils of the UK to take strategic decisions and how to manage and fund investments in priority projects.

Currently the UK spends £ 230 million per annum of public finds on capital expenditure for large facility projects. £ 100 million of this is from the Large Facilities Capital Equipment Fund of the Office of Science and Technology, with the remaining coming from various sources such as other Government Departments, the Research Councils, international partners etc. The cost of large facilities can vary from between £ 25 million and £ 300 million per project.

5.3 The Australian National Collaborative Research Infrastructure Strategy (NCRIS)[8]

The NCRIS was established in response to the Australian governments announcement that it would invest A$ 542 million in research infrastructure over the next five years as part of a package to implement the "Backing Australia's Ability: Building our Future through Science and Technology" strategy.

The process of developing the roadmap was consultative and transparent and involved several steps of consultations, scoping of options, expert advisory committees and wide consultation on an initial draft. Important to note is that the roadmap identifies the capabilities Australia should develop rather than specific infrastructure and that these have been prioritised in accordance with the following principles:

- Investment in research infrastructure should be planned and implemented with the aim of maximising the contribution of the R&D system to economic development, national security, social wellbeing, and environmental sustainability.
- Infrastructure resources should be focused in areas where Australia is, or has the potential to be world class and provides international leadership.
- The research infrastructure should serve the research and innovation system broadly – not just the host institution and should encourage collaboration and co-investment.
- The Infrastructure should be readily accessible to all conducting meritorious research.
- Support should be for the life-span of the infrastructure.
- It should enable fuller participation by Australian researchers at international level.

Through the process 16 priority areas were identified, nine of which are considered as being of high priority for which detailed investment profiles are being developed for funding approval later this year.

[8] Australian Department of Education, Science and Training, February 2006

5.4 The European Strategy Forum of Research Infrastructures (ESFRI)[9]

ESFRI was set up by the European Commission in late 2001 with the purpose of developing a more coordinated approach for policy making regarding research infrastructure in Europe. In order to achieve this, ESFRI decided to prepare a roadmap for research infrastructure in order "to provide an overview of the needs for research infrastructures of pan-European interest" for the next 10 - 20 years. This includes major upgrades and will cover all scientific areas, regardless of possible location. The outcome of the roadmap will be used to facilitate decision-making by member states and by the European Commission. ESFRI will not be prioritising the infrastructure nor will it decide on funding and the location of future infrastructures.

To develop the first roadmap, ESFRI has set up a number of Expert Working Groups, ten in the physical sciences and engineering, three in the biological sciences and medical sciences and two in the social sciences and humanities. The first roadmap is to be completed towards the end of 2006 and will be updated periodically.

5.5 Access by South African Scientists to Large Research Infrastructure Abroad

The view of senior officials in the Department of Science and Technology is that South Africa must grow its research base to be regarded as a serious player in science. This they point out can often only be achieved if South African scientists have access to large infrastructure facilities. The DST sees it as its responsibility to facilitate access to such large research infrastructure facilities and considers the following approaches important in achieving this.

- South Africa as preferred destination for science by strategically locating key infrastructure in South Africa. Examples are SALT (Southern African Large Telescope), the SKA (Square Kilometer Array), as well as South Africa's bid for an International Centre for Biotechnology and Genetic Engineering (ICBGE) to be located in the Western Cape and to develop a major biotechnology hub around such a Centre. It will be important in this regard to continuously scrutinise very closely the roadmap developments referred to above in order to identify in which areas and how South Africa needs to position itself in order to attract such large infrastructure facilities to South Africa.
- Partnership agreements, whereby South Africa obtains access to large infrastructure facilities. Possible examples where access can be negotiated, either separately as is the case between the NRF and CERN, or within the context of existing bilateral agreements, include:
  - Access to synchrotron facilities. Studies show that such big facilities are underutilised worldwide, and there are good indications that under such agreements South African scientists can access this infrastructure free of charge, in some cases by way of research collaborations.
  - The plasma fusion reactor or Mega Amp Spherical Tokamak (MAST) in the UK, which in turn will improve chances to obtain access to the International Thermonuclear Experimental Facility (ITER) to be built in future as a collaborative venture between the EU and Japan in France.

[9] http://cordis.europa.eu/esfri/home.html

  - Connecting to high performance computing GRID technology abroad.
- Arrangements within the context of the above two or independently where access to South African facilities is negotiated in exchange for access to large facilities abroad.
- Ensuring that sufficient resources are available for South Africans to access large facilities abroad by way of mobility grants.

5.6 Research infrastructure within an African context

South Africa is widely seen as a leader and provider in Africa, yet as attractive as it may seem to locate expensive research infrastructure here, this is contrary to the spirit of NEPAD (New Partnership for Africa's Development) to build capacity across Africa. Because of politically sensitivities in this regard, the approach by DST is one of a community of practice, i.e. where the relevant communities in Africa decide on the most appropriate placement of infrastructure. The establishment of Southern African Network for Biosciences (SANBio) at the CSIR was decided on this basis by SADC, as well as the first biotechnology node for Africa at the International Livestock Research Institute (ILRI) in Kenya. The African Laser Centre (ALC) is another example where infrastructure is shared at continental level.

6 Science Infrastructure

6.1 The Science Missions

Before discussing the infrastructure requirements for the various science missions, it is necessary to comment on the science missions as defined in the terms of reference, the big science approach and the policy context within which the science missions have to operate.

6.1.1 Reconceptualising the Science Missions

The terms of reference for this investigation referred to the following five areas as being well placed to exploit the principle of South Africa's geographic advantage for competitiveness:

- Astronomy and Earth Observations
- Indigenous Knowledge
- Biodiversity
- Palaeontology
- Antarctica and Southern Oceans

However, developments since publication of the National Research and Development Strategy necessitated a redefinition of these from a geographical advantage perspective, for the following reasons.

1. Discussions in recent times have placed an increasing emphasis on South Africa and Africa's capacity in Space Science. These discussions have culminated in the recent announcement in Parliament by the Minister of Science and Technology that his department is investigating the establishment of a National Space Agency. In discussions leading to this announcement, R&D activities to be clustered under such a Space Agency include astronomy, space physics and satellite technology.

2. The focus of debates on biodiversity has shifted in recent years from a species approach to an ecosystems approach[10] which emphasises the importance of understanding the functioning of ecosystems in the conservation of biodiversity. Climate change in turn impacts significantly on the functioning of ecosystems and therefore needs to be taken into consideration when considering infrastructure needs linked to biodiversity.

3. Earth Observation has been given due recognition in the NRDS and its clustering together with astronomy was informed by the importance of earth observations from space. Global recognition for the need of a comprehensive and integrated approach to earth observation to assess among others the impact of climate change on sustainable development has given rise to the Global Earth Observation System (GEOS) initiative and the subsequent Global Earth Observation System of Systems (GEOSS) implementation strategy. As a result, Cabinet has

[10] National Biodiversity Strategy and Action Plan, 2005

very recently approved the implementation of a South African Earth Observation System (SAEOS) strategy that will link into GEOSS. In addition, earth observation is defined much more broadly than merely observations from space, so that it is seen as an infrastructural requirement of high priority in its own right in this investigation.

4. Earth Science is included as this has been referred to in the NRDS as another possible area of research that is well placed to exploit South Africa's geographical advantage. South Africa's geology is in many respects unique for reasons that will be briefly touched upon in the appropriate section below.

5. Included under the science mission is a section that deals with "Poverty Reduction and Health", even though this was identified as an integral component of the priority area "science and technology for poverty reduction" under the technology missions in the NRDS. The rationale for this is that the causes of poverty and health need to be fully understood before appropriate technological interventions can be considered. This is recognised in the NRDS where it is stated that "The mission to reduce the impact of poverty needs to deal with the causes of poverty and the impact of poverty on women and the disabled, ..."(p 44) and furthermore lists among others the following which "should form the core of the effort"(p 43):

    - Understanding the social impact of disease.
    - Developing care and support strategies.
    - Understanding the challenges in providing access to prevention and care measures.
    - Developing innovative preventative strategies.
    - Developing novel therapeutic regimes, including the utilisation of indigenous knowledge.

    These are largely social public health issues rather than clinically orientated technologies. Inclusion of "Poverty Reduction and Health" under the science mission was furthermore also informed by the role Indigenous Knowledge can play in this regard, and because poverty and health impact on the bio-resources available particularly to rural communities and *vice versa*.

The following are therefore the science missions as they are dealt with in this investigation:

- *Space Science* including Astronomy, Space Physics and Satellite Technology, with the latter being dealt with under the Technology Missions
- *Biodiversity*, both terrestrial and marine including climate change and oceanography
- *Antarctica, Islands and Southern Oceans*
- *Earth Science*
- *Palaeo-sciences* including Palaeontology, palaeoanthropology, archaeology and palaeoclimatology
- *Poverty Reduction and Health*
- *Indigenous Knowledge*
- *Earth Observations*

From the discussion above, it already becomes evident that one can not view any one of these particular science missions in isolation as each one has in one way or another a bearing on the other. So e.g. will research in Antarctica contribute to our understanding of climate change and its impact on biodiversity, our presence in Antarctica is among others to conduct research in space physics, palaeoclimatology is key in predicting trends in climate change, as is the study of profiles through ice sheets in Antarctica, geological processes determine the preservation of fossils whilst geology is a component of Antarctica, the Islands and as marine geology ties in with the study of our marine environment, etc. These interrelationships, illustrated diagrammatically in Figure 1, indicate that most of the science missions can collectively be referred to as "Earth System Science" from South Africa's geographic advantage perspective.

South Africa's Geographic Advantage from an Earth System Science Perspective

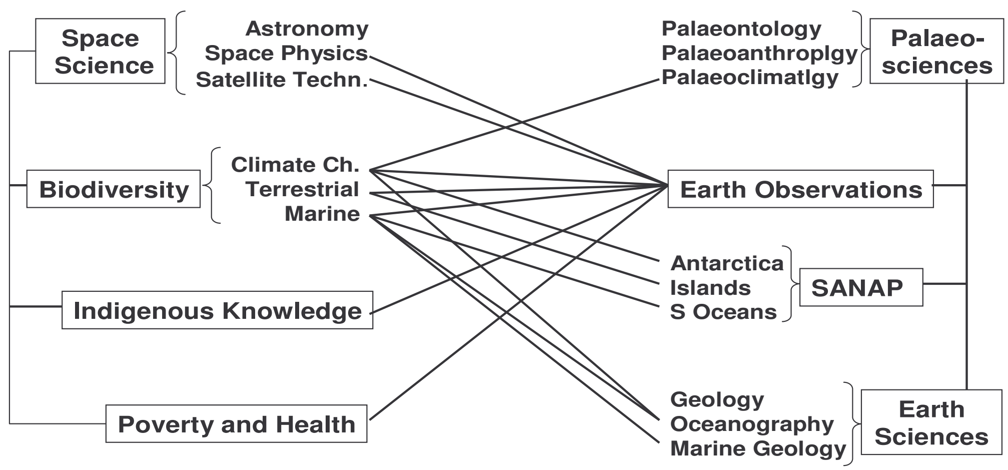

Figure 1: *Interdependency of the Science Missions*

6.1.2 Large scale research *vs.* large scale infrastructure

In the surveys of infrastructure roadmaps for the future of science, emphasis in most instances is placed on big, expensive and complex infrastructure facilities of the kind that is required for revolutionary scientific and technological advances. Large scale infrastructure of this nature is often beyond the capability of any one nation and hence the tendency of several nations to collaboratively enter into ventures of this nature. Developments in recent years have shown that, from a geographic advantage perspective, South Africa can aspire to the placement of big and complex research infrastructure, such as is for instance the case of SALT and the SKA, and that South Africa also has the capabilities to proactively position itself in this regard, e.g. the construction of the KAT (Karoo Array Telescope) in the case of SKA. Although opportunities for the placement of big infrastructure of this nature in South Africa should continuously be pursued, big infrastructure need not be seen as a prerequisite to conduct big science. The exploitation of South Africa's geographical advantage therefore requires a "big science" approach within the context of nationally affordable infrastructure, but with negotiated access to big infrastructure abroad as and when the need arises. This approach is akin to the Australian road mapping exercise that identified the required infrastructure within the context of the capabilities it should develop.

6.1.3 Policies and Strategies

For the identification of big science themes from the perspective of geographical advantage requires strategic plans for the individual science missions. No such official DST approved strategic plans exist for any one of the science missions, except for the South African Earth Observation Systems Strategy approved by Cabinet recently but for which a strategy document is not as yet in the public domain. It would seem though as if strategic plans are in the process of being compiled for some of the science missions. This is in stark contrast to the technology missions where a number of official strategies exist and which are being implemented and funded in accordance with the needs and opportunities identified in these strategies.

In several instances though, the scientific community has proceeded to conceptualise and implement big science programmes from a geographical advantage perspective in the absence of any official strategies. Prime examples of these are Inkaba ye Africa in the earth sciences and the African Coelacanth Ecosystem Project. In both cases implementation in the absence of a national strategy has resulted in collaboration with partners from the north, among others to access infrastructure, with the result that they have either remained "north" dominated by virtue of their resources or South African researchers have lost opportunities because of the lack of appropriate co-investment by South Africa.

The identification of big science themes from the geographical advantage perspective for the various science missions is beyond the scope of this exercise, suffice it to say that the infrastructure requirements identified here would in all likelihood be required anyway for any such big science themes, had they been identified.

An aspect that will require serious attention in order to conduct internationally competitive research in areas of geographical advantage is that some elements of the science missions have different political "homes". This relates specifically to the roles and responsibilities regarding the DEAT and DST in the funding of research and research infrastructure requirements in biodiversity and in Antarctic and Southern Ocean, as well as the statutory functions of the South African National Biodiversity Institute (SANBI) regarding the conservation and management of our biodiversity.

Another similar problem relates to the extensive natural history collections and associated research and research support staff located in the various national museums, all of which resort under the Department of Arts and Culture (DAC). These collections constitute an important component of the scientific infrastructure for biodiversity and palaeo-sciences research. The natural history collections and research on them do not contribute to the mission of the DAC and hence they do not receive the attention and support from museum management required to properly maintain these collections and to retain a critical mass of staff.

6.2 Space Science

The Space Affairs Act of 1993, makes provision for a South African Council for Space Affairs as a regulatory and policy setting body. It has taken a number of years to implement this act and the Council has only recently been established. Furthermore the Department of Trade and Industry under which the Space Affairs Act resides, has commissioned consultants to draw up a National Space Policy Framework for consideration and on the basis of which a national space policy can be developed by the Department. The work of this commission has drawn on conceptual work done by a National Working Group on Space Science, established in 2003 by the relevant Government Departments. The work by this commission has focussed on high level coordination and organizational aspects of space policy, such as the separation of policy and implementation, as well as the establishment of a Space Agency under which the various space related activities should resort (Figure 2). No comment will be made on these high level policy developments, suffice it to say that the various science activities in the space arena should be operated as a coordinated network of National Facilities.

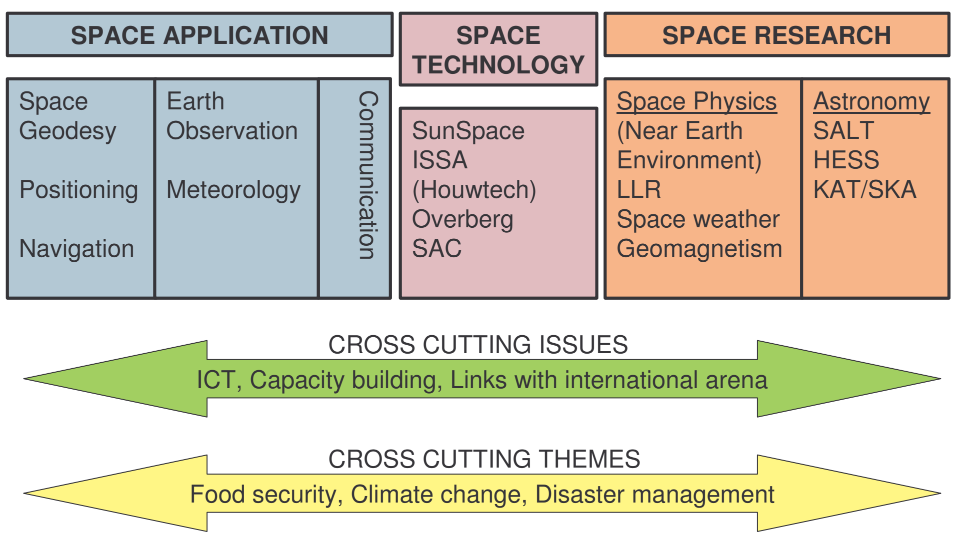

Figure 2: *Space Agency Components*

It is evident from the present state of affairs that little attention has to date been given to the development of a Space Science Strategy which should give direction to what South Africa's activities in space should entail. Over the past few years South African space science has evolved in a somewhat opportunistic way, informed to a large extent by international developments and has resulted in a large variety of activities that span the spectrum from astronomy to space physics to satellite technology and earth observations. We will deal here with the various activities separately, and will comment on integration where appropriate.

6.2.1 Optical Astronomy

From an infrastructural perspective South African science is well served by the recently commissioned SALT and operated on behalf of the SALT consortium by the South African Astronomical Observatory (SAAO). South Africa has a 33 % share in this telescope which, given the data collection capabilities of the instrument is more than enough to meet the needs of South African astronomers and enable them to conduct cutting edge science for many years to come either on their own or in conjunction with SALT and other partners. However to remain internationally competitive with the science SALT is capable of producing, attention must now already be given to ***Second Generation Instrumentation*** on this telescope. Such instrumentation normally takes a minimum of five years to design and build, and in many cases involves research and development of new or improved technologies. SAAO needs to be part of this in order to retain its 33 % share in the SALT and hence requires apart from the capital injection to contribute to the 2nd generation instruments, also the capabilities in its laboratories to conduct research to design and build such instruments. 2nd generation instruments on a 10 m class telescope can cost anything between US$ 5 to 10 million. At an average cost of US$ 8 million and given South Africa's 33 % share in SALT requires a contribution of US$ 2.6 million over a five year period, i.e. US$ 520 000 (close to R4 million at current exchange rate in excess of R 7 per US$) annually. In addition it will be necessary to ensure that SAAO is able to maintain a well found laboratory infrastructure and highly skilled technical staff at an additional estimated cost of about R 1 million annually. Skills required in instrumentation include those of optics design and analysis, mechanical modelling, including finite element analysis/finite element modelling (FEA/FEM), thermal modelling and detector physics. Some skills exist, but there will be a clear need to increase the skills level and number of personnel involved in front-line instrument design and fabrication.

The infrastructure both at SAAO in Cape Town and at Sutherland is such that it is not able and has never been designed to handle an operation of the magnitude of SALT. Initially it was anticipated that the technical support for SALT could be handled to a large extent from SAAO offices in Cape Town. This turns out not to be the case given the intricacies of managing a complex instrument of the size of SALT. Hence, provision needs to be made for accommodation of additional technical support staff at SAAO in Sutherland, in addition to the upgrading and renewal of basic infrastructure, some 30 years old, and the provision of basic services, e.g. water, sanitation and electricity.

On the other hand, the ***IT infrastructure at the SAAO*** in Cape Town is totally inadequate to handle SALT and SALT data and data back-up. This requires significant upgrading without which South African scientists will not be able to conduct science equivalent in scale and quality to that of partners abroad and hence not be able to conduct internationally competitive science with the South African share of SALT.

The upgrading of infrastructure at both Sutherland and SAAO in Cape Town requires an urgent capital injection of R 10 million this year (2006/07), with a comparable sum in the following financial year.

6.2.2 Radio-astronomy

The South African government has committed substantial amounts of money for the development of the Karoo Array Telescope, widely regarded as a potential pathfinder (or Phase 1) of the Square Kilometre Array due for construction in 2015 and commissioning by 2020. With this investment South Africa hopes to make a strong claim to hosting the multi-billion SKA in future, as well as other big science infrastructure projects such as a deep space probe contemplated by NASA and the C-Band All Sky Survey, a joint venture initiative of Caltech and universities in the United Kingdom.

The KAT is very much still in a design stage, and a project for South Africa to demonstrate the capacity and skills base for a much larger project such as the SKA. A strategic consideration in building the KAT is that on its completion in 2008 will make Southern Africa with SALT and HESS (High Energy Spectroscopic System in Namibia) the only region in the world with first class observation facilities to engage in a multi-wavelength approach to astronomy.

Available resources of R 300 million from the South African Government and an investment from partners abroad of R 100 million presently being negotiated will allow an array of 20 dishes to be built. However, the sensitivity of the instrument increases significantly as the size of the array increases and the project team is therefore trying to raise further funds from potential partners abroad to build an ***array of up to 40 such dishes***. This is of some importance to ensure that the KAT remains the instrument of choice internationally for cutting edge radio-astronomy until the SKA becomes operative sometime after 2015.

As a brand new development there are no ready made technologies available. This requires KAT to recruiting suitably qualified systems and electronic engineers for cutting edge R&D in developing the new technologies. As such engineers are in short supply, mechanisms are required that will allow optimisation of collateral benefits, but this can only happen if industry and the SKA constitute closely collaborating teams to create the capacity for R&D of the required technologies and their ultimate application. This however poses the danger of KAT running foul of the Public Finance and Management Act (PFMA) if KAT provides any assistance to such concerns in order to build the required capacity that will enable them to bid for a project of this nature. If this problem is not overcome, South Africa will loose out on any opportunities that a SKA or even the NASA Deep Space Probe may present in future.

6.2.3 Cherenkov Telescope Array (HESS 2)

The international consortium for the High Energy Spectroscopic System (HESS) is presently designing the first prototype for HESS 2 which is a dish of 30 metre in diameter. The ultimate aim is to build a ***7 square km array of HESS 2 type dishes*** at a total cost of R 800 million. This has become a high priority project for the international astronomy community, because of the major new insights gained with the HESS 1 array in Namibia.

The HESS consortium is now asking whether South Africa wishes to be part of the HESS 2 initiative. One way to participate would be for an offer from South Africa to pay for the local costs of the construction of the steel framework of this demonstrator. Apparently South Africa does have the capacity to build this construction, and a company MMS in Centurion was mentioned in this regard. Another option would be to make an offer to pay for the construction of the mirrors, which could also be manufactured locally. Either way, the expected investment would be R 6 million to be spent locally. Successful participation has the potential for South Africa to become a preferred supplier when the HESS 2 array is rolled out in 5 to 10 years time and to stand a chance of earning a significant slice of the estimated R 800 million to be spent on this project. South Africa will however be expected to make another contribution then.

South Africa presently has three scientists participating in HESS. Participation costs of about R100 000 per scientist/PhD student are presently not covered in the DST grant. Ideally such costs should be seen as part of the participation (running) costs in future.

CNRS seems keen to partner South Africa both regarding HESS and KAT science.

6.2.4 Human Resource Capacity in Astronomy

The three top class astronomy facilities HESS, SALT and KAT (and later stage possibly also the SKA) unfolding in Southern Africa presents a unique opportunity for a multi-wavelength approach to astronomy. This is an opportunity not to be missed and we urgently need to build the local capacity and capabilities, including student training very rapidly in order to derive optimal benefits from this advantage. The local astronomy community has recognised this and developed an ambitious Astronomy Frontiers Programme which was submitted to the DST for consideration. One of the key elements of this programme is the continued funding of the National Astronomy and Space Science Programme (NASSP), a programme with emphasis on the training of post-graduate students.

In the absence of an Astronomy strategy it is recommended that:

- The Astronomy Frontiers Programme which contains many strategic elements be recast as a matter of urgency into an Astronomy Strategy for South Africa. Such a strategy should make provision for the establishment of a limited number of Research Chairs that focus in particular on the multi-wavelength approach to astronomy.
- The DST makes available and amount of R 2.5 million annually as bridging finance to ensure continuation of the NASSP programme until such time as an Astronomy Strategy has been approved and is being funded.

6.2.5 Space Geodesy

The science of Space Geodesy is changing very rapidly and for South Africa to retain its strategic position in the Southern Hemisphere as an important component of an international network of geodetic facilities it will need to make some investments in the renewal of infrastructure over the next few years.

6.2.5.1 Very Long Baseline Interferometry (VLBI)

For VLBI the move is towards ***smaller dedicated antennas*** between 10-12 m in diameter, capable of observing over a continuous frequency range of up to 34 GHz. Once these smaller units become operational globally, the existing dish and wavelength limitations at HartRAO will no longer meet the requirements of an international network. This infrastructure renewal programme is spearheaded by the Global Geodetic Observation System (GGOS), a project of IAG (International Association of Geodesy). The technology for such smaller antennas is still under development, but possibility of building a high frequency version of the KAT that uses the same design principles needs to be investigated. Estimated cost of such a telescope is R 10 million, with a cluster of 4 such telescopes being an ideal configuration. It is planned to have the first of these types of telescopes in operation by 2010.

6.2.5.2 Satellite Laser Ranging (SLR)

SLR stations are moving towards faster sampling rates and higher accuracies. This is technology driven by NASA who plans to replace the MOBLAS (Mobilisation Level Application Software) instruments with more ***automated SLR2000 instruments***. These are still under development and will be less operator intensive, but would still require technical support for alignment, calibration and maintenance. 12 of these instruments will be deployed, one of which in South Africa.

6.2.5.3 Lunar Laser Ranging (LLR)

Two such instruments are presently operational in the northern hemisphere and the LLR community is very keen to see such a facility be established in South Africa. This would greatly enhance accuracy of information relevant to a variety of fundamental questions in physics, such as gravitational forces in the solar system.

The French have agreed to provide on a long term basis a 1 meter diameter telescope which could readily be converted into a ***LLR***. The telescope frame has an estimated value of R 10 million, but the conversion process would take about five years and cost an estimated R 22 million. The technology involved is such that this could be designed and installed locally, amongst others also by involving postgraduate students (akin to the Sunspace group at the University of Stellenbosch).

6.2.5.4 Global Positioning System (GPS) receivers

Several additional ***dual frequency GPS receivers*** are required across southern Africa for this region to have a sound geodetic reference system on which to base its geospacial information requirements. Presently only two GPS systems provide real-time data (Sutherland and HartRAO), with six others deployed on Marion, at Richards Bay and Simonstown (linked to tidal gauges) and one each in Zambia, Mozambique and Botswana. At least another six GPS receivers are required for an appropriate network in the SADC region with real-time data transmission facilities in order to enhance their value in ionospheric research and for meteorological (weather forecasting) services. The estimated cost of six such receivers is R 1.5 million.

6.2.5.5 Future location of a Geodesy Station

HartRAO is not a suitable location for the new generation VLBI and SLR/LLR instrumentation, which will require radio silent environment, minimal cloud cover and a reasonable elevation. SAAO has been considered but limited infrastructure, e.g. water and the "intrusion factor" count against this site. An alternative would be at Matjiesfontein where the owner has apparently already agreed to make a site with adequate water available. The establishment of an ***Institute for Space Geodesy and Earth Observation (ISGEO)*** has been proposed for the contemplated activities on the site. The total estimated cost of providing the necessary infrastructure of such an Institute is R 39 million. Running expenses including salaries of research and support staff would be R 6 million annually (up from the ~R 2 million spent presently on geodesy activities at HartRAO).

6.2.6 Space Physics

Space Physics in South Africa comprises a variety of research activities on the near Earth space environment and to a more limited extent also on heliospheric physics. These activities are largely centred on the Hermanus Magnetic Observatory and a number of Physics Departments, notably at the Universities of KwaZulu Natal, Northwest and Rhodes University. Representatives from these and other institutions have gathered recently to develop a big science "Flagship Programme" in Space Physics termed "Ihlabathi: Core to Space" aimed at focussing several of their activities on understanding features of the Earth's geomagnetic field that are unique to the Southern African region. These relate to:

1. the suggestion that a reverse dynamo may be developing beneath the southern tip of Africa, which could be the first manifestations of a long overdue geomagnetic field reversal, and
2. the rapidly weakening of the already weak geomagnetic field over the South Atlantic region generally referred to as the South Atlantic Anomaly (SAA) where the shielding effect of the magnetic field against hazardous solar radiation is greatly reduced.

Space physics, as an observational science, requires various observatory instruments that gather data of natural phenomena over long periods of time. Such data sets provide information to scientists working on a variety of problems, often long after the observations are made. The archiving of data and making it widely available is therefore a crucial aspect of such activity. The observations do not only serve the needs of a single scientist or group, but the needs of scientists in different fields and different institutions. Cutting edge space science, even if it focuses on local phenomena like those identified in the flagship programme referred to above, is often dependent on global coverage and synchronised measurements by various instruments.

Space physics research based on these observations has a direct bearing on:

1. the study of space weather, i.e. the disturbance of the Earth's magnetosphere by strong gusts of solar wind, and its hazards. The latter, although more pronounced in higher latitudes,

causes such disturbances as geomagnetically induced currents in power systems, damage to spacecraft electronics, interference in HF (high frequency) radio waves, etc.

2. Characterisation of the ionosphere such as the total electron content which adversely affects the radio signals observed by radio telescopes, and ionospheric disturbances which cause scintillations in radio signals, both of which are important in the planning and operation of the KAT and SKA projects.

Additional infrastructure requirements to undertake cutting edge research in space physics and enable South African researchers to be internationally competitive include the following:

6.2.6.1 Low latitude HF Radar

A ***low latitude HF radar*** which incorporates a steerable system with multiple fields of view from the chosen site. The fully steerable array is a unique concept that, if proven to work, will no doubt be adopted as standard at future SuperDARN (Super Dual Auroral Radar Network) stations internationally (see section 6.4.2). This steerability will allow the radar's field of view to be pointed west towards the South Atlantic Anomaly, south to add to the current auroral region studies or even north for an analysis of the equatorial electrojet. To this end it is important that the site be located in the western part of South Africa due to its proximity to the SAA as well as allowing north and south pointing ability. The site should have broadband internet access to allow the real-time analysis of data and the incorporation into the current SuperDARN real-time data system. A suitable site on the premises of the SAAO at Sutherland has been provisionally identified.

Total estimated construction and installation cost: R 3 million

6.2.6.2 Ionosonde

A network of three ionosondes[11] is currently operated in South Africa. These are the only ionosondes in Africa with continuously processed data and remote access. All three are owned by the SANDF, maintained by Grintek Ewation, while HMO is responsible for the data collection, quality control, archiving, and distribution. The data provide a valuable archive depicting ionospheric behaviour that is highly valued internationally, since they partially fill the large gap in ionospheric data coverage over Africa and surrounding oceans. However, a shortcoming of the network is that the area coverage of the three existing ionosondes does not extend south into the Western Cape. A further shortcoming is that the SANDF and Grintek Ewation do not permit the ionosondes to be operated in special modes, which are required from time to time for research purposes. The data also play an important role for the validation and calibration of the GPS-derived total electron count (TEC) and electron density profiles. A ***research ionosonde*** in the form of a Digisonde DPS-4, therefore needs to be acquired as part of the *Ihlabathi: Core to Space* flagship project, and installed at the HMO, close to the southern-most point of Africa. Total cost: R 1.6 million

[11] The traditional technique for measuring the properties of the ionosphere by transmission and reception of vertically incident radio pulses at swept frequencies in the HF range

6.2.6.3 Dual frequency GPS receivers

The dual-frequency GPS receivers permit local real-time ionospheric mapping of the total electron content and the derivation of electron density profiles. New algorithms are also being developed for combining ground based GPS dual frequency receiver data and ionosonde data with occultation data, which would be obtained from signals between GPS satellites and GPS receivers on board Low Earth Orbiting (LEO) satellites, such as CHAMP and ZASat (the proposed South African satellite). This will provide an unrivalled opportunity to integrate observations from these ground and space-based systems to investigate the solar-terrestrial coupling processes, specifically relating to the SAA. There are hardly any ground-based GPS receivers spanning the South Atlantic region. Suitably equipped GPS receivers on the islands in the South Atlantic region, such as Marion, Tristan da Cunha, Gough and Bouvet, could partly address this shortcoming. Ideally, to improve coverage considerably, a limited number of anchored buoys should be deployed in the shallower parts of the mid-oceanic ridges of the Southern Atlantic. Although expensive, such anchored buoys equipped with appropriate instrumentation could also serve a number of other purposes, such as meteorologists (South African Weather Services) and oceanographers. In addition, a dual frequency GPS receiver should be a permanent fixture on board the SA Agulhas and its successor vessel, to collect GPS data for ionospheric characterisation during its voyages to Antarctica and to Gough and Marion Islands.

Cost estimates of a ***dual beam GPS receiver network*** covering the South Atlantic would be R 31.25 million, made up as follows:

- Five ground based dual beam GPS receivers (Islands and Agulhas) @ R 250 000 each or R 1.25 million
- Five multi purpose anchored buoys, including dual beam GPS receivers @ R 6 million each or R 30 million

6.2.6.4 Smaller instrumentation

Additional smaller instrumentation required for the kind of cutting edge research envisaged amongst others in the “Flagship Programme” referred to above includes a ***low-latitude meridian chain of induction magnetometers and an omnipal receiver network***.

Total estimated costs: R 0.75 million

6.2.6.5 Physical space requirements

The expanded space physics activities at the HMO will require upgrading of some existing laboratories and some additional office space for researchers and research students at an estimated cost of R 1 million.

6.2.7 Satellite Application Centre (SAC)

The SAC at present has two strategic functions, viz.

- Data capture, manipulation and storage of satellite based imagery which it makes available to government, industry and researchers.
- Telemetry, tracking and command (TT&C), primarily in support of launching and tracking satellites for satellite owners.

A third function, dealt with research based applications development, e.g. the development (software) of automated methodologies, for the provision of information for decision making was transferred to the Meraka Institute recently, whereas any R&D for commercial applications is now being handled by Knowledge Services of the CSIR.

Its present operational budget of R 32 million is largely recovered from the services it provides, i.e. sales of satellite images and the TT&C activities. Many researchers actually reported that they purchase their imagery from abroad because of costs and difficulties to access such data from the SAC.

Incorporation and transformation of a facility like SAC as a National Facility within a Space Agency implies that it will need to provide a service across the entire value chain, i.e. from data acquisition to the supply of useable images. This would require in addition to the present staff also domain specialists, such as e.g. in agriculture, ecology, hydrology, etc. who would select the most appropriate datasets and manipulate them in order to provide the best images to the client for further analysis.

The infrastructure at SAC would also require recapitalisation in two respects:

- Newer earth observation satellites have been designed to collect and store data on board and to download it periodically. The ***new generation smart dishes*** are therefore designed to fulfil a dual purpose, i.e. to download stored data and the tracking of real-time data. The real-time data is essential for disaster management. SAC needs to be gearing up within the next 18 months to install such new dishes and would require a capital expenditure of about R 50 million for this.
- The ***data storage facilities*** require renewal. Data is presently stored on tape which makes the process of accessing such data very tedious for the user. A new data storage facility with sufficient disc capacity is estimated to cost about R 10 million.

SAC could operate as a ***National Facility*** with a core budget from government of about R 18 million annually. With such a grant it could run the infrastructure and provide all the services of a national facility to government departments and the research community. Income from continued TT&C, other contract work and sales of images to the private sector would cover the balance of the operational costs.

The TT&C section of SAC has the basic infrastructure to be readily converted into a mission control centre should South Africa decide to launch its own satellite or for the ARM (African Resource Monitoring) Constellation under discussion with other African partners.

6.3 Biodiversity

A comprehensive National Biodiversity Strategy and Action Plan (2005) was recently completed by the DEAT. This strategy was compiled to some extent in compliance with the Convention on Biological Diversity (CBD) which the South African Government ratified in 1995. The plan highlights South Africa as one of the most biologically diverse countries in the world and although it covers only 2 % of the land surface it is home to nearly 10 % of the world's plant species, 7 % of the world's reptiles, birds and mammals, and 15 % of the known global marine species. About 25 % of the latter species are endemic to South African waters.

In preparation of this strategy, a National Spatial Biodiversity Assessment (NSBA) was undertaken. This was the first comprehensive national assessment of the status of our biodiversity at ecosystem level aimed at identifying national priority areas for conservation action. The study identified several terrestrial, river, estuarine and marine ecosystems that are critically endangered, mainly due to changing land use patterns and associated clearing of natural vegetation, the invasion and spread of alien species (closely correlated with human activities) and climate change. These three factors often create synergies that exacerbate and compound the impact on biodiversity.

Several key points inform the strategy and include among others the following:

- The need to mainstream biodiversity throughout the economy, which implies that all sectors that impact on biodiversity need to factor biodiversity considerations into their policies, plans and programmes.
- The recognition of the value and importance of biodiversity to the livelihoods of people and the need to integrate biodiversity with poverty alleviation strategies.
- The need to identify and deal with the causes of biodiversity loss in order to ensure conservation and sustainable use of biodiversity.
- The need for research as well as continuous monitoring and evaluation programmes to provide information for integrated management systems in support of implementation.
- The existence of a biodiversity related policy and legislative framework which now requires implementation by relevant spheres of government through partnerships and collaborative programmes.

The overall goal of the strategy and action plan is stated as "Conserve and manage terrestrial and aquatic biodiversity to ensure sustainable and equitable benefits to the people of South Africa, now and in the future". The following five strategic objectives have been identified to address this goal:

1. An enabling policy and legislative framework to integrate biodiversity management objectives into the economy.

2. Enhanced institutional efficiency and effectiveness to ensure good governance in the biodiversity sector.
3. Integrated terrestrial and aquatic management across the country to minimize the impacts of threatening processes on biodiversity, enhance ecosystem services and improve social and economic security.
4. Enhanced human development and well-being through sustainable use of biological resources and equitable sharing of benefits.
5. A network of protected areas to conserve a representative sample of biodiversity and to maintain key ecological processes across the landscape and seascape.

For each one of these strategic objectives a comprehensive set of outcomes and activities with associated targets, indicators, lead agencies and partners has been identified. The plan recognises the importance of research in its implementation strategy and that we require the capacity to create the knowledge required for decision-making and implementation processes. Research is addressed in one way or another, either directly or indirectly in all of the five strategic objectives listed above. SANBI is assigned the role of lead agency in all these research and research related endeavours, but with due recognition that research and research capacity and knowledge management in biodiversity vests in various institutions. SANBI's key function is therefore one of co-ordinating the collation and management of biodiversity information, biodiversity research and the knowledge requirements for bioregional planning and monitoring.

Important to note are several references in the implementation section of the plan for the need to develop a national biodiversity research strategy aimed at ensuring that the research programmes fill gaps in knowledge and understanding of biodiversity, that the research supports planning and decision making processes in managing biodiversity in South Africa and that the necessary capacity exists to collate the required biodiversity data at genetic, species and ecosystems levels.

The National Biodiversity Strategy and Action Plan provides an important framework for the conservation of biodiversity and has identified numerous key issues for implementation as well as the different role players that need to be involved in the implementation process. For research, however, a national biodiversity research strategy needs to spell out much more clearly what the roles and responsibilities of the different role players are, not only in terms of research funding and in the provision of the required research infrastructure, but also in terms of conducting the research. As with all the other science missions, the identified research infrastructure requirements are not informed by an official research strategy, but rather by what the research community perceives to be the most important needs in this regard.

In the conceptualisation of the infrastructure requirements for biodiversity research as an identified priority of the NRDS, a concerted effort was made to view biodiversity from an ecosystems perspective rather than from a more narrowly focused species perspective. In addition, issues such as climate change and pollution are also included here because of their significant impact on biodiversity. These are not dealt with under separate sections, but referred to wherever appropriate in the various subheadings below.

6.3.1 Marine Biodiversity (Including Oceanography)

It is not generally appreciated that South Africa is a marine nation. The area of ocean under the jurisdiction of South Africa is much larger than the land, particularly if the continental shelf areas of the Mozambique Ridge and the Agulhas Plateau beyond the exclusive economic zone are also taken into consideration, for which South Africa is presently preparing a claim in terms of the UN Law of the Sea Convention. Yet when it comes to marine research, South Africa is not making any significant impact on the global scene. Different researchers interviewed gave accounts of foreign research vessels that enter into South African waters, conduct research and leave again with all their research results.

Locally, comparatively little marine research is being conducted at depths greater than about 40 meters, i.e. the depth normal diving equipment allows, because costs of conducting research increase virtually exponentially as depth increases. Although this is also reflected in the research output, it does not imply that South Africa is not capable of conducting deep offshore work, the quality of which is amply illustrated by the work done by researchers within the Marine and Coastal Management (MCM) division of DEAT and academics on fisheries, by offshore flagship projects such as African Coelacanth Ecosystems Project (ACEP), the Benguela Current Large Marine Ecosystem Programme (BCLME) and the Antarctic and Southern Ocean programme. However, if understanding of the processes that govern South Africa's near shore and offshore ecosystems are to be understood, then a greater integration of the two is necessary and more needs to be invested in the more costly offshore environment and long-term monitoring. This is largely an infrastructure issue. Also, an ecosystems approach to biodiversity in the marine environment requires a sound understanding of physical oceanography, aspects of which are therefore included in the infrastructure requirements outlined below.

Lines of responsibility of funding research and infrastructure are by no means clearly defined. MCM will pursue and fund their specific mission driven research, i.e. inasmuch as it has a direct bearing on the management of our fisheries resources. It does not see it as its responsibility to support research for the broader public good, which should be the responsibility of the DST. Presently the latter is being supported by way of competitive grant funding through the NRF Conservation and Management of Ecosystems and Biodiversity focus area programme. This programme does however not have the resources to cover expensive infrastructural items such as ships time and fuel costs, instrumentation for oceanographic and marine geological research, or submersibles. However, if a marine ecosystems approach is adopted then research that aims to understand the functioning of such ecosystems and the influence of climate change, is by definition also of interest to MCM in managing the fisheries resources, as well as to the broader scientific community. The way to resolve this would be by way of an overarching policy agreed upon between the DEAT and the DST which dictates that multidisciplinary research with a marine ecosystems approach should be strategy driven, i.e. the strategy should define the research needs and tasks, the cost implications and the respective financing responsibilities up front. The policy should also dictate how these strategies should be developed, who will be involved in developing them and who will take responsibility for their implementation. Situations should be avoided to create steering committees that do not have any decision making powers.

Over the years there have been big research efforts regarding the west coast because of its importance to the fisheries industry. In comparison very little is known and understood about the marine ecosystems of the east coast and the south coast. Moves are now afoot to develop a national research strategy for the east coast and to increase the research support from DST on the basis of such a strategy. The idea is that the South African leg of ACEP be incorporated into such a broader strategy. The terms of reference for such a strategy are apparently being drafted and a facilitator needs to be identified now to run a national workshop and to develop such a strategy.

A strength of the marine sciences in South Africa is that the research community is well organised under the South African Network for Coastal and Oceanic Research (SANCOR). As such it has contributed to cutting-edge marine science for many years through two successive national Sea and Coast programmes with the support of funding from both the DEAT through MCM and the NRF and its predecessor the FRD. SANCOR has recently critically reassessed its approach to research and developed a new research programme referred to as the Society, Ecosystems and Change Programme (SEAChange). This programme firstly recognises the important place of humans in dynamic marine ecosystems, secondly, the need to shift to an ecosystems approach and thirdly, the fact that both the natural environment and societal processes are changing at an unprecedented rate. SEAChange has been conceptualised as a high quality programme characterised among others by the following:

- Greater cohesion and more focus than the former Sea and Coast programmes.
- A 'big science' approach with a limited number of umbrella themes.
- Multi-disciplinarity and inclusiveness to cater for the social sciences and humanities.
- Alignment with and complementary to policies and objectives of relevant government entities.
- Collaboration within the context of regional programmes such as the Benguela Current Large Marine Ecosystem Programme (BCLME), the African Coelacanth Ecosystems Programme (ACEP), the Agulhas Somali Current Large Marine Ecosystem Programme (ASCLME), and the South West Indian Ocean Fisheries Project (SWIOFP).

Four themes listed in Table 1 are proposed for the SEAChange Programme, three of which embrace ecosystems as the central focus.

The SEAChange programme is highlighted here as it embraces many elements of a research strategy for marine research in South Africa. The proposed programme also served as point of departure for identifying the infrastructure requirements in the discussions with the SANCOR community.

Table 1: *Themes for SEAChange Programme*

Ecosystems & Change	Temporal and spatial changes in marine ecosystems, including climate change and variability, biogeographic studies, etc.
Ecosystems & Society	Interactions between ecosystems (and their components) and societal processes, including human activities and development in the coastal environment, such as tourism and marine aquaculture, governance and compliance etc
Ecosystem Functioning	Ecosystem structure and functioning, and factors influencing ecosystem dynamics, including biodiversity, conservation, ecology, etc.
Biotechnology	Development of new and improved technologies, including genetics, marine aquaculture, bio-prospecting, etc.

6.3.1.1 Research Vessels

Southern Ocean

The research community enthusiastically welcomes the prospect of ***replacement of the SA Agulhas*** with a new and modern research and supply vessel with icebreaker capabilities, as well as the desire by MCM of the DEAT to involve the science community in identifying the research infrastructure requirements such as laboratory space and equipment on the new vessel (See section 6.4.1 under Antarctica and the Southern Ocean for further details).

The problem in doing Southern Ocean research though is the lack of ship time. The Agulhas travels to SANAE and Marion once a year, always very much the same time every year and essentially follows the same route. This is of little use for marine and oceanographic research and hence researchers have to rely very heavily on foreign vessels and then fit into schedules of such vessels for their research. This is too opportunistic an approach and will not lead to a sustained, internationally competitive big science approach to oceanographic research.

What is required is a dedicated supply and research vessel for the Antarctic and Southern Oceans such as the contemplated Agulhas replacement vessel but available for much longer periods of time for oceanographic research.

Near shore research

MCM operates a fleet of three smaller vessels, the R.S. *Algoa*, the R.S. *Africana* and the M/V *Sardinops*. The latter is being replaced in mid 2007 by a new ***near shore research vessel*** at a cost of R 110 million. These vessels are used most of the time by MCM for mission driven surveys and research, but are also made available to others, mostly for three regional Global Environment Fund (GEF) supported programmes, *viz*:

- The Agulhas-Somali Large Marine Ecosystem Programme (ASCLME)
- The South Western Indian Ocean Fisheries Programme (SWIOFP)
- The Benguela Current Large Marine Ecosystem Programme (BCLME) and the linked Benguela Environment Fisheries Interaction and Training Programme (BENEFIT)

In addition to the above, these vessels are also made available, time permitting, for non-MCM research at no cost, except for the fuel for which the research programme is required to pay. For the next few years MCM has budgeted for the availability of these vessels to be at least 100 days per year in total. What will complicate this arrangement in future is that the Norwegian research vessel the *Dr Fridtjof Nansen*, which serviced the three big regional GEF programmes referred to above, will in future be redeployed and therefore no longer be available to the region.

From the above and the feedback from the research community, the available ship time is totally inadequate for the requirements of the research community. The research agenda is to a large extent determined by the availability of vessels from MCM and not by the scientific considerations such as seasons and duration of surveys to obtain scientifically sound data. Serious consideration therefore needs to be given to the acquisition of a dedicated near shore research vessel with some deeper ocean capabilities. Such a vessel, DP (dynamic positioning) rated and with capabilities to handle submersibles, would be ideal and would enable many of the activities envisaged in the SEAChange programme.

No assessment has been made of the cost of such a dedicated research vessel. However, if the replacement cost of the *Sardinops* is considered together with handling capacity of a submersible and other research infrastructure, an estimate of R 150 million for such a dedicated vessel does not seem inappropriate, together with an annual expense of R 20 million for operational costs. Such a research vessel should be seen, together with the replacement research vessel of the Agulhas and submersibles (see below), as part of the large research infrastructure of the country and managed as a national research facility by an agency whose primary object is research (see also section 6.4.4 below).

Both the research vessels should, amongst others, be equipped with operational CTD (Conductivity-Temperature-Depth) recorder instrumentation and auto-analysers of sea samples for inorganic and organic substances (nutrients) capable of taking measurements to depths of at least 2000 m. CTD instruments measure the conductivity, temperature, depth, salinity, oxygen, etc. continuously as the instrument is lowered and raised from ships.

Serious consideration needs to be given within a regional context regarding the withdrawal of the Norwegian research vessel the *Dr Fridtjof Nansen*, as the availability of the MCM vessels is totally inadequate the meet the needs of these programmes. It is therefore proposed that a new ***research vessel for Regional GEF programmes*** is acquired for the region for which South Africa makes a financial contribution of 50 % with the remaining funds being provided by the participating countries or by aid agencies on their behalf. Such a vessel could be operated on behalf of the region by the same agency responsible for the other research vessels. The 50 % contribution to the cost of a research vessel with capabilities akin to the *Dr Fridtjof Nansen* would be R 150 million, plus a pro rata contribution to the operating expenses of such a vessel of about R 15 million annually.

Submersible

A ***manned submersible*** is the only option for South Africa at this stage. ***Remotely Operated Vehicles (ROV)*** that are capable of doing similar work are extremely expensive, whereas cheaper versions, although suitable for routine exploration work, can not do many of the required tasks that can be undertaken with a submersible. Ideally for a research programme such as ACEP would be a combination of a manned submersible with ROVs, which could also be used for rescue operations if required. The range of costs is huge depending on what instrumentation is being placed on them, the depth to which they are to operate and other capabilities. For South Africa's initial needs a submersible of about R 10 million with additions from overseas partners and the private sector would be acceptable. An adequate ROV would cost an estimated R 6 million. Although much cheaper versions are available, they are cheaper in every sense but a risk for professional work and as a backup to the submersible. Provision of about R2 million for operational costs of the submersibles will be required.

In order to launch a ROV from a ship requires Dynamic Positioning (DP) System facilities. None of the South African vessels have such a facility. Also, the launch of submersibles from the Algoa can not be done during high swells because of the construction of the hoist. A hydraulically operated mobile A-frame is far superior to a crane for launching and recovering submersibles. A dedicated research vessel with such facilities has already been referred to above.

6.3.1.2 Research Instrumentation

In order to conduct meaningful oceanographic research over the vast expanse of ocean and the extent of our coastline under jurisdiction requires a substantive investment in several types of instrumentation to record on a continuous basis several physical and biological parameters. This will require some advanced data capture and transmission technologies, such as for real time data or alternatively the submission of batches of data at short intervals.

Data logging and listening devices

South Africa is a partner on a global funding proposal that aims to establish monitoring ***arrays of data-logging devices*** around the world. Such data-logging devices monitor physical oceanographic features as well as the movements and migrations of tagged animals (fish, birds, dolphins, sharks, whales etc.). The prototype of the new data-logging and listening device consists of an acoustic receiver (to log the presence or absence of tagged animals), a suite of sensors (to measure oceanographic data) and an acoustic modem (to "dial-up" and retrieve stored data).

The global programme hinges on the success of the CoML (Census of Marine Life) funded project called POST (Pacific Ocean and Shelf Tracking project) undertaken on the west coast of North America. The main advantage of being a partner in such a global project is that South Africa will benefit from the technology that is being developed and, if the funding proposal is successful, will supply the country with some of these units to set up one or two listening arrays. It will be the responsibility of South Africa to deploy the instruments, tag the animals and download the data.

A permanent continental scale array of at least 10 to 15 such data logging lines of several instruments each deployed perpendicularly along the coastline of South Africa to constitute a network of data logging and listening arrays would be ideal. The deployment of the instruments will require dedicated ship time, but downloading of data can be done from a large ski-boat. It would furthermore require the tagging of large number of fish species which in itself would be a costly exercise.

Acoustic Doppler Current Profiler (ADCP)

An ***Acoustic Doppler Current Profiler (ADCP)*** measures the direction, speed and changes in currents in the water. A variety of different configurations exist. The bottom placed version is anchored to the sea floor and requires an acoustic releaser to bring equipment to the surface. At the moment there are very few, perhaps 7, of such instruments along the east coast. It is considered that deployment of 50 of such instruments along the entire coastline will provide meaningful data of sea current variations. Estimated cost per instrument is about R 2 million to R 3 million for the deep set versions. Those set in shallow water are cheaper. The deeper they are set, the more expensive they are to withstand pressure and to ensure that they receive signals from the surface.

Moored Buoys

Moored buoys provide ideal platforms for the placement and suspension of a variety of equipment to provide data on various physical and biological aspects of the ocean. In addition to sensors on the ocean surface, sensors could be placed at various depths down the mooring rope to record information. Bursts of data are normally sent at regular intervals via satellite using existing channels available to the GEOS. These types of buoys are very expensive though, in the order of R 6 million each, depending on the instrumentation and could only be placed in areas where the ocean was comparatively shallow, e.g. the Mid-Atlantic Ridge and on sea mounts. Such buoys would require annual maintenance service and to replace batteries.

In view of the strategic importance of the location of the Southern Ocean to the southwest of South Africa from the perspective of weather forecasts and the South Atlantic Magnetic Anomaly, the deployment of five such buoys in this area at a total cost of R 36 million should be seriously considered. Such buoys should apart from hosting standard items of equipment to monitor physical and biological aspects of the ocean, also be equipped with magnetometers and with dual frequency GPS receivers for ionospheric research.

Because of the expense involved in their manufacture, maintenance and the satellite transmission of data, a regional approach with partners such as NOAA (National Oceanic and Atmospheric Administration), GOOS (Global Ocean Observing System), IOGOOS (Indian Ocean Global Ocean Observing System), IOC (Intergovernmental Oceanographic Commission) and others may create economies of scale if South Africa partners in regional programmes.

Profiling drifters submerge and pop up again and measure temperature and salinity vertically. They provide critical information for climate change. These provide data into the global pool of information, to which South Africans has access.

6.3.1.3 Modelling capacity

South Africa has been leading marine research from the ecosystems perspective, but the country is rapidly loosing capacity in this regard. Considerably more capacity is required in the ***modelling of ecosystems*** which, with the impact of climate change, is becoming of increasing importance. This is to some extent addressed in the new marine science programme SEAChange of SANCOR, but will only become meaningful if sufficient instrumentation such as data logging devices in several arrays around the coastline, additional ACDP equipment, as well as the tagging and satellite tracking of animals are deployed to capture the data required for such modelling.

A call was made for the need of an integrated network for data capture and management as part of conceptualising the SEAChange programme, rather than several individual networks that will be difficult to link at a later stage. Such an integrated network should be designed for future expansion. The newly established SAEON node at SAIAB (South African Institute for Aquatic Biodiversity) in Grahamstown should be enabled to provide such data capture and management as well as modelling support.

6.3.1.4 Marine Aquaculture

The need was expressed for a ***National Marine Aquaculture Research Facility*** similar to one that exists at Eilat in Israel. Presently a number of small makeshift and totally inappropriate facilities exist at universities. Unless a substantive facility is available South Africa will never exploit the potential of the sustainable commercial exploitation of its marine resources. Such a facility would undertake public good research with a focus on nutritional and genetic aspects of candidate species for commercialisation and also development work up to the commercialisation stage. Its responsibility would therefore be primarily to develop new technologies in marine aquaculture together with universities. Such facilities would also be ideal for experiments to study fish under controlled conditions.

There seems scope for industry and the state to jointly fund such a facility and the research. As a facility it should be operated independently from the fisheries authorities, hence preferentially with DST the government sponsor, but with input from MCM. Total estimated cost to construct such a facility would be about R 50 million with R 7.5 million annual support staff and operating costs

The existing MCM facilities at Sea Point are also not big enough for this purpose. Because they are underutilised, they could be useful to study very specific aspects, such as e.g. special diseases.

6.3.2 Terrestrial Biodiversity

Terrestrial biodiversity is the subject of research of a large and diverse cohort of researchers in all institutions of Higher Education, several Science Councils, government research laboratories particularly SANBI, three National Research Facilities of the NRF, national, provincial and municipal museums, national and provincial parks, and NGOs (non-governmental organisations). These pursue an array of different interest such as classical descriptive taxonomy, molecular biology, genetics, conservation management, wildlife medicine, behavioural science, etc. All these varied activities are either pursued by virtue of personal vested interests in specific subjects, or they are mission driven by the institutions concerned, or they are undertaken in compliance with international treaties and agreements.

As indicated earlier, the National Spatial Biodiversity Assessment has identified several terrestrial, river, estuarine and marine ecosystems to be severely threatened by human activity, invasive species and climate change. Such areas are by implication earmarked as priority areas for conservation in the National Biodiversity Strategy and Action Plan. In addition three globally recognised biodiversity hotspots, defined as areas of high concentration of biodiversity which are under serious threat have been identified in South Africa, *viz.* the Cape Floral Kingdom, the Succulent Karoo biome and the Maputoland – Pondoland – Albany centre of endemism.

The likely impact of climate change on biodiversity and ecosystem services should be of major concern to South Africa. Little is known about how different biomes will be affected by climate change and how these will interact with resultant disturbances such as fire and invasive species. Large scale field experiments have not been conducted in the Southern Hemisphere to understand these issues. Most recent reviews on environmental change note that little is known about likely responses to climate change in the South, but they are expected to be different to those in the North because the dynamics are controlled more by water-temperature-fire interactions than by temperature or temperature-fire interactions alone. Predictions for the South are largely inferred from the northern dominated modelling of actual and experimental data. Large scale field experiments are of essence in testing their validity, in understanding the effects of climate change and to devise mitigating and adaptation interventions for sustainable development. Partnerships with other countries of the South, particularly Australia and Brazil would be important in this regard.

6.3.2.1 Observation and Research Sites

SAEON/LTER Sites

Given the state of affairs regarding endangered ecosystems and the impact of climate change referred to above, many researchers have commented on the necessity to strategically locate ***Long Term Ecological Research (LTER) facilities*** akin to the Gobabeb station in Namibia in South Africa. Although all researchers are very supportive of the objectives of the South African Environmental Observation Network (SAEON), established to collect longitudinal datasets in various biomes across the country for research and to inform policy decisions, many are of the opinion that this falls short of what is urgently required today. Consequently there is strong support for upgrading a select number of the SAEON nodes to LTER sites or even create some LTER sites in addition to the SEAON nodes. Regarding the latter reference was made to a number of catchment research sites such as e.g. at Jonkershoek and at Cathedral Peak in the KwaZulu-Natal Drakensberg where valuable data was recorded for many years, but which were closed in the middle nineties because of lack of funds. Such LTER sites should provide basic laboratory infrastructure and accommodation for visiting scientists, in addition to some specialised equipment for data collection such as flux towers and instrumentation for eco-physiological research.

Infrastructure required would entail the establishment of five LTER sites at R 7 million per site plus R 1.5 million per site for support staff and running expenses, i.e. R 35 million in total for infrastructure and R 7.5 million annually for recurring costs. In addition, SAEON nodes not selected as LTER sites would also require some additional instrumentation referred to above at R 0.8 million per site for en estimated five sites, i.e. R 4 million.

Long-term Experimental Field Sites across South Africa's biomes

By setting up a system of large-scale field experiments under controlled concentrations of varying combinations of moisture, CO_2 and tropospheric ozone (which negates CO_2 effects in many cases) modelled predictions of climate change can be verified and ideas may be formulated of the changes that might continue to happen. Such experimental sites will also allow benchmarking and correction of simulation models, aspects that will require continuous development as more information comes to hand. A network of such experimental sites could readily fit into major programmes of the National System of Innovation such as SAEON or the LTER sites proposed above. These ***FACE-type*** (Free Air Carbon Dioxide Enrichment) manipulations could be done at any ***sites*** though, but the mix of agricultural and conserved landscapes is probably essential. Different approaches could be adopted in different ecosystems. Sections of the landscape could e.g. be isolated to simulate drought conditions or wet conditions over a period of time and monitor the response, e.g. the creation of an artificial moist savannah in an arid savannah environment or vice versa. The infrastructure needs for such experiments would be substantial because this is big science, and the possibility of co-funding of those industries that have a direct interest in reducing the impact of their respective activities on the environment or rehabilitation thereof as a result of mining activities can be pursued in this regard.

The approach would be similar to the integrated instrumented catchments sites presently being designed for long term (up to 10 year) projects with support from industry to understand the impacts of pollutants (i.e. the addition of N and S) on biodiversity and water quality. This requires the deployment of numerous instruments and data-loggers in the field, access to state of the art clean analytical laboratory facilities equipped with Gas Chromatography linked Mass Spectrometers (GC-MS) for the detection of small quantities of N and nitric components, sulphides and sulphates, K isotopes as a trace for the source of pollutants (e.g. biomass burning vs. coal derived), as well as access to higher sensitivity Accelerator Mass Spectroscopy (AMS) techniques.

It is proposed that provision be made initially for four additional instrumented FACE-type field experiments at a capital cost of R 5 million per site and an annual running cost of R 1 million each.

6.3.2.2 An "Ecotron"-type Facility

This is essentially a large set of ***environmentally controlled rooms*** in which one can simultaneously control temperature, humidity, and gas concentrations. The major questions here would be to try to understand experimentally what climate change will mean for plant-animal interactions in South Africa. Predictions are for widespread change, but nobody has as yet seriously studied the interactions between CO_2, temperature and precipitation change and the likely interactive responses. The facility would allow such experiments, and depending on the mix of species it would allow understanding of invasive (both exotics and local species) responses to climate change, responses of ecosystems by bush encroaches and pest-crop interactions. Experiments of this nature to assess future behaviour of species would also be particularly useful where they are based on observed long term trends. Although it would be difficult to provide adequate environments in such a facility, it would allow tests to determine what is likely to happen.

A facility of this nature could also be used to test the response of select organisms to specific regimes, the testing of biological control agents on indigenous and targeted (invasive) species under controlled conditions, and to understand ecological assessment of risk posed by GMOs (genetically modified organisms) under conditions of change. South Africa is moving ahead to explore the question of GM products in a wide variety of arenas and that ecological risk assessment is a question of substantive concern. Such a facility would allow these questions to be addressed.

A facility of this nature consisting of dozens of insulated small laboratories with controllable temperature and atmosphere conditions and recording equipment will be expensive. No costing has been attempted, but it is envisaged that an amount of at least R 100 million will be required, with an annual budget for support staff and running expenses of about R 15 million. Clearly, such a facility will need to operate as a National Research Facility, with a small core research staff working closely with academics in higher education for the design and implementation of the required experiments.

Such a facility could also develop into a hub for a local equivalent of the National Centre for Ecological Analysis and Synthesis in the US, but with a strong focus on southern hemisphere ecosystems. It would be a think-tank with teams of researchers, mainly from countries in the south, coming and going in order to explore the many questions on the impact of climate change and the synthesis of information available in the South.

6.3.2.3 Other National Research Facilities

Research infrastructure at the National Zoological Gardens (NZG)

The proclamation of the National Zoological Gardens of South Africa as a National Research Facility of the NRF on 1 April 2004 implies that research has to become one of its core competencies. The required research competency as a national facility has been identified by way of a comprehensive strategic planning process which identified the NZG's mission as "The leading zoological garden to advance awareness, the creation of knowledge, and innovation in the conservation of Africa's biodiversity for the benefit and well-being of society." Within this context the NZG sees its research function to "Facilitate and undertake high quality research with emphasis on *in situ* conservation that can be addressed in *ex situ* environments."[12] To operate as a National Research Facility, the NZG plans to appoint a small core research staff that will facilitate, conduct and supervise research in areas such as conservation biology, genetics, wildlife medicine and zoo technology, and to convert an existing building on site into a ***NZG Research Centre***. The latter, fully equipped with office space for staff and visiting researchers and research students, as well as laboratory space will cost an estimated R 15 million. Salary costs and running expenses are already factored into operational budget of the NZG.

Airborne Surveys

Several scientists have expressed the need for ***airborne surveys***. These are essential as the resolution of available remote sensing data from space is in many instances not sufficient and airborne data, as an intermediate dataset between ground-based and space observations, is required among others also for calibration and validation purposes. Also, the availability of aircraft would allow for the resumption of airborne census of animal populations in the larger national parks which ceased in the mid nineties because of lack of resources. Recent analysis of such data yielded interesting information on patterns of species abundance and the systematic decline in numbers of some. Such surveys therefore need to continue in order to ascertain whether observed trends have prevailed and the impact of these on the animal species abundance in the parks.

In addition hyper-spectral airborne surveys would be required in order to obtain a complete spectral signature of the objects under surveillance. Such data would e.g. provide information on the protein level of grass, by analysing the appropriate spectral bands. Data of this nature, linked to ground based tracking, would provide valuable information on the function of ecosystems. Satellite imagery is not of the right scale for such observations.

Three aircraft currently owned and operated by South African Weather Services were purchased in the 1970s for cloud seeding and weather modification purposes. This has ceased some years ago, and the aircraft are now used virtually exclusively for atmospheric physics and atmospheric chemistry. This work, mostly done by the Climatology Research Group at the University of the Witwatersrand for the DEAT serves mainly to monitor pollution levels in the atmosphere.

[12] Strategic Plan, National Zoological Gardens of South Africa, 2006, 26p.

Presently the aircraft only operate for two months or so of the year, and could be usefully engaged for various biodiversity and atmospheric science activities referred to above. From discussions with senior officials of the South African Weather Service an approach to operate the aircraft as a national facility would be received very favourably. Maintenance cost of the aircraft and salaries of pilots amounts to about R 2 million annually. As a national facility it would be expected for the three aircraft to undertake several aerial surveys in support of approved research projects at no cost. At a reasonable amount of airtime for public good research of say 200 hours per aircraft per year at R 11 000 per hour would amount to R 6.6 million per year.

Airtime in addition to the 200 hours per aircraft should be generated through contract research programmes sponsored by e.g. Sasol, Eskom and DEAT as well as contract geophysical surveys for e.g. the Council for Geosciences. Guaranteed access to the aircraft for statutory requirements such as pollution monitoring by the DEAT should be safeguarded by way of contractual agreements.

It would be necessary to do some modifications to one of the aircraft in order to equip it with appropriate instrumentation for ecological research such as multi- and hyper-spectral remote sensors. An amount of R 7 million is required for modification and installation of such equipment.

6.3.2.4 Biobanks

On a global scale, the biosciences field has been recognised as the driving force behind one of the next revolutionary waves of scientific and technological advancement. The primary driver behind this revolution is fuelled by an intense industry interest in biotechnology. The impact of this interest has in turn resulted in a dramatic increase in the pressure to apply science to matters of biodiversity protection and conservation. With the growing global market in biomaterials and biodiversity informatics, developing countries, particularly those that are recognised as 'mega-diverse countries', face the enormous challenges of setting up systems to govern access to biodiversity and sustainable utilisation of biodiversity heritage.

Biobanking facilities (gene-banks) and other types of reference collections, as shown in Figure 3 are increasingly becoming a key research infrastructure of countries worldwide to address the above challenges and opportunities. Their importance in the conservation and sustainable utilization of biodiversity has among others been emphasised in the Biodiversity Flagship programme of NEPAD's "Consolidated Plan of Action for Science and Technology", which was adopted for implementation by the Second Ministerial Conference on Science and Technology in Dakar, Senegal in September 2005.

Given the extent of South Africa's wildlife biodiversity, the uncontrolled sampling and export of biomaterials from South Africa and other African countries by researchers of the North and the resultant loss in potentially important biomaterials for research and technology development, there is an urgent need:

- To provide for state of the art infrastructure to preserve our wildlife biomaterial.
- To provide for statutory regulations, policy and procedures in the ownership, utilisation, export and control of such biomaterials.
- To provide for an extended network of regional stakeholders for accessing, processing, banking, using and where necessary distributing (with follow-up tracking) components of biodiversity (biomaterials) to the benefit of all the relevant stakeholders and society.

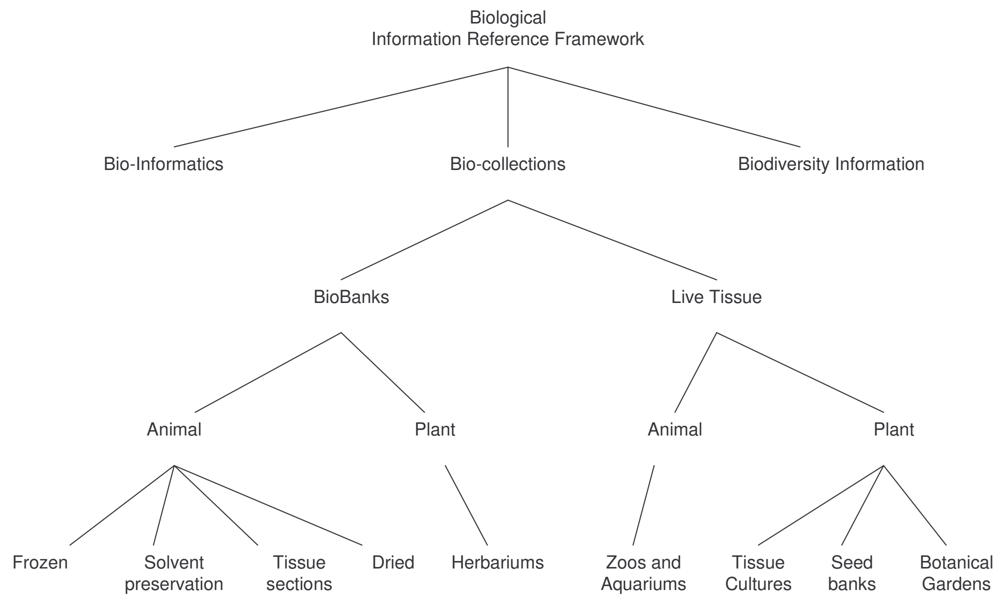

Figure 3: *Reference framework for Biological Information*

Biomaterials are used by a multi-disciplinary community of scientists for research and development on molecular and population genetics, endocrine disruptors, natural reproduction, assisted reproduction technology, disease and epidemiology, pollutants and toxicology, animal physiology, tissue culture, as well as transcending health issues and well-being at the interface between wildlife, domestic livestock and humans.

A state of the art facility for the storage of different biomaterials will require banks of liquid nitrogen tanks for storage at ultra low temperatures (-196°C), walk in freezers, laboratory fridges and freezers, clean laboratories with laminar flow hoods, incubators, various sample and preparation facilities, appropriate safety features and back up electrical supply facilities. Such a facility, with a databank of all the material in storage and links to greater integrative databases of information such as the South African Biodiversity Information Facility (SABIF) of SANBI and the National Bioinformatics Network (NBN), as well as equipment to characterise the material for quality control, research such as a real-time PCR (Polymerase Chain Reaction) machine, DNA sequencer and general laboratory equipment will allow South Africa, and the region, to maintain and grow its competitive advantage in the fast developing biosciences and biotechnology arena.

A facility of this nature should also have the capacity to store and grow live tissue (fungal) cultures for research. Although such a collection will require very different storage techniques as traditional Biobanks, because of cell cultures that need to be maintained, the reason for their preservation, management approach in terms of accessibility, ownership and usage, as well as some laboratory infrastructure requirements are all very similar. Their importance lies among others in the study of plant disease and the potential of mining specific chemicals for technology development and applications. A national storage facility for such collections is required as many of the existing collections have been established by virtue of specific research foci within the institutions and that with change of focus such collections are either poorly maintained or destroyed. Presently such collections exist in a variety of institutions, with the larger ones at FABI (Forestry and Agricultural Biotechnology Institute at the University of Pretoria), CSIR and the MRC. A case in hand is the preservation of the MRC collection[13].

Given the change of focus of institutions referred to above, such collections should not remain the responsibility of the institutions concerned, but rather be supported and managed as a national collection with the required specialised support staff and some expertise on the uses of these collections.

The biobanking facility as envisaged above should, in the spirit of cooperation within the context of the NEPAD Plan of Action which proposes a limited number of regional banking facilities of this nature, also be available to some extent for the banking and safekeeping of wildlife biomaterials from our neighbouring African states who do not as yet have ready access to such a facility in their own respective countries.

The development of a ***National Biobank Facility*** for South Africa's wildlife heritage is still in its infancy, as BioBankSA as a repository of tissue for cryogenic preservation (and other preservation techniques) on behalf of various owners of the tissue, was only initiated by the Wildlife Biological Resources Centre (wBRC) of the Endangered Wildlife Trust a few years ago. With the transfer of the wBRC to the National Zoological Gardens (NZG), now a National Facility of the NRF, the responsibility of managing and preserving biomaterials under the auspices of BioBankSA has also been transferred to the NZG. These samples are presently housed in one of the buildings of the Nuclear Energy Corporation of South Africa (NECSA). The occupancy contract with NECSA extends to the end of 2007. BioBAnkSA is presently supported by way of an annual grant from the DST.

The estimated cost of establishing a first class facility as outlined above would be about R 50 million for a special purpose designed building with specialised laboratory and storage facilities such as freezes, as well as office space and R 2.5 million for equipping the research laboratories. In addition, provision on a recurring basis would be required for technical support staff

[13] Presently being maintained by Dr Wally Marasas who is about to retire

responsible for maintaining and growing the collection, characterisation and quality control of the collected biomaterial, preparation of biomaterial for storage (value enhancing), banking and the day to day running and maintenance of the facility, as well as to assist legitimate users in accessing biomaterials (legalities and physical) in a safe, economical and efficient manner. Salaries as well as running expenses, mostly liquid nitrogen and other preservation material, are estimated initially to be about R 4.5 million annually and growing to R 7 million as the amount of banked material increases. In like vein, a limited number of liquid nitrogen and other freezers would be required initially, which would reduce the initial capital requirements by a few million.

6.3.2.5 Natural History Collections

Museums, their scientists and their collections are the traditional homes for taxonomy and biosystematics research and they have made seminal contributions in terms of documenting South Africa's exceptional zoological biodiversity. The collections and information that resides in museums has and still is providing a foundation upon which downstream zoology and ecology rests and many of the tools upon which zoologists and ecologists rely. The research at museums and their collections are therefore indispensable and as such of incalculable value as one of the primary resources of preserved biological specimens and their associated information.

The last ten years, however, has seen an alarming decline in human capacity within the museum sector, both regarding researchers and collections support staff. This is exacerbated in more recent years by the anomalous situation that fundamental biodiversity research is of no relevance to those structures funding and governing the national museums and who are primarily responsible for service and delivery in arts and culture. Consequently, investment in this sector has received little attention as museums are pressured to devote ever more of their resources to activities linked to arts and culture.

The situation is now reaching crisis proportions. Loss of staff dedicated to these collections is resulting in a steep decline of use and maintenance of the collections, and as use of the collections declines they will no longer be perceived to be of value. This situation jeopardizes the foundations of biodiversity science in the country, as well as the capacity for proper identification of species in the case of biodiversity assessments of many kinds. It is the scientists with vested interest in these collections that make them a useable product through research, outreach and dissemination of the wealth of information contained in them. Hence the scientists, the collections and their support staff need to operate in an environment that has a vested interest in them.

The ***long term storage of the collections*** concerned requires state-of-the-art preservation techniques in stable and clean environments under controlled climatic conditions, as it is key to retain the DNA of the specimens, the importance of which to potential biotechnology applications is becoming more and more explicit. Contamination and degrading of the specimens in these collections must therefore be prevented at all cost. Ongoing and structured systematic attention to revised and refined classification systems and nomenclature, based on modern molecular biological techniques and in identifying genetic lineages through barcoding techniques amongst species is essential, not only in the understanding of the biodiversity but also with regard to potential biotechnology applications.

Given the present state of crisis of these collections in museums, and the statutory mandate of SANBI to establish, manage and control collections of this nature, SANBI is making a case to Government for the establishment of a National Biodiversity Collections Facility (NBCF) over the next MTEF (Medium Term Expenditure Framework) period. Such a centralized facility is intended to fill the gap that presently exists in the national infrastructure for collections management, taxonomy and biosystematics, for the animal, plant and microbial kingdoms. It is intended to provide the effective and necessary preservation and curation environment for those animal and microbial taxa that are not yet provided for in the country's infrastructure or those where it is necessary to transfer collections from satellite facilities to the NBCF. The contemplated facility will be state-of-the-art with laboratories and research equipment all of which will be readily accessible by researchers. All information on the collections will be digitised and linked to SABIF. A Plant Seed Bank will be an integral component of the facility.

The estimated capital cost to establish such a facility consisting of a building with modern storage facilities and laboratories is R 40 million, and an annual expenditure for salaries and running expenses of about R 5 million.

An alternative to centralisation would be the recognition of four National Collections in the museum environment with the National Insect Collection presently housed and supported by the Plant Protection Research Institute of the ARC as a fifth one. The four National Collections would be those presently housed in the National Museum in Bloemfontein, the Natal Museum in Pietermaritzburg, the South African Museum of the Iziko Flagship Museum and the Transvaal Museum of the Northern Flagship Museum. The collections housed by provincial museums such as the Albany Museum and the Port Elisabeth Museum, as well as collections housed in municipal museums such as Durban and East London could become satellite collections of one or the other of the National Collections and thereby and integral part of them.

Such an approach would require a similar capital injection for the upgrade of the collection facilities and annual recurring grants for support staff and running expenses of four such facilities as the national collection facility proposed by SANBI. Critically important under both scenarios would be that the management and ownership of these collections be transferred from the museums which report to the Department of Arts and Culture to a National Facility under the control of either SANBI or another DST funded agency. For reasons already stated above it would be essential to transfer the research staff attached to these collections to the national facility under both scenarios. Provision for this would require an additional annually recurring expenditure, estimated to be R 5 million.

The first priority to pave the way to create the national biodiversity collection facility will require a policy decision that these collections as well as any other natural history collections such as mineralogy, palaeontology, palaeo-anthropology, archaeology and others, are inappropriately located in museums reporting to the Department of Arts and Culture. Ideally, the natural history components of the Flagship museums and the Natal and National Museums, which are primarily still natural history museums should then be transferred under the jurisdiction of the DST. DST would then need to negotiate with the DEAT/SANBI how best to manage the biodiversity components of the collections of such museums and with due recognition of SANBI's statutory mandate in this regard.

6.3.2.6 Specialised Analytical Equipment

High Throughput Genotyping Facility

Every population of living organisms shows genetic variations (single nucleotide polymorphisms [SNPs] and variable number tandem repeats [VNTRs]) that contribute to the phenotypes of individuals (whether plant, animal or micro-organism) which in turn determines their fitness under specific environmental conditions. Currently, medium to high throughput genotyping is only possible through collaborative efforts with researchers in other countries where it is routinely available. The unique biological resources in southern Africa found among its peoples, pathogens, plants and animals provide an ideal opportunity for researchers to study genetic diversity, its evolutionary history and implications. By adopting strategic approaches that contribute to magnifying the view of diversity at the genome level would lead to a better understanding of how this variation contributes to health and states of pathology.

It is not desirable to export DNA samples out of South Africa where they will be accessible to scientists abroad who may have little incentive to continue to involve their African collaborators once they have the DNA in hand. A ***South African genotyping facility*** will offer many advantages including enhancing research quality by providing a platform for highly accurate and reproducible data and the ability to generate large datasets to increase local ability to compete internationally.

The facility is ideally suited for multi-disciplinary genomic studies in areas such as:

- Genetic susceptibility to complex multifactorial disease traits
- Human evolutionary studies
- Zoological preservation and diversity control
- Molecular epidemiology of disease
- Pathogen genetic diversity

Such a facility, consisting of several items of equipment, will require a capital investment of about R 7 million and support staff and running expenses of about R 1million annually. A facility of this nature is best placed in an environment in Higher Education with a strong genetics research capability.

National Light Isotope and Trace Element Facility

A ***National Light Isotope and Trace Element Facility*** is required. Studies of isotopic ratios of various elements in a variety of organic material (live animals, charcoal both modern and ancient, tree rings, N-isotope fixation ratios in plants) have become important tools in recent years for cutting edge science to understand the impact of climate change and to what extent such climate change is human induced. In addition very little is understood about the biosphere/atmosphere interaction and the role of Biogenic Volatile Organic Compounds

(BVOC) in the atmosphere. The rich botanical diversity is a likely source to provide a wide variety of BVOC, but the changes in relative concentration of these brought about by changing land-use patterns and emissions are poorly understood. Studies are required to assess the impact of fluctuating BVOC on air quality and the resulting secondary products such as ozone, undue concentrations of which may impact on plant biodiversity and the generation of greenhouse gasses.

The above types of investigation require access to clean laboratories, very sensitive Gas Chromatography Mass Spectrometer (GC-MS) techniques and Accelerator Mass Spectrometry (AMS) analysis, for the detection of small quantities of N and nitric components, sulphides and sulphates, K isotopes and their source (biomass burning vs., coal derived). In addition very specialised skills are required with a sound understanding of the complicated separation and analytical techniques as well as the atmospheric chemistry involved. Nobody locally has the capacity to separate the compounds concerned and samples are being sent to the USA for analysis.

Part of the analytical infrastructure should be a facility for providing quality analyses of atmospheric samples by supporting the establishment of an internationally accredited laboratory capable of participating in the WMO (World Meteorological Organization) inter-calibration programme. A large component of the required infrastructure and specialised skills in atmospheric chemistry already exists in the Department of Biochemistry at the University of the North-West. To convert this laboratory into an accredited facility would require only a limited investment. Equipment required in addition to existing facility would be two ion chromatography systems of the Dionex ICS 3000 type, auto-samplers and optical carbon analysers at a total capital cost of R 4 million. A contribution to running expenses and support staff to provide an analytical service to researchers would amount to R 1 million.

There are a number of light isotope gas source mass spectrometers for O, N and H stable isotope analyses available in the country, with the one at UCT the only facility in the country linked to silicate extraction lines. These facilities seem to meet the requirements of the research community at present, with additional demand in the near future possibly being taken care of when the AMS facility of iThemba Gauteng comes on stream (see section 6.6.3.2 under Palaeo-sciences for details).

6.3.2.7 Some impediments to conducting terrestrial biodiversity research

Accessibility of species for research

Ever since the promulgation of the *National Environmental Management: Biodiversity Act*, provincial authorities have tightened control measures regarding permits for the collection and transport of species. This legislative environment within which scientists have to operate today is one of the biggest inhibitors of conducting research. This relates primarily to the movement of animal species and the removal of plants and their transport for research purposes across provincial boundaries. Each province has jurisdiction over its biodiversity and the way the law is written makes every scientist guilty of an offence if he/she transports species, be it plant, insect or animal for research across a provincial boundary without the necessary permits. Certain provinces don't seem to allow collecting of invertebrate species at all and it would seem as if some interpret the Biodiversity Act the same for invertebrates and vertebrates. This has become a big frustration, so much so that it has become virtually impossible to do surveys and collect species for research amongst others for adherence to the Convention of Biological Diversity.

Apparently the DEAT is in the process of drafting regulations for a standardised national permitting system that will be applied throughout the country. The provincial systems will then fall away, but the provinces will retain the responsibility of issuing and applying the new procedures. Under such a system the administrative procedures for researchers to collect species in various provinces remains cumbersome. The solution to this clearly lies in SANBI being afforded an accreditation function for bona fide researchers and the issuing of permits to researchers that can be used country wide.

Expense of Fieldwork

Fieldwork, a key element in biodiversity research, is being neglected because research grants are not sufficient to cover such costs. This relates particularly to research in the national and provincial parks and if these are considered the key infrastructure for biodiversity research, then there is a problem regarding access to this infrastructure. However, it is because of the large number of researchers both locally and from abroad wishing to conduct research in the parks that they now are required to pay for services provided. Such services includes rangers which have to accompany researchers in the field and for accommodation which was provided at very reasonable rates in the past, but which has become quite expensive and for which many researchers do not have the financial resources. It needs to be acknowledged though that SANParks does have its own research priorities and where research coincides with these priorities they often provide substantial support, e.g. staff, vehicles and helicopters for catching and tagging animals.

6.4 Antarctica and Southern Ocean

South Africa is one of the founder members of the Antarctic Treaty, which was signed together with 11 other countries in 1959. All original and subsequent signatories of the Treaty have undertaken that the Antarctic Continent and the Southern Ocean will be used for peaceful and scientific purposes only. Subsequently, South Africa became a party to various other conventions, treaties and agreements pertaining to Antarctica and the Southern Ocean. It is the only African country with a presence in Antarctica, as well as being a member country of the Scientific Committee on Antarctic Research (SCAR).

South Africa maintains the SANAE IV base in Antarctica and bases at Marion and Gough Islands, administered by the Department of Environmental Affairs and Tourism. Marion Island and Prince Edward Island constitute the Prince Edward Islands Group, which was annexed by South Africa in 1947. Gough Island is a British protectorate and is largely uninhabited, except for the personnel at the South African meteorological station, which it operates within the context of an agreement between South Africa and the United Kingdom.

In 2003, Cabinet approved the transfer of the scientific research functions of the South African National Antarctic Programme (SANAP) from the DEAT to the DST. DEAT however retains responsibility for the logistics and infrastructure, while the National Research Foundation is the agency responsible for grant making on behalf of the DST.

As signatory of the Antarctic Treaty, the South African Government recognises, by way of policy, amongst others the following:

- The global and national importance of safeguarding the environment of the Antarctic and Southern Ocean and protecting the integrity of ecosystems, both marine and terrestrial, in the regions.
- The important role played by the Southern Ocean in global climate processes, including climate change, and its implications for South Africa and the African Continent as a whole.
- The uniqueness of Antarctica as a region for coupling phenomena in geospace and the atmosphere and their interactions.
- The urgency of ensuring the protection of the Antarctic and Southern Ocean environments and the conservation of their resources.
- That it is essential to increase knowledge of Antarctic and Southern Ocean ecosystems and their components so as to be able to base decisions on their management on the best scientific information available.
- The need for international co-operation in scientific research of all involved states in the protection of the Antarctic and Southern Ocean natural environments and the conservation of their resources.
- The responsibility of signatories of the Antarctic Treaty for the protection and preservation of the Antarctic environment and, in particular, their responsibility for the preservation and conservation of living resources in Antarctica.

The DST's vision in taking on the responsibility for the scientific research function for SANAP is to create a demographically balanced Antarctic research programme that strives for internationally competitive research, promotes interdisciplinarity and creates links with other African countries.

The DST sponsored research programme has the following five themes:

- Antarctica: A window into Geospace
- Climate variability: Past, present and future
- Biodiversity responses to Earth System variability
- Engineering and sustainable presence in Antarctica
- The history, sociology, politics and culture of Antarctic research and exploration.

As can be seen from the above, the objectives of this programme overlap to a large extent with the some of the other science missions, in particular space science, earth science and biodiversity.

6.4.1 SA Agulhas and SANAE IV

The ***replacement of the SA Agulhas*** as a supply and research vessel with icebreaker capabilities is in the planning stage. The possibility of going a PPP (public-private-partnership) route has been rejected based on a detailed feasibility study which has showed such an option as being far too costly. Consequently a request for the required R 650 million will be made by the DEAT to Treasury directly.

The new vessel will be a supply and research vessel virtually exclusively for servicing the need of the science community working in the Southern Ocean and Antarctica. As such laboratory space will constitute an integral part of the design. MCM has a budget available in this financial year to do the design specifications. DST and the science community will need to interact with MCM as a matter of urgency in order to ascertain the laboratory space that will be required on the vessel.

The research vessel is seen by DEAT as a National Asset. Under the agreement reached with DST, DST has taken the responsibility of the science part of the Antarctica and Island Programme. DEAT/MCM therefore argues that in terms of the present agreement the research equipment to be placed on the new vessel, as well as maintenance and technical support of such equipment should be DST responsibility. Marine and Coastal Management (MCM) can therefore only justify placement and maintenance of equipment on the ship inasmuch that equipment is used for research in support of the mandate of MCM, i.e. the management of fisheries resources and related obligations under international treaties. For this MCM largely uses a fleet of three smaller vessels. It does not see it as its responsibility to fund or subsidise any research equipment to be used for the broader public good. Hence DST should also see the ship as a national asset and take co-ownership of the process of designing a new vessel as a multipurpose research platform.

MCM is also supportive of the concept that the new research vessel should be operated as a National Asset. The day to day management of the present ship has been outsourced to a private concern. The only task being done by a small MCM staff component is the logistics and scheduling of the research and supply trips. From the discussion with various stakeholders, the present arrangement of split responsibility for research and for logistics and scheduling does not work well and the two functions should ideally be combined and placed in the hands of an agency to operate the ship and the bases in Antarctica and on the islands as a national facility. The responsible agency should have the task to implement and facilitate the research programme and operate the vessel accordingly and to do the longer term science planning. The problem which exists with the present "Steering Committee" consisting of DST, DEAT and NRF is that it is an advisory committee with no implementation powers. This would imply that research and operating costs are transferred to the agency concerned which should then implement the research agenda in accordance with contractual agreements both with DST and with DEAT, and in accordance with a longer term strategy for marine and Antarctic research. The interests of the South African Weather Services will need to be factored into such an arrangement, as it requires the vessel for the deployment of weather buoys in the Southern ocean and for servicing the weather station on Gough Island.

Of interest to note is that the Council for Geosciences plans to increase its marine geology programme considerably in the light of the planned expanded territorial waters. The Council therefore also has a direct interest in the new research vessel and would like it to be equipped with facilities for multi-beam swath bathymetry[14], rock sampling and off-shore drilling.

It is estimated that the cost to equip the research vessel with on board computing network and various instrumentation for research and marine geology will be in the order of R 75 million. For the maintenance of this equipment technical support staff would be required, estimated to cost about R 2 million annually. Outsourced operating costs and fuel for the vessel is estimated by MCM to be about R 45 million annually.

6.4.2 The HF Radar Facility and connectivity

The SHARE (Southern Hemisphere Aural Radar Experiment) radar is the major South African experiment in space sciences in Antarctica. SHARE is part of the international Super Dual Auroral Radar Network (SuperDARN), an observational facility used by the whole space community as well as providing products and services to other communities (see section 6.2.6.1. The new HF radar proposed in the Hermanus Magnetic Observatory's flagship project will also be part of SuperDARN (See Space Physics). It is a network of 17 radars, 7 of which in the Southern Hemisphere and 11 participating countries. The importance of SuperDARN is highlighted by the fact that it:

- is today the primary tool for studying meso- and global-scale ionospheric convection. A major data product is the on-line real-time convection map produced by combining the data from the northern hemisphere radars. This is soon to be extended to the southern hemisphere radars.
- has become a primary ground-based resource for satellite researchers and is recognized as such by NASA and COSPAR.

The South African SHARE radar is an important component of SuperDARN but its contribution is now being limited by serious deficiencies in the infrastructure to the extent that, shortly, it will be unable to meet its full obligations.

SuperDARN produces large quantities of data. The northern hemisphere and Australian data are received by their home institutions on line and by the end of this year all Antarctic countries *except* South Africa will have the broadband capacity to bring back data in real time. This will have serious consequences for South African researchers in that it will no longer form part of the collaborative venture and therefore loose access to the data circulated to all partners, nor will it be able to contribute to real-time polar cap convection map, the quality of which will be compromised as a result. It is therefore vital that adequate broadband satellite communications be provided for SANAE IV, otherwise the investment in the radar will be wasted. The current operation could be well served by a 10Mb/s link at an estimated cost of R 0.5 million annually.

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[14]Sea-Floor Mapping Technology - the measurement of the depth of the ocean floor from the water surface; the oceanic equivalent of topography

Since the funding of the scientific aspects of the Antarctic programme was transferred to the NRF the management and operation of the SHARE HF radar has been handled in the same way as a normal programme grant to a researcher. This leads to a number of difficulties in that:

- The radar serves the differing needs of many researchers and provides data for an ongoing international programme; it should be regarded as a facility rather than the activity of a single researcher or group.
- The radar is a complex, state-of-the-art instrument requiring ongoing maintenance and development from specialized radar engineers and information technology specialists, which can not be appointed from short term grants provided by the NRF.
- The grant structure does not provide a proper process for planning for the ongoing operations, nor does it provide support fro the international obligations in data management, distribution and storage that are outside the normal activities of a university department.

It is therefore proposed that the ***operation of the radar becomes part of the operations of a National Facility*** – the Hermanus Magnetic Observatory. Continuity of operation and data security could then be guaranteed. This would require an increase in the baseline funding of the HMO of about R1 million.

6.4.3 Prince Edward Islands

6.4.3.1 Research Infrastructure, Marion Island Base:

A ***new base on Marion*** is presently being built at a cost of R 200 million and will be commissioned in 18 months. The new base will consist of the basic infrastructure only. To date no resources have been allocated to the science infrastructure such as laboratory equipment. DEAT/MCM does no longer consider it to be its mandate to support the research being done at the Marion and SANAE IV bases ever since DST took on the funding responsibility for that. Hence equipping of the new laboratory spaces on Marion and that on Antarctica with scientific instrumentation, as well as the running, maintenance, calibration and technical support of such equipment should be the responsibility of the DST. A recent survey[15] regarding the necessary laboratory equipment for the Marion Base, indicates that an amount of R 10 million is required for a ***well-found laboratory.*** Some funds would also need to be set aside for support staff to maintain this equipment and for standard running expenses. This would require as a matter of urgency also significant upgrading of the satellite bandwidth. A total annual amount of R 1 million would be required for this.

6.4.3.2 Landscape Dynamics (Instrumented landscape)

Given the history of work at the Prince Edward Islands and the rate of change there, researchers are in a remarkable position to understand how warming drives changes in landscape dynamics (such as mobility, freeze-thaw cycles, wind flow patterns). These landscape dynamics affect all kinds of vegetation and animal distribution processes at a population level. In turn, previously

[15] Conducted by Candice Levieux of the NRF

unrecognized interactions among animal species (e.g. albatrosses and caterpillars) mediate these changes. With a well-instrumented island landscape and a good ***set of laboratory facilities*** researchers could be at the forefront of understanding earth system influences from the regional to local, and could indeed lead the way. A capital investment of R 2 million for a long term experimental field site would enable such an investigation.

6.4.4 A National Facility for Marine and Antarctic Research

The importance of the Southern Ocean to South Africa is in the spotlight at present because of the process to lay claim to the continental shelf areas surrounding the Prince Edward Islands in terms of the UN Law of the Sea Convention. The substantial increase in South African territorial waters opens up a vast area of uncharted terrain for cutting edge research and discoveries, which require substantial investment of new money into research. This claim, as well as the claim to the continental shelf areas surrounding South Africa and referred to under Marine Biodiversity above, emphasises the need to considerably enhance the capacity for multi-disciplinary marine research and the required infrastructure in terms of research vessels to do so. It also begs the question of whether, with an increase in activities, the present split in responsibility for logistics (DEAT) and responsibility for research (DST) is the most effective and efficient way of pursuing a high profile and internationally significant research agenda. Serious consideration needs to be given to revisiting the present arrangement, and to establish a ***National Facility for Marine and Antarctic Research*** with full jurisdiction over the two research vessels, i.e. a smaller one for near shore research as proposed in the Marine Biodiversity section above, and a larger research and supply vessel with ice breaking ability for deep water, the Southern Ocean and Antarctica, as well as the operations of the bases in Antarctica and on the Islands.

Such a facility should also be tasked to proactively reinvigorate South Africa's deep water oceanographic capability, which is just about eroded. South Africa has hardly any scientists left who are studying the Southern Ocean. This area is a major source of resources and has a huge influence on our weather. Deep water oceanographers can be counted on the fingers of one hand and those who have the expertise to do ship-based work are rare. With the planned replacement of the SA Agulhas by a state-of-the-art new research vessel, it is urgently needed to utilise the existing limited capacity to train a new generation of researchers in oceanography. Already the limited capacity to participate meaningfully in the International Polar Year is a matter of concern.

As with several of the other science missions, the stimulation of oceanographic research can best be achieved through the establishment of at least two research chairs with appropriate support for postgraduate and postdoctoral research positions. This in turn would require two annual grants of R 3 million each to two universities for a period of at least 10 years.

6.5 Earth Science

South Africa's geology is in many respects very unique in the world. Several factors contribute to this uniqueness. Firstly, no other country in the world has a preserved geological record of events dating back with comparatively few interruptions from the present to 3 600 million years. Secondly, within this geological record evidence of several globally important events are preserved such as the changing composition of the Earth's atmosphere, the evolution of life from the earliest primitive cell structures to the remarkable record of human evolution, the assembly and fragmentation of super continents and exceptionally well preserved meteorite impact structures. Thirdly, no country on earth can boast with the same magnitude and diversity of mineral resources.

This uniqueness has ensured continuous international interest in South African geology for many decades and local researchers have as a result established important international collaborative partnerships in research. This was necessitated to some extent by the critical lack of state-of-the-art infrastructure locally to conduct internationally cutting edge research, so that much of the credit for cutting edge advances in geology based on South Africa's unique geology goes to others beyond our borders.

Earth Science has correctly, by way of the Kaapvaal Kraton, been identified as an obvious geographical advantage in the National R&D Strategy. However, as with the other science missions, this has as not yet been followed up with an appropriate strategy aimed at exploiting this advantage for the benefit of South African science. As a result, several ad hoc initiatives that have been launched in recent years to conduct "big science" projects in collaboration with partners from the North remain "North" dominated by virtue of their resources and the lack of an appropriate co-investment by South Africa. "Inkaba ye Afrika" is a prime example of this.

Infrastructural requirements to enable South African scientists to exploit our competitive advantage fully are discussed subsequently.

6.5.1 Geodata Storage and Retrieval Facilities

The Council for Geoscience has a statutory obligation to manage the National Geosciences Library and the National Core Library. The latter is a large core shed outside Pretoria which presently houses in excess of 1 000 km of borehole core, most of which drilled by exploration companies and donated to the Council for curation and research. The storage facility is also being used to store all the samples collected for the regional geochemical surveys, a National Lithology Library containing samples from field based surveys for which chemical analyses are available and on which physical parameters have been determined. The facility will also house the palaeontological collection of the Council in future.

What is still required nationally is a ***Geological Data Archiving Facility*** which can serve as a repository of land and marine exploration and other geological information, including geophysical surveys, contained in numerous documents of mining companies and no longer of interest or use to these companies. The digitisation and integration of such datasets will e.g. allow for secondary data analysis such as 3D modelling of features such as the Wits basin, the Bushveld Complex and other areas of interest that have been explored extensively in the past. Seismic survey data in particular can be of immense value to researchers who would be able to reprocess any such data with more advanced software technology and reinterpret the information to obtain new insights in subsurface geology.

In principle, such a facility could be very similar to the South African Data Archive (SADA) operated by the NRF on behalf of the social sciences and humanities. Such a data archiving facility would require, apart from data storage and computing capacity, also some skilled staff in digitising, handling, managing and manipulating large earth data sets. A facility of this nature would be akin to a bioinformatics facility, albeit on a smaller scale, but bring together in a central facility several hundreds of million rands worth of exploration data, which would otherwise be lost. Although no costing of such a facility has been done, a start up grant of R 5 million and a recurring grant of R 2 million per annum should go a long way towards establishing such a facility.

6.5.2 Analytical and Characterisation facilities

For internationally competitive research in the earth sciences, researchers require ready access to a range of ***state-of-the-art analytical and characterisation equipment***. Such a range of equipment can not be duplicated at every university, but should be readily accessible within each region of the country. The range of equipment referred to includes ICPMS (Inductively Coupled Plasma Mass Spectrometry), Electron Microprobe, XRF (X-Ray Fluorescence), XRD (X-Ray Diffraction) and a mass spectrometer for isotope geochemistry. Four such sets would be required for the country, elements of which already exist in several regions, e.g. a complete range at UCT (University of Cape Town) in the western Cape; XRD, XRF and Microprobe at the University of Pretoria; an ICPMS, Microprobe, XRD and XRF at the UKZN (University of KwaZulu-Natal). A detailed analysis of the available analytical infrastructure would be required, as well as a management model of these in order to ensure availability and accessibility of users in each region. An estimate at this stage though suggests that one complete range of these instruments plus two mass spectrometers for isotope geochemistry would be required within the next few years in order to fill gaps in the regions and to replace items of ageing equipment. This will cost of the order of R 25 million, an amount which also makes some provision for the upgrading of associated laboratories.

Although more specialised equipment such as e.g. QEMSEM (Quantitative Evaluation of Minerals by Scanning Electron Microscope) is available at Mintek and in at the Angloplats Laboratories, this is not readily available for research by outsiders. Such a facility is important for complicated ore mineralogy as well as the study of micro-textures in rocks which find their application in rock engineering. Consideration should be given of placing such an instrument at one of the northern regional characterisation facilities, as instrumentation of this nature also has industrial applications. The cost of a QEMSEM is estimated to be R 5 million.

For real cutting edge research in the geosciences access to a high precision trace element ion-beam facility such as Secondary Ion Mass Spectroscopy (SIMS) would be required. Such a facility is more focused and accurate than a laser ablation beam attached to an ICPMS or the ionprobes at iThemba LABS. The cost of such a facility is estimated to be R 25 million and would best be located in a centralised facility for Imaging and Microanalysis, such as at iThemba LABS (Gauteng). Such a centre where key equipment for microanalysis and imaging is centralised under one roof exists e.g. in Western Australia where it serves the needs of the entire region. It is situated on the campus of the University of Western Australia but not part of it and available to universities, industry and science councils. The possibility of co-locating some of these analytical facilities in the Centralised Advanced Characterisation Facility should be considered (see section 7.1.3.3)

6.5.3 Dating

A Multi-collector ICPMS equipped with a short wavelength laser for dating by means of laser ablation techniques is presently being installed at UCT as part of a package of isotope facilities acquired with an Innovation Fund (IF) grant. This instrument is ideal for U/Pb and U/Th dating on Uranium bearing minerals. Its accuracy is virtually comparable with that of a ***SHRIMP (Sensitive High Resolution Ion MicroProbe)*** because of the focussed laser beam. With the installation of this equipment, the immediate need for a SHRIMP largely falls away. The SHRIMP is a non-destructive technique and provides a better resolution. The argument made, however, is that there is a need for a large number of good dates in Africa, not necessarily of the highest precision.

With the acquisition of a dedicated multi-collector ICPMS at UCT for dating, the needs of the country for geological age determination older than 2.5 million years should be met for the foreseeable future. For younger ages a northern facility consisting of AMS techniques and a revitalised QUADRU (Quaternary Dating Research Unit) facility at the CSIR and managed by iThemba LABS is proposed (See Palaeosciences, section 6.6).

There is some scepticism regarding the dating capability of the ICPMS at UCT. It is therefore proposed that the need for a SHRIMP be revisited after the dating facility at UCT is on line and well into production. Depending on the performance of the UCT facility, a SHRIMP may be justified in the medium term (five year time scale) and would then require an investment of about R 40 million (half of which for the equipment and half for specially equipped building).

6.5.4 Facilities at UCT

A package of equipment purchased with IF money is presently being installed at UCT and includes the following:

- A JOEL JXA-8100 Electron Microprobe, already delivered and being commissioned at present.
- Two Multi-collector ICPMS machines:
  - The first one of these is designed for solution ICPMS and a tool for normal isotope analysis at trace level and ideal to study Rb/Sr, Sm/Nd, Lu/Hf, U/Pb/Th, and other systems. It is also to be used for environmental studies on various other isotopes such as Si, Fe and Mg the significance of which in environmental research and understanding processes in nature is being recognised more and more.
  - The second instrument is equipped with a shorter wavelength laser for dating by means of laser ablation techniques. It is ideal for U/Pb and U/Th dating on U bearing minerals, and is referred to under "dating" above.
- A Noble Gas Mass Spectrometer which will allow for Argon dating as well as the analyses of noble gas isotopes (Ne, Xe, He), which are very powerful tracers in mantle evolution studies.

Older, still functional equipment includes a Quadrupole ICPMS for trace element analyses down to parts per trillion levels, and a thermal ionisation mass spectrometer for high precision isotope analysis. The former is equipped for both solution and laser ablation analyses, e.g. to study zoning in minerals, the latter, although old, is still operational but will need replacing in the next few years.

The above instrumentation is supported by existing clean laboratory facilities funded by the University.

The new equipment at UCT will be run like a national facility, although there will be some costs involved for all users (with some preferential tariffs for users from UCT) essentially to cover consumables plus 10%, the latter being a contribution to a fund to cover costs of that portion of repairs that UCT normally does not provide. The equipment will be available to a variable extent for contract work which will be charged at much higher rates. The income from this will largely be used to reduce the cost to researchers and research students.

The equipment will be managed and run by scientists (academic staff) who have a direct interest in the proper functioning of the equipment because of own research interests. The University prefers researchers and research students to come and use the equipment, rather than providing an analytical service. The scientists in charge will train and assist in ensuring quality of data as this can normally not be left to a technician.

The university has made two scientist posts available to be in charge of the new ICPMS machines. A specialist scientist is however also required to operate the noble gas mass spectrometer, for which the University does not have the resources.

The array of analytical and dating equipment at UCT will be able to revolutionise South African capabilities in the earth sciences. Important though is that these facilities must be made accessible as a national facility in order for the entire earth science community to benefit from this and be managed as such. In order to achieve this and to ensure that this will not present an undue burden on UCT, it is proposed that:

- an annual grant be made available to UCT to enable it to offer the infrastructure to other users as a national facility, and
- a formal agreement be entered into between UCT and the appropriate funding authority regarding accessibility of the infrastructure as a national facility.

It is furthermore proposed that such a grant should cover the expenses of a number of support staff, including a facilities manager (administrative), some of the running and maintenance costs, as well as regular meetings of a user advisory committee to be chaired by a senior official of UCT. An annual grant of R 2 million is proposed in this regard.

6.5.5 Infrastructure Access Fund

For the earth science community to fully exploit the geographical advantage of South Africa's unique geology and conduct internationally competitive research, it will require access to scientifically motivated deep drilling and deep geophysical soundings such as Vibroseis surveys. As equipment of this nature is not standard infrastructure for research, it would have to be accessed as and when the need arises from commercial contractors who normally provide these services for the mining industry. It is therefore proposed that a geological infrastructure access fund to an amount of R 3 million be made available annually. Grants should be made available on a competitive basis to the earth science community for cutting edge research projects that require geophysical information and or geological information by deep drilling techniques. An ***Infrastructure Access Fund*** needs to be carefully managed and supported projects should be decided on by a small committee of senior earth scientists who would determine the priorities and screen applications on the basis of a rigorous peer review process.

6.5.6 Marine Geology

Off-shore geology has been neglected by South African researchers for many years and activities are largely restricted to off-shore exploration activities linked to diamonds and oil. Some interest has been stimulated in recent years by the Inkaba ye Afrika programme, a component of which aims to investigate the continental margins along the west coast.

Interest in marine geology needs to increase though, now that countries can make claims to continental shelf areas that extend beyond the economic exclusion zone. South Africa's area of jurisdiction stands to increase by another 700 000 square km. It has to be demonstrated though that the shelf in question is an extension of the land. South Africa is presently surveying these shelf margin areas with multi-beam swath bathymetry equipment that sweeps the ocean floor and provides images (like photographs) of the sea floor. This is presently being done by the Petroleum Agency of South Africa (PASA) with assistance from the South African Navy.

In order to stimulate research in marine geology, the Council for Geoscience (CGS) is contemplating the purchase of a multi-beam swath system for systematic mapping of the near shore ocean floor up to about 200 – 300 m depth and to purchase a boat to do that. Such information is required for research purposes, e.g. the ACEP, routing of underwater cables, infrastructure work (harbours) and also for subsequent rock sampling of the ocean floor, in order to understand the off shore geology and its mineral potential. Although the amount of work involved in such surveys would keep several ships occupied for a number of years, the council is keenly interested in the proposal of two research vessels proposed by the oceanographic research community, *viz*. the SA Agulhas replacement and a dedicated smaller vessel for near shore research. Such research vessels would be ideal for the surveys contemplated. The CGS plans to liaise with DEAT regarding the specifications of a replacement vessel for the SA Agulhas as such a vessel should be designed from the onset to do ocean floor rock sampling and to some extent even off shore drilling.

6.6 Palaeosciences

South Africa's fossil and human genetic heritage is remarkable. No other country in the world can boast with the oldest evidence of life on Earth extending back more than 3 billion years, the oldest multi-cellular organisms, the most primitive land-living plants, the most distant ancestors of dinosaurs, the most complete record of the more than 80 million year ancestry of mammals, and, together with several other African countries, a most remarkable record of human origins and of human achievements through the last eight million years. This is truly a unique geographic advantage where a big science approach can locate South African science squarely onto centre stage in the world. However, just as with all the other science missions identified in the NRDS, there is no government approved strategy in place as yet to inform investment of resources in this area. A draft strategy is presently being considered though, and proposals below pertaining to the required infrastructural needs, are aligned to this draft strategy.

6.6.1 The Policy Environment

As with biodiversity, several organs of state have jurisdiction over our palaeontological heritage. Fossils are classified by the National Heritage Resources Act as "national estate" and as such their excavation, collection and use for research are governed by several statutory requirements. In addition, several of the larger fossil collections are housed in natural history museums which report to the Department of Arts and Culture as "Declared Cultural Institutions". This has some implications for their sustained care and accessibility, aspects which are elaborated upon in some more detail under the section on Biodiversity (see section 6.3).

6.6.2 Collections and their Curation

South Africa's palaeontological and archaeological heritage is the property of the state, as defined by the 'national estate' in the National Heritage Resources Act. The exploitation of this heritage for research has been subjected to statutory requirements both pre and post 1 April 2000, when the National Heritage Resources Act came into operation. Ownership before 2000 vested in the institution to which the researcher was affiliated, on condition that the collected material was properly curated, whilst post 2000 ownership of the material vests in the state, with the researcher's home institution fulfilling the role of custodian on behalf of the state. Over the years, the amount of excavated material that accumulated has reached significant proportions. Proper storage of this material, its preparation for research and its curation has as a result become a serious burden on the institutions with large collections, both universities and museums alike, so much so that the integrity of these collections is at risk if not appropriately supported.

These collections, and the material to be added in years to come, collectively constitute an important national asset and their proper conservation and curation is critical to the success of the palaeo-science mission of the NRDS. The collections are presently housed in a variety of institutions with varying curation capacity. For these collections to become a true national asset, the following needs to be pursued:

- Rationalising the multitude of collections to create a limited number of key repositories that are recognised as ***national collections*** with the appropriate infrastructure and support staff to ensure proper curation and accessibility for research and science outreach activities. Such an approach will create economies of scale within the context of limited resources.
- Digitization of the collections and the creation of a national databank of palaeontological material for education and research.
- A commitment by owners of pre-2000 fossil collections to make available these collections for research and educational exhibits in the national interest.
- An agreement with SAHRA (South African Heritage Resources Agency) and the provincial heritage resources agencies which will limit the conservation of excavated fossiliferous material to those repositories recognised and supported by the DST as housing the "national" collections.
- The development of a collections policy based on internationally benchmarked standards for conservation and curation of these "national" collections.

The repositories recognised to house the "national" collections need to be equipped with appropriate laboratory facilities and trained staff to extract fossils from the rock in accordance with the latest technologies. Such facilities will have to be available to researchers both from the institution that hosts such a repository and researchers who do not have such facilities at their own institutions.

Four accredited "national collection" repository sites are proposed. Support to provide proper state-of-the-art compactor storage and best practise curation infrastructure will entail an initial capital investment of about R 10 million per site, plus an annual grant of R 4 million per site for the curation of these "national collections". The latter is to cover the salaries of support staff as well as running expenses and equipment for the establishment and maintenance of digitised databases that include digital photographic images. The databases should be linked to GIS (Global Information System) containing detailed references to localities, both regarding cave deposits and regionally distributed collection sites. One of these national collections should be identified as a central reference facility to house and manage all digital data generated for archiving, future reference and research purposes and must be supplied with the necessary support staff.

6.6.3 Characterisation

6.6.3.1 Imaging

State-of-the-art non destructive imaging techniques for high resolution 3D visualisation and tomography of key fossil material by nuclear and X-ray scanning techniques are becoming increasingly more important in palaeontological and palaeoanthropological research. Such techniques have been used to a limited extent by South African researchers in the past, amongst others by using some of the facilities and skills available at NECSA. Given that NECSA has a range of nuclear and X-ray based analytical and materials characterisation techniques and supporting expertise on offer and is in a process of developing capacity in some complementary techniques, it is proposed that a ***National Radiography/Tomography Facility*** be established here. Such a national facility would require the following investment to become fully operational in gamma-, neutron- and X-ray radiation:

A new X-ray radiography/tomography capability:	R 3 million
The refurbishment of an existing micro-focus X-ray machine:	R 5 million
Laboratory infrastructure at NECSA for housing this equipment:	R 3 million
Total capital expenditure:	R 11 million

This equipment would complement other existing facilities for X-ray and neutron diffraction and radiation analysis. It is estimated that an amount of about R 1 million would be required on a recurring basis for the salaries of specialised technical and scientific support staff as well as for running and maintenance of the facility in order to provide a service to researchers as a national facility.

Important to note though is that the facilities referred to above can only scan samples with a maximum size of 20 x 20 cm. CT (Computerised Tomography) Scanning equipment that can handle larger samples, e.g. skulls of hominids and other fossils is considerably more expensive and would require an additional R 25 million. Because of similar techniques involved, such a scanner is best also placed together with the other radiography and tomography facilities at NECSA

It needs to be pointed out that such a national facility will have the capabilities of servicing the needs of a variety of other key stakeholders in universities and in industry such as the PBMR (Pebble Bed Modular Reactor), so that a significant portion of the operational costs could be recovered from sources other than the state.

High resolution 3D visualisation and tomography facilities should initially be available routinely for research purposes, and subsequently for routine documentation of individual fossils in collections. Fossil material would initially have to be transported safely and securely to the facility for characterisation. The acquisition of mobile CT scanning facilities that can handle samples larger than 20 cm x 20 cm will need to be investigated as possible future extensions of the capabilities of the national facility.

6.6.3.2 Dating

This country's capacity to do high quality dating of fossiliferous deposits of Pleistocene/Holocene age has deteriorated over the past decade and requires urgent attention. Fortunately much of the basic infrastructure to resurrect this capability exists, but it will require some investment in infrastructure and high level skills to do justice to the palaeontological heritage of the country. The following will be required:

Accelerator Mass Spectrometry (AMS)

AMS has developed into a major analytical tool over the past two decades. The importance of the technique lies in its sensitivity (which is as much as a million times better than conventional mass spectrometry), the small sample size (up to 1 000 times smaller than that required for other decay counting techniques), and high throughput. A facility of this nature requires a tandem nuclear accelerator, which is available in iThemba LABS (Gauteng), the former Schonland Research Centre.

The establishment of an AMS facility at iThemba LABS (Gauteng) was envisaged as part of the entire recapitalisation programme when the Schonland Centre was transferred to iThemba LABS. Planning of the refurbishment of the iThemba LABS accelerator seems to be at an advanced state. Once the refurbishment is completed, the capabilities of the iThemba LABS accelerator will rank among the best in the world. The upgrading of the tandem accelerator to an AMS was not provided for in the recapitalisation of the Schonland infrastructure when it was transferred to iThemba LABS. An application for a R 6 million grant has therefore been submitted to IAEA (International Atomic Energy Agency) as a contribution from its research infrastructure support for developing countries for the establishment of the AMS facility. An additional amount of R 10 million will however be required for this task, including the establishment of specialised sample preparation laboratories at the facility.

Complicated facilities of this nature generally do not supply a routine service. Their operation requires highly specialized scientific skills on which the quality of the data depends. Such skills are not readily available in South Africa and hence an issue that requires serious consideration by management of iThemba LABS in order to operate the AMS as a national facility. Additional recurring expenses of about R 1 million per annum is required

It needs to be noted that AMS techniques have apart from palaeontology, application in a large variety of disciplines, such as environmental sciences, climatology and Global Climate Change, palaeoclimatology, oceanography, hydrology, archaeology, space physics, material sciences and several others.

CSIR (ex QUADRU)

The C^{14} detector facility to do conventional C^{14} dating, situated in a shielded bunker several tens of metres underground, is among the best in the world. Although the CSIR does continue to support C^{14} dating on a cost recovery basis as a service to the broader science community, it no longer considers chronology as one of its core functions.

Given that the expense involved in C^{14} dating with AMS is 2 – 3 higher than for conventional C^{14} dating, and the anticipated demand for AMS in a variety of disciplines, the C^{14} dating facility at the CSIR should be retained.

The Luminescence equipment at the CSIR is a top of the range research facility that requires a highly skilled and dedicated person to operate, i.e. somebody who is passionate about the subject as a research area. It is not operational at present because of the recent resignation of the responsible research scientist. The facility does not lend itself as a routine dating service, and will require a dedicated research scientist to become operational again.

Both these facilities can not operate optimally within the CSIR under its present funding models and they can not be subsidised from its parliamentary grant as the CSIR does not consider chronology to be a core function. What is required is national facility type support to create a research environment for the facilities by funding the salaries of a core of research scientists, technical support staff and the running expenses to operate and maintain these facilities.

It would seem as if there are only limited capital items required to resurrect these facilities. This relates specifically to the demand on luminescence dating where a second instrument at about R 3 million would be required, given the time required on the machine to obtain one analysis. The main expense would be of a recurring nature, i.e. salaries and running expenses, estimated to be about R 1 million annually.

The age-gap 250 000 to 2.5 million years

This age gap is of critical importance to palaeoanthropology and covers the range intermediate of that which can readily be covered by C^{14} and Luminescence techniques (<250 000 years) on the one hand, and Thermal Ionisation Mass Spectroscopy (TIMS) (>2.5 million years) of which there only seems to be one operational facility at UCT on the other hand. It is anticipated though that the new ICPMS facility being installed at UCT should be able to readily cover all dating requirements >2.5 million years.

Various other dating techniques have been used in the past to cover the critical age-gap with varying degrees of success, such as Electron Spin Resonance (ESR) and uranium series disequilibrium studies. It would seem though that for absolute dating of fossils in this critical gap AMS seems the best option, but often in conjunction with other techniques. A R&D programme designed to identify the most appropriate dating technologies to cover this gap should be considered once the AMS facility is operational.

In the light of the above, it is recommended that a ***"northern" national dating facility*** be established that focuses on ages <2.5 million years. This northern facility should incorporate the AMS dating capacity to be established at iThemba LABS (Gauteng) and the facilities of the former QUADRU at the CSIR. In order to ensure a critical mass of specialist scientific and technical staff to operate these facilities it is proposed that these resort under the management responsibility of iThemba LABS, an existing National Facility under the NRF. Details of the most appropriate management model particularly as far as the ownership of and access to equipment at the CSIR are concerned will need to be negotiated between iThemba LABS and the CSIR.

For the dating of fossils in rocks older than 2.5 million years a "southern" national dating facility at the University of Cape Town is proposed. Details of such a facility are provided in section 6.5.3 under Earth Science.

6.6.3.3 Stable isotopes and palaeoclimatology

State-of-the-art light isotope gas source mass spectrometers for O, N and H stable isotope analysis exist at UCT and at the CSIR, whereas the facility at iThemba LABS (Gauteng) is somewhat older. The mass spectrometers at UCT are coupled to silicate extraction lines and are run as effective national facilities with users from across the continent. Such facilities have a variety of applications particularly in the environmental sciences to study the effects of climate change and pollution, but also find their application in research to reconstruct late Pleistocene/Holocene climates of southern Africa. This is of importance to understand how climate has changed in different parts of the country in the recent past, so that a better understanding can be developed on how the region is going to fare under future climates, and especially in response to global warming.

In view of the fact that the AMS facility, once completed, will also be able to do high precision analyses for light stable isotopes, and even expand the capabilities to include some elements of higher atomic number, no additional infrastructure seems to be required at this stage in this area.

6.7 Poverty Reduction and Health

Any technology-based interventions to reduce poverty will only be successful if these are properly tried and tested, i.e. based on sound evidence using valid empirical data. Many debates on poverty, and the interventions proposed, are lacking in evidence. Much of the robust evidence required for poverty-minimising interventions can be derived from community-based, longitudinal, socio-economic-demographic and health databases (or surveillance systems), which record critical population events such as deaths, births, and population movements. Datasets of this nature constitute the “backbone” on which multifaceted and strongly interdisciplinary research programmes can be built in support of policy, intervention strategies, monitoring and evaluation of new or innovative technologies, and the assessment of the impact of policy decisions. Networks of such databases, locally, in Africa and abroad, and ensuring their connectivity, can multiply their value.

Quality research in this sphere is based on:

- Empirical, longitudinal data i.e. ensuring an excellent evidence base to find answers to what works and what is being tested.
- Empirical understanding from household- and population-based data that overcomes the bias of selectivity.
- Longitudinal datasets – that follow persons and defined communities through time – that allow an understanding of causality to evolve, as well as the policy-relevant evaluation of social, economic and health impacts in the short, medium and long term.
- Proper management of the data in terms of its standardisation and the harmonisation of variables across data sets, as well as facilitating their accessibility by researchers. This requires advanced technical skills.
- Multi- and inter-disciplinary scientific collaboration, drawing on the best of local, African and international expertise, for the best chance of breaking new ground.

6.7.1 Infrastructure requirements

The infrastructure required to obtain the high quality longitudinal datasets involves establishing a number of well-sited ***health and socio-demographic surveillance sites*** across the country. Two such sites already exist: one, the Agincourt site of the University of the Witwatersrand and Medical Research Council (MRC) near Acornhoek in Limpopo (now Mpumalanga) Province; and the Hlabisa-based rural site in KwaZulu-Natal operated by the UKZN and linked with the MRC. Both are leading nodes in an international network of 37 INDEPTH[16] surveillance sites in developing areas of the world, funded largely from donor grants (some public sector contribution is made to the sites in Tanzania, Ghana and Vietnam).

A prerequisite for South Africa to develop effective and efficient technologies for poverty reduction – notably in rural, as well as in urban areas – and to address the issues raised in the "Science and Technology for Poverty Reduction" priority of the NRDS, is the requirement of at least another five health and demographic surveillance sites across the country, strategically located and with two or more of these located in urban areas (drawing on understanding from the recently established Nairobi Urban Demographic Surveillance System[17]). These should be managed and connected akin to the SAEON sites and be tasked with the collection of standardised longitudinal population (i.e. socio-economic-demographic) and health data. Each one should also have a strong site specific research, research training and science outreach agenda.

The longitudinal demographic and surveillance data must be able to address the following three core issues:

- Social and economic impacts of disease, which includes issues such as:
  - Survival of children
  - Early cognitive development and performance at primary school
  - Younger and older adolescence and their social adjustment
  - Ability to productively enter the workforce
  - Ability to raise income (whether locally or through remittances)
  - Securing the livelihoods of family and household if a breadwinner dies
  - Evaluating the impacts of social grants
  - Ability to demonstrate family and household resilience to health, economic or social 'shocks'
  - Examining the rapidly increasing support and income-generating roles of older persons, particularly women.
- Effects of poverty on disease and vice-versa: Understanding context-specific pathways of how disease relates to poverty and poverty to disease as prerequisites to developing the appropriate technologies of intervention. These include:
  - Technologies of medicine and health (including behavioural interventions)
  - Technologies of access and coverage (essential to positively impact on populations)
  - Technologies of system organisation (including service delivery and accountability)

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[16] INDEPTH: International Network for the Demographic Evaluation of Populations and Their Health

[17] Led by the African Population & Health Research Centre which is funded by an international consortium

- The design of core and support strategies for implementation of the technology based interventions, monitoring their outcome to adapt implementation strategies if required, and finally assessment of the impact of these interventions over time.

6.7.2 New Frontiers

The establishment of such a network opens up a number of new avenues for research opportunities if networked appropriately within the NSI. Examples include the following:

- Connectivity between initiatives such as SAEON and a local INDEPTH type network will exponentially increase the value of research as it opens up a host of new multi- and inter-disciplinary research opportunities that interrogate specifically the understanding of the interaction between human activity linked to poverty and disease and the function of ecosystems.
- The diversity of environments in Africa, and the speed of social change, compared with the "North", provides a unique platform to study the inter-relationship between biological (including genetic) and socio-economic imperatives. There is a greater necessity to follow such an approach in Africa to find answers, rather than in the "North", and hence we have an exceptional opportunity to lead and not merely to follow in a very topical and emerging new area of scientific enquiry.
- The integration of Indigenous Knowledge (traditional beliefs and practices) and technology applications for these to be effective. This is certainly important with respect to illness and its management but a strong case can also be made regarding research development-oriented interventions. From a research perspective this relates specifically to the integration and use of multiple methods from different knowledge systems and the qualitative-quantitative interface that could lead to new and innovative insights.

6.7.3 Cost implications

The establishment of a network of health and demographic surveillance sites would require the core funding of the sites for capital infrastructure (once-off) and support staff and maintenance (recurring) for sustainability. This would constitute the platform on which specific, high functioning research programmes and technological interventions can be launched. The INDEPTH Network has developed effective 'resource kits' to assist with this process.

- Capital expenditure for five new sites is estimated at R 5 million each, i.e. R 25 million
- Recurring expenditure per site (covering a community of ~ 75 000 persons), consisting of 25-30 field and support staff including databank management, running and maintenance, and ensuring annual surveillance updates is estimated at ~ R 2.5 million, i.e. for seven sites (including the two existing ones), R 17.5 Million per annum.

6.7.4 Management

The network of surveillance sites should be operated as a National Facility with the scientific agenda determined by stakeholders and the research community utilising the infrastructure and longitudinal datasets for cutting edge research, technology development and policy advice.

6.8 Indigenous Knowledge

The importance of indigenous knowledge (IK) in the well being of communities of developing countries is widely recognised, as is the potential of such knowledge in innovation, particularly in the pharmaceutical industry and in medicine. The identification and protection of indigenous knowledge has therefore received the attention of policy makers in many countries. South Africa is no exception and an Indigenous Knowledge System (IKS) policy prepared by the DST in consultation with several other Government Departments was duly approved by Cabinet in November 2004[18]. This policy document gives due recognition to the fact that indigenous knowledge is an important factor in the survival and welfare of many South Africans and hence seeks to promote and protect the custodians and practitioners of this knowledge by identifying the following policy drivers:

- The affirmation of African cultural values in the face of globalisation, an imperative given the need to promote a positive African identity.
- The development of services provided by IK holders and practitioners, with a particular focus on traditional medicine, but also including areas such as agriculture, indigenous languages and folklore.
- Underpinning the contribution of IK to the economy, i.e. the role of IK in employment and wealth creation.
- Interfaces with other knowledge systems, for example IK used together with modern biotechnology in the pharmaceutical industry and other sectors to increase the rate of innovation.

Many examples abound, particularly in countries of the east such as India, China, Japan and others where IK has successfully contributed to the innovation system. In South Africa the value of IK was not recognised and actively suppressed over many years of apartheid rule, and it is only in very recent years that its importance is being given due recognition as is highlighted amongst others by the appetite suppressing characteristic of the Hoodia plant which has been known by the San community for centuries. Although the policy document emphasises the need to nurture and develop IK, it emphasises that the full potential ok IK will only be recognised and appreciated if it becomes fully integrated into the NSI. Measures to achieve this include:

- The creation of a legal benefit-sharing framework.
- The establishment of a formal recordal system for IKS.
- Legislation to ensure minimum standards in Information and Material Transfer Agreements in respect of IK research.

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[18] Indigenous Knowledge Systems, Department of Science and Technology, 2004, 40p.

- The promotion of links with the science base by means of targeted funding instruments.
- Amendments in the South African Patent Legislation to enforce IK prior art declaration.

6.8.1 Infrastructure Requirements

The DST has recently begun with the process of implementing the approved policy. Consideration is presently being given to a three pronged implementation strategy *viz.*:

- Policy and advocacy, including a coordinating role in IKS across all Government departments dealing with IKS, functions that will be handled by a national office within DST.
- Knowledge development with the following functions that will require infrastructure:
  - A Centre for Knowledge Studies within Higher Education, to be headed by a Chair.
  - Laboratories to develop indigenous technologies, including a health centre as interface between traditional and modern practitioners and research aimed at merging these approaches to health.
  - Support structures to promote IK and indigenous technology innovation, commercialisation, IP (Intellectual Property) protection and benefit sharing.
  - The establishment of IK Centres in close proximity to local communities to facilitate collaboration between tertiary institutions, NGOs and IK holders and practitioners working in development and promotion of IKS. It is envisaged that such centres will
    - Collect, document and disseminate information on various components of IK.
    - Develop cost-effective and reliable methodologies for recording IK.
    - Conduct trans-disciplinary research on IKS.
    - Assist in the formulation of policies and design technical assistance to alleviate poverty and improve health based on IK.
- Knowledge management, also to be handled by the national office but with the following infrastructural implication:
  - The creation and maintenance of an IKS databank and to link this with databanks of public, academic and research institution for promoting the fair and equitable use of such IK.

No indications are as yet available as to the proposed intensity and extent of the infrastructure and an assessment of the cost implication would be premature at this stage. What is suggested though is that the proposed ***IK Centres*** be located at appropriate SAEON/LTER sites and the proposed population and health surveillance sites (see sections on Terrestrial Biodiversity and on Poverty Reduction and Health) as these sites work closely with the communities in their environment and because these sites in themselves would greatly benefit from IK inputs for their respective observations. This could be implemented fairly rapidly and would involve the establishment of offices and recording laboratories at about R 1.5 million each for seven suitable sites, plus about R 1 million for support staff and running expenses per site per year, i.e. R 10.5 million for infrastructure and R 7 million annually recurring.

6.9 Earth Observation

As already referred to in the introduction to the Science Missions, Cabinet recently approved a strategy for the implementation of a ***South African Earth Observation System*** (SAEOS). SAEOS is the direct result of DST's engagement with the international community in promoting an integrated global earth observation system (GEOS) and in creating a Global Earth Observation System of Systems (GEOSS)[19]. SAEOS is the South African "system" to link into this international network of systems.

The objective of SAEOS is "to coordinate the collection, assimilation and dissemination of South African earth observations, in order that their full potential to support policy, decision-making, economic growth and sustainable development may be realised".[20] Earth observation data includes a large variety of disparate measurements taken of and on the earth's surface, the oceans, the atmosphere and from space for a variety of purposes such as weather and climate, land usage, marine resource management, pollution control etc. These datasets, based on different observation systems, are held by many different institutions in the country and it will be the task of SAEOS to add value to these various observation systems by making them accessible and easily available to users. Figure 4 shows the proposed South African Earth Observation System

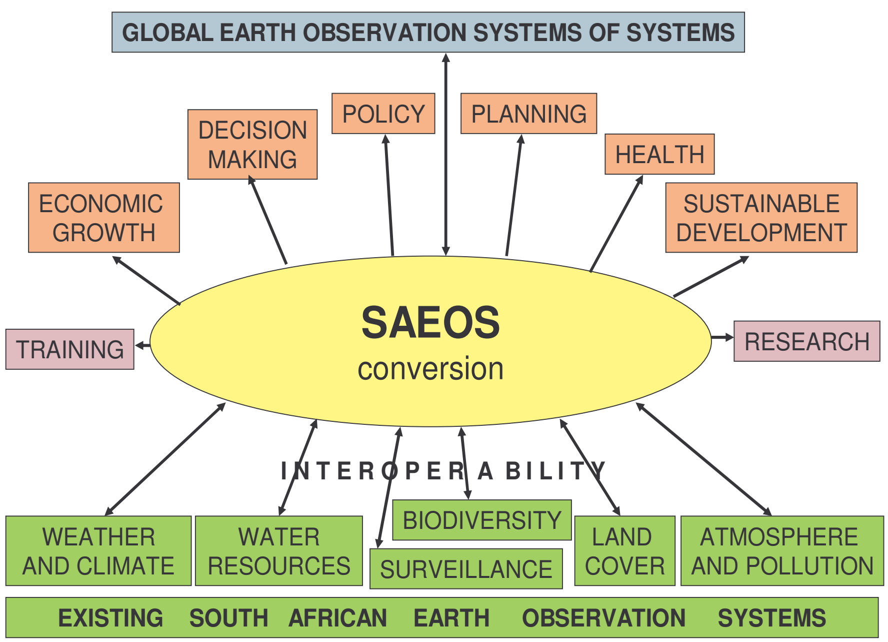

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Figure 4: *The South African Earth Observation System*

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[19] GEOSS, the 10-year implementation plan for the Global Earth Observation System of Systems. ESA, Paris, 2005.

[20] South African Earth Observation System (SAEOS), Final draft for comment, October 2005

SAEOS plans to achieve its objective by:

- Identifying and addressing failures and gaps in the sampling, data processing and information dissemination process.
- Ensuring that the information needs of users are met, in the form that they require, when they need it, and at an affordable cost.
- Exploiting the opportunities for synergies and cost-saving between previous separate systems.
- Developing and promoting standard methodologies.
- Ensuring that crucial datasets are adequately archived.
- Creating value-enhanced datasets by linking together previously stand-alone, incompatible and mutually inaccessible observations, and by linking observations with models.
- Accessing relevant data from observations systems in neighbouring countries and from global observation systems, and in return supplying them with data which they need for the solution of regional or global problems.

SAEOS therefore is an infrastructure that cuts across several of the science missions, in that it will access the observational data generated in several of these missions, such as biodiversity (both terrestrial and marine) and its climate change and atmospheric components, space science data, Antarctica and Southern Ocean, earth science, and population and health data.

SAEOS as conceptualised does not require any capital investment for infrastructure. Its annual operational cost of about R 18 million for staff and running expenses includes the costs of leasing 10 Terabytes of fast access memory and backup capacity as well as fees for bandwidth and data acquisition.

7 Technology Infrastructure

The *technology missions* that were investigated in terms of competitive infrastructure requirements included:

- ICT
- Biotechnology
- Manufacturing Technology
- Resource-based Industries

Attention was also given to the following *frontier science and technology areas*:

- Nanotechnology
- Hydrogen economy
- Energy technologies, especially renewable energy
- Micro-satellite engineering
- Vaccine technologies

The following *high value industries* (as defined by *the dti*) have been investigated from a competitive R&D infrastructure perspective.

- Defence
- Aerospace
- Nuclear

7.1 Technology Missions

In discussing the infrastructure components for the Technology Missions, reference will be made to mission specific strategies where available either in draft form or approved form in order to assess the environment for infrastructure requirements according to the strategies concerned with specific reference in the strategy to infrastructure.

7.1.1 ICT

The ICT Technology Mission includes the focus areas of:

- Human Language Technology (HLT)
- High Performance Computing (HPC)
- Networks
    - SANReN (South African National Research and Education Network)
    - TENET (Tertiary Education Network)
    - UbuntuNet
    - International NRENs

- Wireless and satellite
- Human Computer Interfaces (HCI)
- Geo-information Science
- FutureWeb

7.1.1.1 The ICT R&D and Innovation Strategy and Infrastructure

The Information and Communication Technology (ICT) Research and Development (R&D) and Innovation Strategy (August 2005) has been completed in draft form and has not been released publicly. The purpose of the ICT R&D and Innovation Strategy is to create an enabling framework for the advancement of ICT R&D and Innovation, in a systematic fashion, within the context of the National Research and Development Strategy (NRDS). This strategy is the outcome of the foresight and subsequent technology road mapping exercises referred to in Chapter 2.

One of the main objectives of this strategy addresses *Effective Research Infrastructure* and is to ensure "the establishment of powerful research infrastructure supporting focused research and local and international collaboration".

A specific strategic intervention suggested addresses infrastructure in the following way:

"[An] R&D infrastructure programme - enabling simulation, experimentation, collaboration and other research processes, implemented through a number of specific infrastructures and by supporting research groups through equipment grants as required".

In the strategy document, the following is mentioned as critical infrastructure:

- SANReN, the broad band research and education network
- Centre for High Performance Computing
- Wireless test beds
- Speech technology laboratory
- e-Government laboratory
- Next generation network test bed
- Technology enhanced hearing laboratory
- Electronic design facility
- Tele-health laboratory
- Accessibility laboratory
- Future village

These are described in more detail in the strategy document: in the following way:

- SANReN: The establishment of the South African National Research and Education Network will provide an effective high capacity network to support collaborative R&D and innovation in general (not restricted to ICT R&D) in South Africa. In the case of

ICT R&D and innovation it will contribute not only to scientific collaboration between distributed researchers and between South African researchers and their international peers but it will also serve as a platform for research on new communication and networking technologies and ICT applications.

- High Performance Computing Infrastructure: Through the Centre for High Performance Computing (CHPC) a central facility for high performance software, hardware and ICT expertise will be developed for ICT and other researchers in the country. Tools to parallelise computer code, hardware to optimise cluster and other software development applications and porting tools will be provided. The CHPC will have dedicated laboratories in which all services and direct HPC and scientific computing research will take place. CHPC will actively establish geographically distributed nodes.

- Wireless Test-bed: This includes a test environment for experiments in wireless communication technology and demonstration of new approaches especially where simulation is not feasible, expensive equipment is needed, or where exemption of spectrum regulation is required. The test-bed infrastructure will include simulators, radios (including software defined capability), various network equipment, signal processing equipment, antennas, test measuring equipment, network monitoring equipment, RFID (Radio Frequency Identification), Ultra-Wide Band communications equipment and any other infrastructure that may be pertinent to wireless telecommunications research.

- Next Generation Network Test-bed: This will incorporate state-of-the-art optical technology and simulators to stimulate, anticipate and design the future South African and continental network for multicast multimedia. The test-bed will serve a broad array of problems driven by the needs and research goals of networking researchers. These include modifying and replacing network infrastructure components, protocols, middleware and applications.

- Technology Enhanced Learning Laboratory: A state-of-the-art technology enhanced learning laboratory supporting R&D in the field by providing infrastructure for e-education experiments. Participants will include learners, educators, educational psychologists, pedagogical specialists, educational technologists and ICT researchers. The laboratory will be used to investigate, research and develop advanced teaching and learning technologies and approaches, such as multimedia- and virtual-reality- enhanced learning environments (e.g. gaming and multimodal techniques), active, hands-on and collaborative learning technologies supporting social constructivist approaches, innovative approaches to content creation (e.g. learning object repositories and development tools) and novel educational devices and networking infrastructure.

- Tele-health Laboratory: A national tele-health research laboratory for the testing and development of cost-effective tele-health technologies, will support tele-health networks across the African continent. The tele-health laboratory will focus on technology to be used in Primary Health Care, together with the connectivity issues to be addressed in that environment. The tele-health laboratory will provide support for a virtual hospital telemedicine network to experiment with provision of access to specialist care to rural and distant communities and developing new technologies associated with such services.

- E-Government Laboratory: A facility that will allow the development and demonstration of e-government solutions and testing of these solutions with the stakeholders of e-government. This includes current research enabling future possibilities in areas such as:

  - Human Language Technology
  - Open Source
  - Mobile and Wireless

- Future Village: This includes infrastructure to test and enhance ICT aimed at deployment in rural communities. The facility will support active involvement from the community in the development and adaptation of ICT to local circumstances and the development of innovative new applications. The concept will support showcasing of new technologies and applications as a precursor to large scale rollout. In addition to testing technical feasibility, new business models supporting sustainable deployment will be developed.

Other infrastructure such as a speech technology laboratory, accessibility laboratory, electronic design facility etc. will be supported as the need for these becomes clear through the planning of critical mass research groups.

7.1.1.2 Competitive ICT Infrastructure Requirements

The strategic landscape provides a thorough base for the roll-out of a competitive infrastructure plan. This investigation focused on the immediate needs for ICT infrastructure and addresses ICT according to the main areas identified by the foresighting, *viz.*:

- Human language technologies
- Human computer interaction
- High performance computing
- Wireless and satellite
- Geo-information science
- Future web

The infrastructure components that are subsequently discussed are identified as crucial to a competitive ICT component in the NSI.

7.1.1.3 Human Language Technologies (HLT)

The ICT R&D and Innovation draft strategy addresses interventions around HLT as follows:

"Human Language Technology (HLT) holds immense promise for bridging the digital divide, since it provides means for people with limited literacy to interact with modern information sources. Research focusing on HLT (text-based language processing and speech processing) will support innovations in our multilingual society to serve the developing world context and other multilingual societies (including, for example the European Union)".

In terms of implementation, the strategy states:

"An HLT Research Network will facilitate collaboration on a focussed research plan by institutions that are currently doing research and development of technologies and applications in speech technology, translation and human factors in South African languages".

Research areas are stated to include:

- Speech processing including Speech Recognition and Speech Synthesis in local languages
- Natural Language Processing including statistical translation in local languages
- Human factors in Speech applications
- HLT resource collection
- Application of HLT, e.g. to extend access or to support multilingualism

This study revealed that critical infrastructure is required to advance the objectives for these focus areas in the strategy.

The high level models developed to date for infrastructure components in this focus area of the strategy revolved around the following aspects:

- Resources and capacity building
- Standardisation
- Enabling technologies

The enabling technologies typically include:

- Speech recognition
- Language processing
- Language synthesis and generation

The history of developing a national focus for HLT includes negotiations between the NRF, DST and Department of Arts and Culture to create a national facility around the resources and capacity building as well as a proposal for a Centre of Excellence by the University of Stellenbosch. Both these initiatives were met with considerable enthusiasm, and have been referred to the Department of Arts and Culture as lead department responsible for promoting the official languages some years ago. No decisions regarding either have been forthcoming from this department.

It is suggested from a competitive infrastructure point of view that a ***National Centre for Human Language Technology*** be created as a matter of urgency.

This centre should consist of three main elements:

- A facility for resources and capacity building
- A facility for enabling technologies
- Management and standardisation

This approach proposes to set up the required support infrastructure under the DST and to include the engineering and technology aspects of HLT. This includes technologies for speech recognition, language processing, language synthesis and generation. The resource centre becomes a databank of human language reference material, speech records and a national collection of references to develop speech technology. This is heavily dependent on advanced storage technology, data banks, databases and redundancy and data security management processes. The advantage of making this a central facility that will be very visible and that networks with the several other laboratories that already conduct R&D work in this field (University of Stellenbosch, North West University, the Meraka Insitute and the University of Pretoria) is recognised. An amount of R 50 million will be required to establish such infrastructure. The motivation for creating a centralised data centre for language resources is based on the fact that it is expensive technology, difficult to develop and that it should be managed similar to a national collection or tissue bank or a bioinformatics network for national access to language reference material. It is envisaged that the language resources component and standardisation and management be co-located in a physical facility which will require a new building. Language technology activities could be co-located, but also where they already exist elsewhere, be networked in. The most appropriate location for the new National Centre for Human Language Technology would be Stellenbosch, given the existing expertise there. Such a centre will also serve as a critical mass centre for HLT in the country.

The language technology researchers also have well established links with Africa and such a resource could be extended to become a regional facility, linking strongly with language standards that are developed for the whole continent. Such a facility could also replace neglected sound archives that may still be available, but which are not managed well, with the result that some losses have already occurred.

A dedicated group totalling between 20 and 25 people will be required to staff such a national centre.

7.1.1.4 Human Computer Interaction (HCI)

The ICT R&D and Innovation draft strategy describes the domain of HCI as: "The effectiveness of ICT systems depends crucially on interfaces between humans and computers. The study of such interfaces is a significant activity worldwide, and South Africans have developed expertise in areas such as usability and ergonomics, data visualization, and virtual reality. Such "traditional" HCI research can be combined with a strong multicultural focus, to extend the usability of ICT systems in a variety of ways that will serve our people and their needs".

The implementation aspects include: "An HCI Technology Research network [that] will facilitate collaboration on a focussed research plan by institutions that are currently doing research and development on Human Computer Interface technologies and applications…"

Research areas will include:

- Cultural factors in HCI including intercultural and multicultural issues
- Application of HCI to address barriers to access and use
- Visualisation
- Non-visual interfaces
- Accessibility
- Education [Curricula for HCI]
- Kids and Computers
- HCI and the World Wide Web
- HCI Design, evaluation and test processes
- Virtual and Augmented Reality

It is clear that the networking approach does not require a centralised infrastructure and that infrastructural components will be linked to specific research activities. The HCI aspect of the ICT technology mission has not been developed into a full strategy in the technology road mapping and is not distinguishable as an infrastructure issue. It is, however, part of many of the other areas as a delivery interface and should be covered in discussions on the other ICT focus areas.

7.1.1.5 High Performance Computing

The ICT R&D and Innovation draft strategy addresses high performance computing as a domain by stating: "The need for solving increasingly complex problems requires the handling of very large datasets and volumes of data, all of which make higher demands on the available computing capacity required. Solving such problems is efficiently achieved by using networks of connected computers; such distributed networks are also a mechanism for utilizing the tremendous number of computer cycles that are currently being wasted on a daily basis".

In terms of implementation the strategy states: "A Centre for High Performance Computing (CHPC) is currently being planned as a Research Centre under the Meraka Institute in collaboration with the University of Cape Town and the University of the Western Cape. The CHPC will have as its central mission the provision of high-end computing and computing expertise for all research in South Africa, including disciplines ranging from the natural sciences, medicine, engineering and social sciences. The CHPC will be a central holding house of scientific computing and HPC research activities and will foster research that will address grand challenges and grow computational research alongside experiment and theory across all academic disciplines, as a third mode of research and peer methodology".

Research areas will include:

- Materials modelling and minerals processing and computational fluid dynamics
- Bioinformatics, and medical imaging technologies
- Geophysics, with potential impact on the oil exploration industry
- Computational chemistry, drug discovery and design, HIV/AIDS research, molecular modelling to improve process mining
- Short and long-term climate systems modelling
- Modelling and simulation in the social sciences and economics
- Radio-astronomy and astrophysics, with particular reference to the SKA project
- Image and visualisation technologies
- Data mining and optimisation
- GRID technology and systems
- Defence applications

It is recommended that the establishment of the ***Centre for High Performance Computing*** (CHPC) be continued and expanded as a critical competitive infrastructure component. It is clear that the CHPC as a central infrastructural component is critical to many of the other science and technology missions and that it is critical to setting up a competitive NSI.

A positioning paper[21] on HPC states that it deals with two main components:

- Computational Science
    - Simulation
    - Database mining
- High Performance Computing as embedded in Computer Science
    - Advanced computing platforms
    - Future computing technologies
    - Cluster principle
    - GRID[22] computing

The positioning paper further states that: "…high performance computing facilities is of central importance to the success of the technology missions identified in the National R&D Strategy. Key examples in this regard are Biotechnology, particularly with reference to research into the major infectious diseases such as HIV/AIDS and tuberculosis, advanced manufacturing technology (e.g., computational simulations of design and manufacturing processes, and computational materials design), technologies to utilise and protect our natural resources and ensure food security (e.g., climate systems analysis and disaster forecasting), and technology for poverty reduction (e.g., behavioural modelling in social research; financial management; HPC in

[21] *High Performance Computing in South Africa: Computing in Support of African Development*, R Adam, C de la Rey, K J Naidoo and D Reddy, CT Watch Quarterly, February 2006

[22] Applying the resources of many computers in a network to a single problem at the same time – usually a scientific or technical problem that requires a great number of computer processing cycles or access to large amounts of data. GRID computing uses software to divide and farm out pieces of a program to as many as several thousand computers, www.bl.uk/about/strategic/glossary.html

SMEs). Similarly, a number of science missions were identified in the R&D Strategy as standing to benefit from the establishment of an HPC; examples are the Square Kilometre Array (SKA), the National Bioinformatics Network (NBN) and Global Earth Observing System of Systems (GEOSS). High Performance Computing is therefore clearly perceived, in relevant national strategic plans, to be a platform for scientific and technological innovation through which the national R&D strategy can be accelerated".

The analysis under the Science Missions in this report also makes it clear that many aspects of competitive research in these fields are critically dependent on HPC.

Funding for three years (2006-2008) has been secured for the high performance computing initiative. In addition, parallel investment in a South African National Research Network (SANReN), intends to provide high bandwidth connectivity for South African researchers (see section 7.1.1.9).

The funding that has been secured for HPC is:

2006: R 10 million
2007: R 50 million
2008: R 60 million

The position paper further states that: "The core CHPC facility will be established in Cape Town (UCT) [in a building on the Rosebank premises of the CSIR], with the University of Cape Town designated as its formal host. The considerable existing strengths in scientific computing at various research institutes in South Africa form a large pool of expertise on which the CHPC will be based. Indeed, planning for the establishment of a CHPC began in Western Cape universities with a group of researchers in areas such as computational chemistry, grid computing in theoretical physics, climate modelling, bioinformatics, computational mechanics, radar signal processing and machine vision. Since assuming national proportions, the pool of expertise in scientific computing and HPC has been expanded, for example to include groups in computational physics at universities in Limpopo and Kwazulu-Natal provinces".

The main founding members are:

- GRID computing (mainly UCT Physics)
- Molecular modelling (UCT Chemistry)
- Climate modelling (UCT)
- Advanced radar development (UCT)
- Materials modelling (UCT and University of Limpopo)
- Bioinformatics (University of the Western Cape, UCT, University of Stellenbosch (US), Rhodes University (RU), the University of the Witwatersrand (Wits), the University of Pretoria (UP), the University of KwaZulu-Natal (UKZN) and the University of the Free State (UFS))

It is planned that about 40 people will be employed by the CHPC. In addition about 120 scientists in 10 special interest groups will be serviced.

The CHPC will be centralised initially as a national initiative, but as demand increases, more centres may be added. The centre will also interact with existing clusters located at research institutions and form a grid of clusters. The facility will be managed by the Meraka Institute. The research: commercial user mix is set at 70:30.

The idea is that ultimately a central cluster of about 1 000 CPUs is established (although it may grow from an initial 256), with other existing smaller clusters linking into it. Additional computing infrastructure will include:

- Vector computing
- Virtual Reality cluster
- Data bank

It is seen as essential that critical mass will be built by having a central HPC facility. Apart from setting up the infrastructure for which a budget of about R 120 million has been committed over 3 years, a long term commitment to expanding and renewing such a centre is important. It should have the status of a national facility.

The facility is dependent on personal computer technology arranged in a cluster. Such technology has to be renewed every three years and budgeting has to allow for this in a sustainable funding support scheme.

Processing for large data streams such as to be generated in the Karoo Array Telescope (KAT) and Square Kilometer Array (SKA) (if the bid is allocated to South Africa) should be budgeted for separately, with possible dedicated infrastructure, such as data compression, processing and networking to be supplied to these projects.

Initial focus will be on projects such as:

- Virtual Reality (movie industry)
- SKA post processing
- Linking with a cluster on site at KAT in Pinelands
- Bioinformatics
- Software on demand (Open Source Systems)

Commercial computers will be bought with a cluster based on CPU (Central Processing Unit) chipsets, supported by Linux networks.

The linkage of the CHPC and SANReN is crucial. Centres such as this will put South Africa on the first tier of major GRID computing experiments internationally. GRID computing though is still in an experimental phase and once it becomes more accepted, such a centre will be crucial to enable competitive participation for South Africa as a country.

Government should prepare itself to sustainably support the CHPC and its derivatives that will develop over the long term, commitments that may run from 10 to 15 years.

The South African Weather Services has very recently installed a High Performance Computing facility to replace its old equipment. It is a vector machine with 8 CPUs with a 17 gigaflop processing capacity (~140 gigaflop/second in total) as well as several hard discs with 1.3 Tera-byte capacity. The computer is used four times a day for weather forecasting purposes when it runs for about one hour, and from time to time for other big internal processing tasks. The South African Weather Services would consider making the machine available for others on request, although it would then require some support staff to assist outsiders with the setting up the data and for data processing. Licensing agreements with the provider place some restrictions on usage, e.g. excluding nuclear research. This facility could become a key component of the GRID as envisaged above.

7.1.1.6 Wireless and satellite

The ICT R&D and Innovation Strategy describes the domain of wireless and satellite technology (as mobile technologies) as: "The need for low-cost access and the creation of the information society in South Africa are drivers for innovation in communications technologies including cellular networks, mobile Internet and mobile e-commerce, voice and data services, broadband Internet services, IP and digital video broadcast services on fixed satellite systems, and digital broadband entertainment".

The implementation involves: "A Mobile, Wireless and Satellite Technologies Research Network conducting long-term interdisciplinary research in appropriate mobile, wireless and satellite technology will be initiated through development of a research roadmap by the top researchers and leaders in the field. The technical focus areas will be agreed and implemented through appropriate R&D projects. One focus of the initiative will be affordable broadband for all. Another focus will be the fast-growing field of Radio Frequency Identification (RFID)…"

Research areas will include:

- Ad-hoc wireless networks
- Software defined radios
- Mobile applications (e.g. geomatics applications and applications in government)
- Information Security in wireless networks
- RFID in manufacturing, supply chain, logistics and asset tracking

The satellite component refers to using satellites as a communications medium and not to the micro-satellite industry that is emerging in South Africa (see separate discussion in section 7.2.4).

The major focus here is to create live laboratories in real community context and to develop a wireless test bed. It is recommended that a ***Wireless Test Bed*** be established. Such a wireless test facility requires a dedicated building, various nodes and software to test wireless protocols. The estimated cost of the infrastructure required for a wireless test bed is R 20 million.

7.1.1.7 Geo-information science

This field involves Geomatics and Spatial Technologies. The domain is defined by the strategy as: "A well-developed national information infrastructure, enabling the dissemination and sharing of valuable, geographically referenced information is widely accepted as an essential asset for any country to maintain and to advance its social and economic well-being. These technologies are developing rapidly and undergoing convergence with other application areas, allowing new services to citizens and governments".

The implementation suggested by the strategy involves: "An Interdisciplinary Geomatics Research Group will be established to conduct collaborative research in computational domains in support of spatial applications (and later environmental and biomedical informatics). The group will facilitate collaboration between the spatial and computer science communities and will work closely with other groups in the fields of high performance computing and domain groupings focused on the application of cyber infrastructure. The focus of this group will be on research leading to the development of technology domains in support of the broader geomatics area, but with application potential in other emerging fields dealing with the same challenges. The group will concern itself initially with the computational issues in spatial and geographic information science".

Research areas will include:

- Integrated spatial data handling
- Automation of monotonic processes
- Scale and scope of spatial data and computation
- Dealing with complexity and non-monotonic reasoning in drawing conclusions from spatial data

Geo-spatial information is covered in more than one mission where spatial information is an important support mechanism. A possible need was identified for a Geospatial Analysis Test Bed. This facility has not been scoped yet and is not included in the cost estimates for competitive infrastructure. It will have to be part of the interdisciplinary research group. The built environment will especially benefit from having such infrastructure available. Elements of this will also impact on technology for poverty alleviation.

7.1.1.8 Future web

The Future Web involves not only new protocols, but also new ways of using the World Wide web. Two of the current emerging environments of future web use is the so-called "wikis" and "blogs."

Wiki[23]: A website or similar online resource which allows users to add and edit content collectively.

[23] "Wiki wiki" means "rapidly" in the Hawaiian language

Blog: Blog is short for weblog. A weblog is a journal (or newsletter) that is frequently updated and intended for general public consumption. Blogs generally represent the personality of the author or the Web site.

Future web developments[24] world wide include projects such as the so-called Internet2. Internet2 refers to a project to develop new technologies for high-performance computer networking[25]. While specifically developed to facilitate research and educational purposes, the involvement of research, commercial and government organisations also aims to distribute this technology into the wider community. Internet2 is a non-profit consortium which develops and deploys advanced network applications and technologies, mostly for high-speed data transfer. It is led by more than 200 United States universities and partners from the networking and technology industries (such as AT&T, Intel, Sun Microsystems, and Cisco Systems). Some of the technologies it has developed include IPv6[26], IP multicasting and quality of service.

Internet2 includes replacement of packet switching of light in optical fibre by switched light paths technology where peer to peer communication between two computers can take place without breaking the data into packets. This allows for faster transmission.

In a recent workshop on the future of the Web,[27] the following was stated by Sir Tim Berners-Lee, the inventor of the Web:

- The mobile web heads for lift-off.
- "Net neutrality" as a single entity is crucial to the philosophy of the Web.
- IP television and video will start to flood the web.
- Blogs represent the original concept for the web which allows users to edit and add content to web pages, yet it is only recently that this idea has been realised.
- Tools like blogs and wikis are changing the way people work and communicate.
- The next great vision for the web, although it has been talked about for five years, includes the idea of making web pages understandable by machines, known as the semantic web. This now seems to be given serious attention.
- Personal semantic software robots that could organise one's life by bringing together data from calendars, retail information, health records and even global positioning satellites are in the mainstream discussions.
- The semantic web has the potential to drill into this data deeper than ever before and people will have to start taking more seriously the idea of having a life online.

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[24] www.parliament.vic.gov.au/sarc/E-Democracy/Final_Report/Glossary.htm
[25] en.wikipedia.org/wiki/Internet_2
[26] A plan for expansion of the domain name system. It stands for Internet Protocol version 6, a next generation version of the internet protocol. It includes improved address space, quality of service and data security over IPv4, the currently used protocol.
[27] WWW2006, BBC-News, 26 May 2006

Ideas like the semantic web are still in the more remote future, and time scales for implementation are uncertain. Some of the necessary infrastructure is complete in the world and people are now building the tools to create the vision.

FutureWeb was recognised as a strategic priority by the foresight exercise in South Africa. South Africa's role in future web developments has not been explored by a technology road mapping exercise. The main issues refer to being able to link to future web developments world wide such as Internet2. The next generation research and education networks such as Géant2 rely on this new generation technology. At present TENET (Tertiary Education Network) is connected to Internet2.

Géant2 is described as a "Next generation network with massive performance of 500 Gbps [and is] a global reference for scientific networking excellence. The network provides standard IP connections alongside switched links on some routes. The switched circuits provide dedicated point-to-point links, when needed, for the most demanding applications[28]".

7.1.1.9 SANReN (South African National Research and Education Network)

National Research and Education Networks and International Connections

SANReN is a super research and education Intranet. Over the past decade, many countries have formed national research and education networks (NRENs) that inter-connect their universities and research establishments at high-speed but which do not provide connectivity to the Internet generally. Consequently NRENs protect research communications from competition with and network congestion arising from general web browsing, file swopping, email or other interactions with the commodity Internet. "Inter-connect" networks such as Géant in Europe, Internet2 in the USA, Asia Pacific Academic Network (APAN) in the Far East, inter-connect NRENs and connect to each other at very high speeds, thus forming a global high-speed network ("the global research network") that, while it is part of the Internet, carries only traffic that passes between institutions that connect to some NREN.

A South African NReN

The ICT R&D and Innovation Strategy states: "The ICT R&D strategy objective for R&D and Innovation Infrastructure is to implement effective research infrastructure supporting the research, innovation and international collaboration aspects of the strategy. This includes establishment of a powerful South African National Research and Education Network (SANReN) that supports large-scale, nationally cross-cutting ICT R&D and innovation. SANReN should establish strong linkages to other NRENs across the world (such as the European Géant network, CANARIE (Canada) and AREN/AARNET (Australia)), to facilitate international collaborative R&D in general and ICT specifically".

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[28] Quote from presentation by D Martin, *Research and Education Networking in Eastern and Southern Africa*, Workshop on e-Infrastructure Partnerships for African and European Researchers, Pretoria, 2 May 2006

Locally, SANReN will inter-connect the research councils, other research institutions and facilities within statutory bodies, government departments and elsewhere, and the universities, and connect them at high speeds to research networks globally.

The DST is in the process of inviting Requests for Proposal (RFPs) for the establishment of SANReN. The time scales for implementation allow for SANReN to be commissioned before the end of 2006/7 financial year (ending March 2007). The DST will be the overall sponsor and owner of SANReN and implement the SANReN through the Meraka Institute

In accordance with its mandate, as stated in the National R&D Strategy (2002), to create a new ICT Technology Platform for Research the DST issued a SANReN Request for Information (RFI) on 11 July 2005[29]. The DST has decided to separate the procurement of the local SANReN itself from the procurement of SANReN's international connectivity. The DST intends to run one or more separate procurements for SANREN's international connectivity to the European Commission's Géant network in Europe, and to other research networks such as Internet2's Abilene network in the USA, the Australian AARNet and the TEIN2 network in the Far East, as well as to networks and/or institutions in neighbouring countries. This Request for Proposal calls for proposals from network operators that are interested in being "the SANReN Operator" – i.e. in providing and operating the SANReN backbone network, points of presence, and the access circuits to specified sites. The DST appointed the Meraka Institute to act as its agent in all operational and administrative matters concerning SANReN.

A special feature of SANReN will be to allow SANReN users and sites to be able, in a managed way, to conduct networking experiments and run non-standard protocols within and over SANReN, without thereby disrupting services on other parts of the network or coming into conflict with operational standards and procedures that apply to other parts of the network.

TENET

Tertiary Education Network (TENET) is an Association Incorporated under Section 21 of the Companies Act in South Africa. TENET was founded in August 2000 jointly by the then Committee of Technikon Principals (CTP) and the then SA Universities Vice-Chancellors' Association (SAUVCA). These two bodies have since merged to form Higher Education South Africa (HESA).

TENET's main purpose is to secure, for the benefit of South African universities, Internet and information technology services, such as the management of contracts with service providers, ancillary operational functions in support of service delivery and the provision of other value-added services as may from time to time be needed in support of the higher educational sector in South Africa

TENET and TELKOM signed an agreement for the provision of general Internet access and mutual inter-networking to higher education and research institutions. International Internet

[29] South African Research Network (SANReN), Request for Proposal for the SANReN Network (excluding international connectivity), FINAL, April 2006

access is provided by a specified amount of bandwidth on the SAT-3 submarine cable that is dedicated to the higher education institutions collectively, but shared between them. International access makes use of TELKOM's international peering arrangements in London, Amsterdam, New York and Ashburn, Virginia, as well as of TELKOM's backup arrangements whereby the SAFE cable, which crosses the Indian Ocean from Malaysia, with connections from there across the Pacific to the USA and the Internet generally, may be brought into use, if necessary. In addition, the network has a provisional connection to Géant in London.

TENET runs at 130 Mb/s over the SAT3 cable in the Atlantic. The landing point is in Cape Town. TENET has two international connections, one with Abilene in New York, carrying 60% of the traffic and one with Géant, carrying 40% of the traffic.

National Internet access is provided by a specified amount of bandwidth into the SAIX network and its peering arrangements with other first-tier ISPs (Internet Service Providers).

SANReN Link with TENET

It is envisaged that there will be a gateway between SANReN and the TENET network, via which every institution that connects to the TENET network will have access to the SANReN network and, in particular, to SANReN's connections to Géant and other research networks internationally. Once this gateway is operational, the present connection between Géant and the TENET network will be terminated. Institutions that connect to the TENET network will be entitled to connect directly to SANReN, and it has been recommended by DST that those with large communications needs via SANReN should commission these links.

SANReN and TENET will be managed as two working networks. The management model for TENET is bottom-up in the form of a Section 21 Company owned by a consortium of Higher Education Institutions. The management model for SANReN will be top down, with government owning the network and the PFMA (Public Finance Management Act) governance applying. Eventually, the two networks may merge.

Bandwidth specifications in SANReN

The following bandwidth specifications emerge from the RFP:

- The TENET gateway facility should be located in Cape Town. Its capacity should be 512 Mb/s. The TENET gateway is to be regarded as an additional SANReN site.
- Each SANReN local access router (site router) will be located in a secure, managed environment to be provided by the site, and will have a gigabit Ethernet interface to which the site may connect its LAN.
- File transfers in both directions that are sustained at no less than 700 Mb/s for at least 30 minutes between the SANReN sites at the Hartebeesthoek Radio Astronomy Observatory and the University of Cape Town.

- File transfers via the TENET gateway in both directions that are sustained at no less than 10 Mb/s for at least 30 minutes between the SANReN sites at the Hartebeesthoek Radio Astronomy Observatory and Rhodes University.

The RFP for local connection specifies that SANReN should meet the following specific research requirements:

- Hartebeesthoek Radio Astronomy Observatory: The Hartebeesthoek Radio Astronomy Observatory participates in the global Very Long Baseline Interferometry (VLBI) project. There is an urgent requirement to connect the Observatory to Géant at least at 1 Gb/s for purposes of transferring very large data files from the telescope at Hartebeesthoek to the processing centre in the Netherlands. This requirement will grow in 2006 to 2.5 Gb/s and then to 10 Gb/s and possibly more over the next three years.
- Centre for High Performance Computing (CHPC): The CHPC will be a major SANReN node. Users will access the CHPC's computational resources via SANReN.
- National Bioinformatics Network (NBN): The National Bioinformatics Network has nodes at the CSIR and at the Universities of Cape Town, Limpopo (Polokwane), Pretoria and the Western Cape and is currently deployed using ADSL technology. The research program is severely constrained by the systemic inability to download large files from genomic databases at major research centres in other countries. SANReN will alleviate this problem when the NBN nodes connect instead to SANReN.
- ALICE (A Large Ion Collider Experiment) Project at UCT: The high-energy particle research group at the University of Cape Town urgently requires the capacity to download large research data files, via Géant and SANReN, from the European nuclear research facility at CERN, Switzerland.
- SALT (Southern African Large Telescope) in Sutherland: In collaboration with a number of international partners South Africa has built the largest optical telescope in the Southern Hemisphere. SALT will require high capacity bandwidth to ensure exchange of data from the telescope with researchers elsewhere in the world.
- Video-conferencing and video-streaming: Many researchers express the need for regular video-conferences with fellow researchers at other institutions and for having access to streamed video from conferences being held elsewhere. SANReN intends to support researchers in this way.

Establishing high-speed connections with the facilities described above in the very short term provides concrete examples of South Africa's high speed network capacity. This would specifically enhance the South African bid for the SKA radio telescope, which has been submitted in December 2005.

SANReN Architecture

The RFP for local connections states the following architectural components:

Backbone architecture

Research networks commonly use backbone architectures, rather than cloud architectures, because of the intermittent requirement to transport very large files and relatively low numbers of concurrent sessions. DST envisages a backbone network within South Africa (and eventually reaching into neighbouring countries) that inter-connects nodes or Points-of-Presence (PoPs), some or all of which may be located at major user institutions. Sites (other than those that host PoPs) will connect via local access circuits to the nearest PoP. Traffic flows will be far more variable – i.e. less predictable – than those on networks, such as the TENET network, which provide general Internet access to tens of thousands of concurrent users. The links of the backbone network should be sized to cater for the expected peak demand for large file transfers from major users. Research network design is about providing lots of bandwidth – not about providing ways to prioritise different traffic classes over systemically congested links.

Use of non-standard protocols

In common with other NRENs, SANReN will experiment with and use non-standard Internet protocols, such as Tsunami and other specialised file transfer protocols, in addition to the standard suite of Internet protocols.

IPv6 as well as IPv4

While the bulk of SANReN traffic is expected to be IPv4 traffic, SANReN should support native IPv6 connectivity between SANReN sites and via the international gateways.

Address Space and Autonomous System Numbers

SANReN institutions will provide their own Internet address blocks (IPv4 and IPv6) or will be assigned the addresses blocks that they require by TENET. Likewise SANReN will provide its own autonomous system numbers for use in route announcements nationally and globally. Communications network service providers will not be required to provide address space for SANReN nor to announce SANReN addresses as originating within their own autonomous systems.

Possible use of dark fibre[30] and/or wavelengths

Many NRENs in Canada, Europe, the USA and elsewhere have realised substantial cost savings by purchasing rights to use unlit fibres and/or wavelengths on other party's fibre infrastructures. DST is interested in the possibility of deploying the SANReN Backbone (and possibly also the local access circuits to some of the connecting institutions) by procuring rights to use unlit fibres and/or wavelengths within licensed providers' infrastructures.

[30] Dark fibre is optical fibre infrastructure that is currently in place but is not being used.

SANReN will not be a normal customer IP network.

SANReN should not be seen as a normal customer IP network that can be configured within normal transport and routing infrastructures, within which SANReN traffic inter-mingles with non-SANReN traffic on other customers' networks.

SANReN should thus be a dedicated backbone with links inter-connecting SANReN PoPs and Gateways, with these PoPs and Gateways being hosted externally, and with each site (other than one that hosts a PoP) connected by a dedicated link to a suitable PoP. Network service providers bidding for SANReN are invited to consider whether their own research activities could benefit from participation in SANReN as a user and to explore the possibilities of a partnership relationship with SANReN as both provider and user.

Planned SANReN Sites

The RFP provides the following list of sites and bandwidths required:

Table 2: *Proposed institutions to be linked to SANReN*

Site Description	Priority	Bandwidth (Gb/s)
Gateways		
- International Gateway, Cape Town	1	1.0
- International Gateway, Durban	1	1.0
- International Gateway, Gauteng	1	1.0
- TENET Gateway, Bellville	1	0.5
Statutory Research Bodies		
- Agricultural Research Council, Pretoria	2	0.5
- Council for Geoscience, Pretoria	2	0.5
- Council for Mineral Technology, Randburg	1	0.5
- CSIR		0.5
- Pretoria	1	0.5
- Satellite Applications Centre, Hartebeesthoek	1	0.5
- Satellite Applications Centre, Hekpooort	1	0.5
- Durban	2	0.5
- Port Elizabeth	2	0.5
- Cape Town	1	0.5
- HSRC, Pretoria	2	0.5
- Medical Research Council		0.5
- Bellville	2	0.5
- KZN	2	0.5
- National Research Foundation		0.5
- Hartebeesthoek Radio Astronomy Observatory (HartRAO)	1	1.0
- Head Office, Pretoria	2	0.5
- Hermanus Magnetic Observatory, Hermanus	2	0.5
- IThemba Laboratory for Accelerator Based Sciences, Faure	1	0.5

Site Description	Priority	Bandwidth (Gb/s)
- National Laser Centre, Pretoria	2	0.5
- South African Astronomical Observatory, Cape Town	1	0.5
- South African Large Telescope (SALT), Sutherland	1	0.5
- Nuclear Energy Corporation of South Africa, Pelindaba	1	0.5
- Water Research Commission, Pretoria	2	0.5
Other Research Entities		
- Africa Institute of SA, Pretoria	2	0.5
- KAT, Carnavon	2	0.5
- Marine & Coastal Management	2	0.5
- NBN		0.5
- Cape Town (UCT **– to be confirmed**)	1	0.5
- Cape Town (UCT **– to be confirmed**)	2	0.5
- Central, UWC Main Campus, Bellville	1	0.5
- Pretoria (NBI **– to be confirmed**)	1	0.5
- Pretoria (UP**– to be confirmed**)	2	0.5
- South African Institute for Aquatic Biodiversity, Grahamstown	2	0.5
- SAEON	2	0.5
Universities		
- North West University, Potchefstroom	2	0.5
- Rhodes University - Grahamstown	2	0.5
- University of Cape Town	1	0.5
- University of Free State, Bloemfontein	2	0.5
- University of Johannesburg, Auckland Park	2	0.5
- University of Kwazulu Natal - Durban	1	0.5
- University of Kwazulu Natal - Pietermaritzburg	1	0.5
- University of Kwa Zulu Natal, Westville	2	0.5
- University of Limpopo - Sovenga	1	0.5
- University of Port Elizabeth	2	0.5
- University of Pretoria - Main Campus	1	0.5
- University of South Africa - Pretoria	2	0.5
- University of Stellenbosch - Main Campus	1	0.5
- University of the Western Cape - Bellville	1	0.5
- University of the Witwatersrand - Johannesburg	1	0.5

International Connectivity

It is envisaged[31] that SANReN will enter into interconnection agreements with, and will connect to a number of research and education networks (RENs) worldwide, including the European Commission's Géant network, Internet2's Abilene network and various NRENs in Africa as these emerge. It is foreseen that such international connections will be made via some or all of the "African submarine cable systems", viz. the SAT-3 WASC, SAFE and EASSy (once installed) submarine cable systems, as well as via diverse terrestrial links that exist or are planned between South Africa and its neighbouring countries. This submarine cable network is shown in Figure 5.

[31] South African Research Network (SANReN), Request for Proposals for international connectivity required for the SANReN Network, Issued by the Department of Science and Technology, FINAL, April 2006

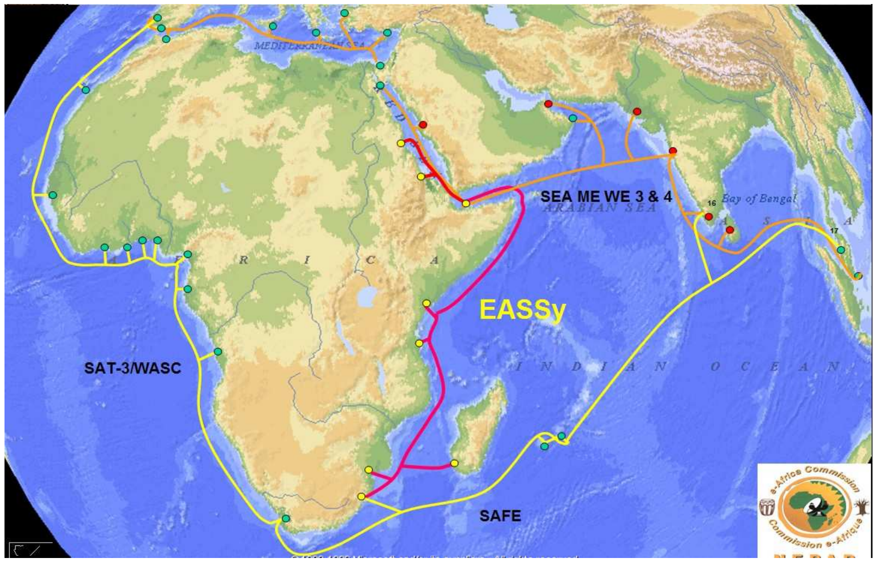

Figure 5: *Optical fibre gateways around the African continent*[32]

At the SANReN end, each international link will emanate from one of three SANReN International Gateways – one in Cape Town that is positioned to exploit the SAT-3 WASC cable; one near Durban that is positioned to exploit the SAFE and EASSy cables (this also allows for redundancy planning); and one in Gauteng that is positioned to cater for connections to institutions and NRENs in neighbouring countries.

At the foreign end, each international link emanates from a Foreign Exchange Point, which may be an international gateway of the NREN concerned, or may be an exchange point such as Telecity in London, where Géant has a point of presence, or 32 Avenue of the Americas in New York City, where Internet2's Manhattan Landing exchange point is located. In some cases a foreign NREN international links with SANReN may emanate directly from one of that NREN's own international gateways as a Foreign Exchange Point. SANReN does not envisage making use of links that include space segments.

The link capacity is stated as 1 Gb/s initially, with an upgrade to 2.5 Gb/s in 2008. Telkom core cable has a capacity of 1.5 Gb/s. SAT3 has a design capacity of 120 Gb/s. Géant has a 10 Gb/s capacity and the interconnection over the Atlantic a maximum capacity of 7.5 Gb/s. The SAT-3 optical fibre link has theoretically enough bandwidth. No need for additional international links is thus foreseen.

[32] From Powerpoint presentation: *NEPAD's Regional ICT Broadband Infrastructure Development Programme*, E-Africa Commission presentation, http://www.uneca.org/eca_programmes/it_for_development/events/accra/Financing/e-Africa%20Commission-brief%20presentation.ppt

SANReN Budgets

It is recommended that SANREN should be pursued and accelerated as the most crucial ICT infrastructure component. The data speeds of 130 Mb/s on TENET should be increased to the 1 Gb/s promise that SANREN holds. However, the SANREN budget may initially only allow for several 100s of Mb/s to be realised. The full exploitation of available bandwidth should be facilitated by negotiating in the regulatory environment as well as making funds available to buy the appropriate bandwidth. The link with Géant should also be optimised to ensure that no bandwidth bottlenecks exist across the Atlantic on the international links.

SANREN should consider connections to small and medium enterprises, large corporate R&D environments and science parks that are reliant on R&D data.

The budget for SANReN has not been determined yet, but it is estimated that it will require of the order R 100 million to R 200 million per annum to ***maintain the broadband service*** and to buy into extra bandwidth as it is required. There is a three year roll-out plan, with the first links envisaged to be made by the end of 2006. The 2006 budget for this is R 22 million. Over the Medium Term Expenditure Framework (MTEF), an amount of R 178 million is budgeted for SANReN. Phase 1 makes provision for linking with the CHPC. Phase two accounts for inclusion of the KAT and SKA projects. The first phase of the project is scheduled to begin at the end of 2006, assuming the tender process flows smoothly, and forms R22 million of the tender. The second phase for further deployments will begin in about March 2007, and is worth R67 million.

UbuntuNet

Research institutions and universities in neighbouring countries will be able to connect to SANReN. Such connections will depend upon the availability and cost of adequate terrestrial and cross-border connectivity.

Established and emerging NRENs in Kenya, Malawi, Mozambique, Rwanda and South Africa have come together as the founders of a new grouping: the UbuntuNet Alliance for Research and Education Networking[33]. Potential additional members include: Tanzania, Zambia, DRC (Democratic Republic of the Congo) and Congo, Burundi, Botswana and Namibia. At present the active members are thus from Eastern and Southern Africa.

The UbuntuNet Alliance plans to link NRENs in its membership region through Géant to other academic and research fibre networks around the globe. The UbuntuNet Alliance is registered in the Trade Register of the Chamber of Commerce and Industry of Amsterdam, pending incorporation as a non-profit association. The Interim Secretariat of the Alliance is University of Malawi.

The objectives of UbuntuNet include:

[33] http://www.ubuntunet.net/index.htm

- To deliver very high speed - gigabits (Gb/s) connectivity instead of the current kilobits (kb/s) between African Universities and Research Institutions and therefore be at par with universities on all the other continents.
- To gain access to bandwidth on the EASSy cable (once established) at a very low price.
- Ultimately to be able to secure adequate connectivity to the European Union's Géant network and the Internet generally.

NReNs in Africa

The following status is reported on NReNs in Africa[28]:

Table 3: *NReNs in Africa*

Operational NRENs
• KENET (Kenya)
• MALICO/MAREN (Malawi)
• TENET (South Africa)
NRENs in formation
• MoRENet (Mozambique)
• RWEDNET (Rwanda)
• SANReN (South Africa)
• TENET (Tanzania)
• RENU (Uganda)
Projects starting up
• Botswana, DRC, Namibia, Somalia, Sudan, Zambia

Figure 6: *The proposed broadband network for Eastern and Southern Africa*[32]

UbuntuNet has the potential to become the African Géant. It is crucial that the SANReN planning takes into account linkages with UbuntuNet.

Interlinkage of Broad Band Networks

Figure 7 shows the various networks and gateways that will affect SANReN implementation. SANReN will initially be run in parallel to TENET. It will connect internationally to networks such as Géant and Abilene. Into Africa, it will link to UbuntuNet. SANReN will not be linked to the general Internet and users should make use of TENET or commercial links to access the Internet.

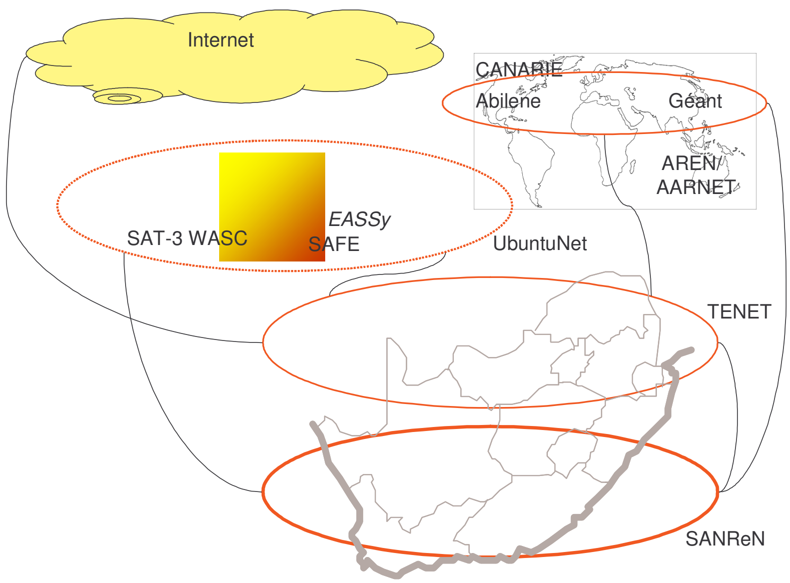

Figure 7: *Interlinkage of network infrastructure*

Crucial links to SANReN for the NSI

Figure 8 shows the crucial links with SANReN for the NSI. The fixed lines represent clusters of institutions as identified in the RFP and shown in Table 2. The dotted lines show types of institutions which are not in the planned connection scheme, but which should be considered. The SMEs refer to those that are dependent on research results and that exist close to the NSI as spin-outs or high tech enterprises.

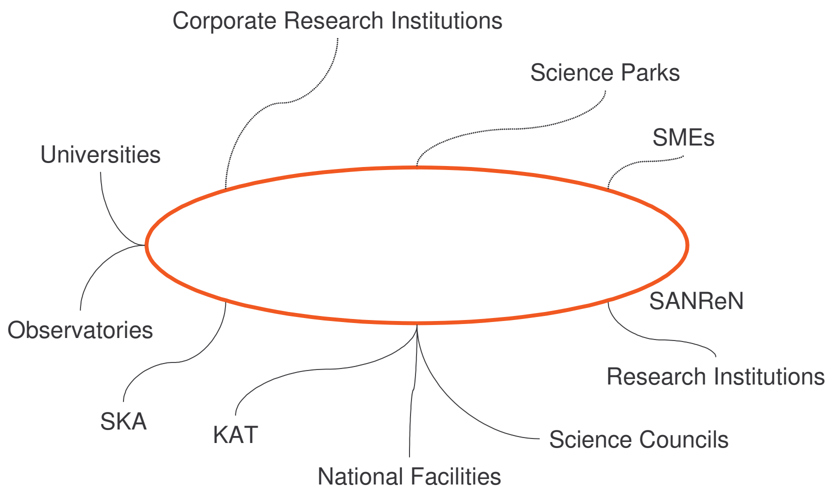

Figure 8: *Crucial links with SANReN for the NSI*

7.1.1.10 Centre for Monitoring and Evaluation

In implementing an ICT strategy and ensuring that the country as a whole benefits from such interventions, the establishment of a Centre for Monitoring and Evaluation should be considered. Such a centre will focus on:

- Ensuring the correct implementation of strategies and activities in ICT.
- Measuring the effect and outcome of interventions to ensure that the country as a whole and the economy benefits from the strategy implementation.
- Guiding long term strategy based on evaluating whether the original intent of the strategy is carrying through.

Such a centre will mostly consist of people with knowledge of ICT implementation and impact at policy, social, economic and enterprise levels.

7.1.2 Biotechnology

The biotechnology mission has been the longest under development, following the Biotechnology Strategy that preceded the National R&D Strategy. The strategy focused on the creation of Biotechnology Regional Innovation Centres (BRICs) to implement the interventions proposed in the strategy.

The Biotechnology Strategy[34] states on infrastructure that:

- "In bioinformatics, the establishment of services and support centres has been inhibited by the high cost (and to some extent low speed) of our communications infrastructure."
- "Bioinformatics has become an indispensable part of the infrastructure required for biotechnology research".
- "There are regions in South Africa that have a number of universities, technikons [now called Universities of Technology] and research institutes in close proximity. Most of these do not collaborate significantly with each other. All require similar infrastructure and equipment, but experience difficulty in acquiring them".
- "Biological Resource Centres (BRC) is an essential component of the infrastructure underpinning biotechnology R&D. They are responsible for preserving and distributing biological materials and information. They are crucial to the exploitation and maintenance of our diverse natural heritage."
- About the BRICS: "It is essential that each centre also accommodates a biotechnology incubator, which in turn will be linked to a number of spin-off companies, thereby ensuring that the outcomes of the R&D in the programmes have the necessary infrastructure to support their commercialisation".

7.1.2.1 Biotechnology Regional Innovation Centres (BRICs)

The Biotechnology Strategy states that BRICs will be established to provide technology platforms in response to the identification of biotechnology focus areas. Each BRIC will establish three or four programmes, according to regional expertise and markets. The technology platforms are envisaged as common areas where capital equipment and specialised expertise will be shared by the biotechnology programmes and industry. Two major components of the platforms have been identified as being crucial for the success of the biotechnology strategy:

- Biological Resource Centres (BRC)
- Bioinformatics Networks

In addition to these, which are considered to be essential facilities or technologies for all the BRICs, it was recommended that each BRIC specialises in a one of a number of more specific areas of technology, which are in turn well aligned with the national imperatives, local expertise and market opportunities. It is essential that each centre also accommodates a biotechnology incubator, which in turn will be linked to a number of spin-off companies, thereby ensuring that the outcomes of the R&D in the programmes have the necessary infrastructure to support their commercialisation. A further component of the BRICs network is the close association with regional anchor investors. These are large companies which will be attracted to the region, as a result of the development of the BRICs in overlapping areas of expertise. A key component of the success of the BRICs is the creation of strong international linkages with equivalent institutions that are at the leading edge of their field.
The mandate given to the BRICs was to:

[34] A National Biotechnology Strategy for South Africa, June 2001

- Create new business entities in biotechnology
- Develop biotechnology platforms
- Do capacity development

To date the following BRICs have been established:

- Biopad (City of Tshwane)
- LifeLab - EcoBio - East Coast Biotechnology Innovation Centre (Durban)
- Cape Biotech (Cape Town)
- PlantBio (Pietermaritzburg)

7.1.2.2 Biological Reference System

A Biological Reference System has been defined and discussed in section 6.3.2.4 and shown in Figure 3. Two aspects are of importance in assisting the Biotechnology Mission:

- Bioinformatics
- Biobank

7.1.2.3 Bioinformatics

Bioinformatics is the science of informatics as applied to biological research. Informatics is the management and analysis of data using advanced computing techniques. It comprises all aspects of the gathering, storing, handling, analysing, interpreting and spreading of biological information and involves powerful computers and innovative programmes which handle vast amounts of coding information on genes and proteins from genomics programmes. It deals with the so-called "dry" information in biotechnology.

The National Bioinformatics Network (NBN)[35] is made up of a network of nodes and a central node, each situated at a University. The mission of the NBN is to develop capacity in bioinformatics in South Africa, especially among disadvantaged groups, and to perform world-class bioinformatics research. The NBN has a central node at the University of the Western Cape. The central administrative and central core is responsible for setting up and managing the central computing and any mirror site equipment, the bioinformatics data banks and their regular updating, as well as communication lines with international data banks and the nodes. Nodes exist at:

- Central Node at the University of the Western Cape
- Rhodes University
- University of the Western Cape
- University of Cape Town

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[35] www.nbn.ac.za

- University of Stellenbosch
- University of the Witwatersrand
- University of Pretoria
- CSIR
- University of the Free State
- Agricultural Research Council (ARC)
- University of Limpopo
- Onderstepoort

The infrastructure component of the NBN mostly comprises of ICT infrastructure such as:

- PC clusters, used in GRID computing
- Clustering tools
- Data warehousing
- Databases
- Networking equipment

The main ICT infrastructural components are thus processing capacity, storage capacity and bandwidth. Dedicated bandwidth of 50 Mb/s is required from a facility such as SANReN.

The NBN is a key participant in the development of the CHPC in Cape Town and will be a principal beneficiary of SANReN.

A need has been identified to buy into international projects to do South African specific research in bioinformatics. Such international participation may cost up to R 20 million per project.

7.1.2.4 Biobank

A Biobank is a biological resource centre that processes, stores, and distributes tissue material, cells and collections of biological cultures. It deals with the so-called "wet" information in biotechnology. Such a biobank needs infrastructure for cryogenic storage of the following:

- Scarce species
- Endangered species
- Species threatened by major diseases (e.g. chickens and avian flu)

These storage facilities are supported by management systems and taxonomies to locate and retrieve samples for research.

Currently South Africa is in need of a ***Central Biobank*** as proposed in section 6.3.2.4. Such a central Biobank should take care of national collections that exist in several places that are not managed well, are not accessible, or that are threatened to disappear after their custodians retire or pass away. The danger of losing precious tissue cultures that are in the possession of individuals or individual organisations could be addressed by the establishment of such a Biobank. Satellite Biobanks will be required to support the biotechnology development facilitated by the BRICs. These satellites may cost up to R 20 million per site.

7.1.2.5 National Preclinical Institute

There is a need for the establishment of a ***National Preclinical Institute***. Such an infrastructural investment will localise preclinical tests and modernise existing disparate facilities. A major emphasis will be on animal holding and a new building is required that will represent excellence in one place and the eradication of duplication. Such a facility typically has a sterile environment, with separate air flow holding units. It contains clean rooms, laminar flow cabinets, and a sophisticated air filtering and supply system. In such a way preclinical tests for cancer, malaria and tuberculosis could be done separately in one facility. It is estimated that erecting such a facility may cost between R 150 million and R 200 million.

7.1.2.6 Vaccine Manufacturing/Bio-manufacturing

Vaccine technologies are mentioned as a Frontier Science and Technology. Currently the major activity is at the South African AIDS Vaccine Initiative (SAAVI) at the Medical Research Council (MRC). The BRICs also get involved in vaccine and drug development and a need for small quantity bio-manufacturing exists.

The commercialisation of vaccines and biotechnology products in the form of medication and drugs require an involved clinical trial period. For vaccines for human use the clinical trial phases are shown in Table 4.

Table 4: *Clinical Trail Phases*

Phase of Clinical Trial	Period for the trial	Number of people involved in being tested	Main emphasis
1	2.5 to 3 years	20 to 50	Safety of the vaccine
2	3 years	100 to 500	Immunity
3	4 years	5 000 to 10 000	Licensing

It can thus take a total of 10 years before a new vaccine or drug that is developed can be released commercially on the market. It would be too late to start developing infrastructure for production of vaccines once the clinical trials are completed. It also has to be realised that many clinical trials run in parallel with staggered start and end dates. After phase 2 a limited volume of the vaccine is outsourced for manufacturing to run phase 3.

The design of new vaccines with no manufacturing infrastructure in mind is a risky venture. At present limited local capacity exists for vaccine and drug manufacturing and is located in the private sector. The main emphasis in South Africa is on packaging of the vaccines. Extension of the local infrastructure to include both manufacturing and packaging is required. A ***Vaccine***

Manufacturing/Bio-manufacturing Facility is proposed as critical competitive infrastructure for vaccine development. Such a manufacturing infrastructure typically includes a new building and equipment and facilities such as: a Class 10 clean room, fermentors that can handle up to 150 litres, IT and networking and analytical equipment such as DNA sequencers. The South African Pharmaceutical Council must license such a facility.

The cost of such a facility is estimated to be of the order R 100 million to R 120 million. It will enable the country to manufacture vaccines for AIDS, Tuberculosis, Malaria, Flu and Avian Flu in large volumes.

In this regard the vaccine manufacturing capabilities, expertise and infrastructure of Onderstepoort Biological Products (OBP) and the Onderstepoort Veterinary Institute (OVI) need to be considered, particularly for animal borne diseases.

7.1.2.7 Biotechnology Hubs/Parks

The BRICs are following the guidelines of the National Biotechnology Strategy and are in the process of setting up the identified specialist technology platforms. In fulfilling their mission to also create and spin out a small and medium sized biotech industry, an infrastructural model has been identified as part of this study. In many cases this model may be idealistic, but could be worked towards to assist the BRICs and the biotechnology mission to achieve their goals in a more efficient manner.

A clear need exists for the creation of an environment where especially small businesses that are spun out by interventions of the BRICs could be cultivated and co-located and be supported by a strong R&D input where several platforms are operated in close proximity. Given the high cost of sophisticated biotechnology related analytical and diagnostic equipment, the prospect of such a central infrastructure is attracting excitement. It is suggested that three ***Biotech Hubs/Parks*** are formed, one in the Western Cape, one in KwaZulu-Natal and one in Gauteng. Where possible, such a hub should be within an area that is already serviced such as a science park or a business park. The Biotech Hub infrastructure would be comprised of the components and activities as shown in Figure 9.

Such a Biotech Hub/park will provide the opportunity of co-location and integrated management as well as access to expensive equipment and facilities used by researchers and development activities in biotechnology. The components highlighted in the figure include:

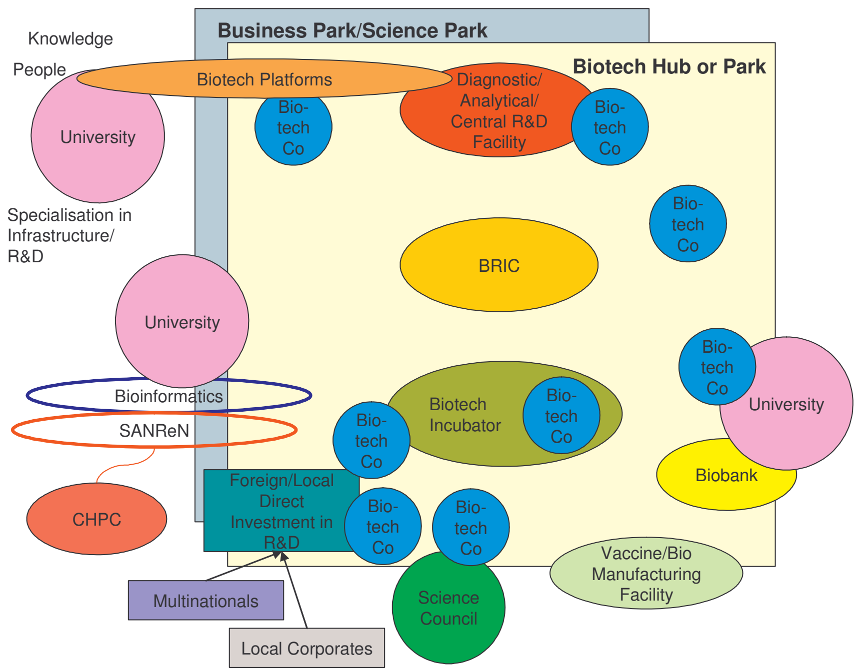

Figure 9: *Biotech Hub/Park infrastructure*

- The BRIC
- A Biotech incubator, if separate and required. The co-location of small start-up businesses may enable the BRIC to fulfil this task.
- A Central R&D Laboratory for diagnostics, characterisation and analytical work, with the following collection of expensive equipment:
  - Laminar flow cabinets
  - Micro-array – a tool for studying how large numbers of genes interact with each other and how a cell's regulatory networks control vast batteries of genes simultaneously
  - Confocal microscopy – making use of a laser to obtain high resolution images and 3-D reconstructions
  - PCR - Polymerase Chain Reaction; a technique for amplifying DNA, making it easier to isolate, clone and sequence
  - Fume and extraction cabinets
  - Sequencers, e.g. DNA sequencer - determining the exact order of the base pairs in a segment of DNA
  - Protein sequencers and genome sequencers
  - Nuclear Magnetic Resonance (NMR) Spectroscopy for measuring large protein structures
  - Matrix-assisted Laser Desorption/Ionisation Time Of Flight Mass Spectrometry (MALDI-TOF MS) which prevents unwanted fragmentation of the bio-molecule
  - Freeze dryer - dehydration process typically used to preserve perishable material

- Several small companies co-locating on the Biotech Hub/Park.
- Strong presence of universities and research institutions, linked to activities on the Biotech Hub/Park or with a presence on the physical premises
- Foreign biotech firms setting up R&D on the Biotech Hub/Park
- Local corporates setting up R&D on the Biotech Hub/Park
- Satellite BioBank tissue storage facilities
- Bioinformatics nodes
- Linkage to SANReN and the CHPC
- Biotechnology platforms as selected by the BRIC
- A Vaccine/Bio Manufacturing Facility to manufacture drugs and vaccines on a small scale for commercialisation development and small scale production (on one of the hubs).

It is estimated that it may cost as much as R 80 million each to establish three operational hubs in the country. The equipment housed in the central diagnostics laboratory may be costing R 50 M per venue and the building may be costing R 30 million and are included in the estimate. The BioBank improvements concern mainly upgraded and extended cryogenic storage facilities and may account for and additional R 20 million of the cost per venue. If the vaccine manufacturing/bio-manufacturing facility is added another R 100 million to R 120 million will be required. It may not be necessary to have more than one large volume plant in the country and possibly a small volume plant at about half the cost, which is R 55 million.

The advantages of establishing such an integrated infrastructure for biotechnology R&D and business incubation include much faster commercialisation of biotechnology R&D, the creation of critical mass by co-locating companies and centralised R&D, and the hub/park representing an attractive environment for Foreign Direct Investment in R&D in biotechnology.

A crucial infrastructure component to optimise the impact of the Bioinformatics Network is the establishment of SANREN and the Centre for High Performance Computing and linking these Biotech Hubs/Parks to the network.

This model is presented as a physical model where co-location adds to critical mass and reduces duplication. In areas where some of these components exist already or the equipment is already available at a research laboratory in a university or science councils, the model may be managed as a virtual model. For that reason the schematics in Figure 9 show some overlap.

The Central R&D Laboratory or components of it may be considered to be run as a commercial facility. There are currently examples of small companies run commercially that provide some of the services in such a laboratory, e.g. Inqaba Biotech in the City of Tshwane.

One of the strongest motivators for such a Biotech Hub/Park is to provide support to the small companies that the BRICs develop. These companies have common areas of needs, such as that their growth is dependent on R&D that they cannot afford to do themselves and R&D infrastructure which they cannot afford to acquire on their own. Co-locating them like this with other services and R&D initiatives will assist them in finding synergies to work together. It has also been established that world-wide only integrated hubs produce cutting edge technology. A similar scheme is pursued by India[36]. Universities will be attracted to become partners and participants in such a Biotech Hub/Park by the forefront R&D that will take place in it. The approach will be to provide a holistic technology view to attract the right science. This means that the enabling technologies need to be in place.

The technology platforms that are pursued by the various BRICs should produce value on its own. The science should be commercially driven in the form of translational research, that is, research that is translated into real products.

7.1.2.8 Driver national goals and flagship projects

To make such an infrastructural investment productive it is essential to combine it with a strong strategy and vision of which products should be developed in biotechnology. The National Biotechnology Strategy is too broad to indicate specific drivers for product development. It is believed that should such flagship projects exist, they will be the catalyst for proper infrastructure development together with capacity development and the building of critical mass. A set of national goals at the product level should be developed to use these in flagship projects to stimulate R&D. These flagship projects will also guide the decision on precisely what infrastructural specifications should be generated.

Table 5: *National Biotechnology focus areas that could lead to flagship projects*

Sector	Focus
Agriculture	Genetically Modified (GM) crops
	Plant diseases
	Biological control
Medical	Vaccines • Malaria • HIV/AIDS • Tuberculosis
Veterinary	Vaccines
Food	Fermentation
	Probiotics (dietary supplements containing potentially beneficial bacteria and yeasts)
	Naturally produced bacteria
Industrial	Biofuel
	Bioleaching/mining
Environmental	Reducing acid mine drainage
	Phytoremediation (using plants for pollution clean-up of contaminated soils or water)
	Bioremediation (use of living organisms (e.g., bacteria) to clean up oil spills or remove other pollutants from soil, water, and wastewater)
	Biodiversity

[36] http://www.hindu.com/2006/06/06/stories/2006060611210500.htm

The biotechnology focus areas listed in Table 5 serve as a landscape against which decisions could be made in the various biotechnology sectors.

In selecting driver projects, focus should be given to aspects that other countries could not do or what South Africa should do. This includes the identification of niches such as focusing on the unique fauna and flora in the biodiversity of South Africa, e.g. sequencing of the Protea or the Coelacanth.

7.1.3 Manufacturing Technology

The South African R&D environment in manufacturing is captured in the Advanced Manufacturing Strategy of the DST.

7.1.3.1 The Advanced Manufacturing Technology Strategy

The Advanced Manufacturing Technology Strategy[37] was developed to address manufacturing specific technologies for selected sectors in context of the Integrated Manufacturing Strategy of *the dti* and the National R&D Strategy.

The technology focus areas include:

- Advanced Materials
- Product Technologies
- Production Technologies
- Logistics
- Cleaner Production Technologies
- ICT in Manufacturing
- Small & Medium Enterprise Development
- Standardisation, Quality Assurance, Accreditation and Metrology (SQAM) Technology issues

The manufacturing sectors that are focused on include:

- Automotive (& Transport)
- Metals (& Minerals)
- Chemicals
- Clothing & Textiles
- Cultural/Craft
- Aerospace
- Capital Goods

[37] A National Advanced Manufacturing Technology Strategy for South Africa

Implementation of the strategy currently focuses on the automotive and aerospace sectors[38]. A number of programmes and initiatives are pursued to achieve the objectives of the strategy:

- Light materials
- Electronics
- Advanced production
- Digital manufacturing (FabLab)
- Advanced Manufacturing Technology Laboratories (AMTLs)
- Human Capacity Development

The AMTLs will focus on:

- Micro-electromechanical systems (MEMS)
- High speed data communications in manufacturing
- Advanced sensor technology

The infrastructural areas that were identified in this section impact on the generic field of advanced manufacturing, advanced materials and metrology. This reflects on needs that exist in the automotive and aerospace sectors. The aerospace sector as an emerging mission will be discussed separately (see section 7.3.2).

The AMTS overlaps with the Resource-based Industry programmes such as the Advanced Metals Initiative which includes Light Metals, New Metals, Speciality Steels and PGMs (Platinum Group Metals), which are discussed separately in section 7.1.4 below.

7.1.3.2 The National Metrology Laboratory (NML)

The NML[39] supports South Africa's global competitiveness through the provision of internationally acceptable measurement standards and measurements. It performs this duty by representing South Africa (and the region) at the organs of the Metre Convention, actively advancing metrology in the region and Africa (AFRIMETS - Inter Africa Metrology System), keeping and maintaining physical and chemical measurement standards and ensure the basic competence to prove measurement equivalence in three metrology competence areas:

- Electromagnetic metrology
- Metrology in chemistry
- Mechanical metrology

The NML is the custodian of very advanced and state-of-the-art measurement equipment to an approximate value of R 120 million. It is considering its future position in terms of new requirements and challenges in metrology. These may demand that a new building be built to

[38] http://www.amts.co.za/main.htm
[39] http://www.csir.co.za/plsql/pTl0002/PTL0002_PGE005_DIVISIONS?DIVISION_NO=7261009

adhere to vibration, environmental and temperature control that do not exist in the current facility. As such the NML facility may potentially be moved to a new site which could influence the competitive infrastructural solutions for the manufacturing and materials environment.

The role that national metrology laboratories are playing in the equivalence of measurements on a regional level has become much more crucial in the recent past to also address technical barriers to trade. This requires not only that the metrology laboratory should be a custodian of measurement standards, but to develop the science of measurement and the tools and techniques for measurement. In many cases, advanced measurement infrastructure is involved. As such a metrology laboratory has well developed knowledge of advanced measurement equipment and the management of environments where this equipment is housed and applied.

7.1.3.3 A Centralised Advanced Characterisation Facility

A clear demand is expressed by several parties in advanced manufacturing and materials, in nanotechnology, in the nuclear industry and the defence industry for an advanced characterisation facility in South Africa. In the past, state-of-the-art equipment which typically makes up such a facility was placed on a regional and national basis in institutions that could best use and manage that equipment. The NRF, in particular, over the years endeavoured to build such a network of advanced and competitive characterisation equipment in institutions. The network management model did not prove to be totally effective, since access and maintenance were among the problems experienced. Often institutions that were housing the equipment neglected the maintenance of the equipment with the result that it was not available when other users required access. The individual institutions also gave preference to their own researchers, with the result that access management was unsatisfactory. For many years there has been a debate about centralising very expensive materials characterisation equipment and to run it and offer services as a national facility. Networking nodes of expertise in expensive analytical equipment has not proven to be a successful management model in South Africa. By focusing on proper acquisitions and adequate management and technical support, the frustrations and non-performance of the past may be eliminated.

There is a strong case to be made to centralise such state-of-the-art characterisation equipment, in a ***Centralised Advanced Characterisation Facility*** especially at a level where the high price of such equipment only justifies one of a kind to be acquired for South Africa, or where the user capacity is not 100%. The advantages of centralisation include:

- Cost saving by optimising placement.
- Properly managed equipment in terms of maintenance and access.
- Specialist research and development in technique development and equipment improvement by a dedicated team of researchers in such a central facility.
- The building of critical mass in knowledge about advanced characterisation.
- Specialist assistance for users of the technique.
- The fact that the Internet could be used in a "collaboratory" (collaborative laboratory) sense and researchers do not always have to be present where the experiment is done, but

could have an Internet presence and even control the experiment via the Internet (in this case SANReN will play a major role).

Such a centralised advanced facility will thus have the nature of a national facility. This concept was supported by people interviewed in advanced manufacturing, nanotechnology, the nuclear industry, aerospace, defence and biotechnology. It is thus a cross-cutting requirement for more than one mission.

The equipment listed in Table 6 is typically housed in such a facility and is required for competitive research several missions

Table 6: *Typical advanced characterisation equipment to be centralised*

Type of Equipment	Typical Price Regime
High Resolution Transmission Electron Microscope (TEM)	R 20 million
High Resolution Scanning Electron Microscope (SEM)	R 20 million
Scanning Probe Microscopy , such as AFM (Atomic Force Microscpy)	R 10 million
High Resolution Magnetic Sector Mass Spectrometer	R 10 million
Surface Analytical Equipment such as SIMS (Secondary Ion Mass Spectrometry), XPS (X-ray Photo-emission Spectroscopy), AES (Auger Electron Spectroscopy)	R 15 million
Sample Preparation facility	R 25 million
GHz Nuclear Magnetic Resonance (NMR) Spectroscopy	R 100 million

The need for state-of-the-art electron microscopy has been raised by several groups, including nanotechnology, the defence sector and the PBMR. The advent of increased nanotechnology activities following the announcement of the Nanotechnology Strategy and the according budget will see an increase in scanning probe microscopy needs. Rather than spreading the equipment over the country a central characterisation facility will be an advantage. The centralisation of such infrastructure could also support the Advanced Manufacturing Technology Laboratories that the AMTS is planning.

It can be seen from Table 6 that an amount of R 200 million will be required to equip such a Centralised Advanced Characterisation Facility.

Such a facility will require specialised building infrastructure. It is envisaged that about 5 000 m^2 will be required for laboratory space, housing of the equipment and office space. This amounts to a capital investment of R 100 million for the building. This building will include visitor working space and space for overnight accommodation. A total investment of R 300 million is thus required for a Centralised Advanced Characterisation Facility.

7.1.3.4 A National Measurement Institute

Merging such a Centralised Advanced Characterisation Facility with a new facility for the NML is advisable since the controlled environments to be created are similar. The knowledge and skills the NML has on managing advanced analytical and characterisation equipment could be applied directly to developing and running a Centralised Advanced Characterisation Facility.

It is thus suggested that a ***National Measurement Institute*** be considered as a national competitive infrastructure component comprising the components and structure as shown in Figure 10.

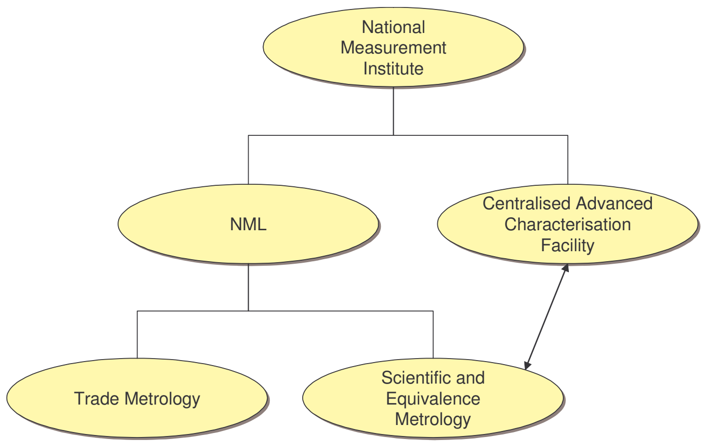

Figure 10: *Structure of a National Measurement Institute*

The National Measurement Institute could thus house the NML and the Centralised Advanced Characterisation Facility. The NML will continue with its two main foci, that of trade metrology and that of scientific metrology and equivalence. The link between the Centralised Advanced Characterisation Facility and the Scientific Metrology focus of the NML will be on the basis of:

- Shared equipment where possible
- Shared knowledge building
- Creating a critical mass of expertise in analytical techniques and applications
- Professional R&D services provision
- Professional management
- Technique development
- Commercial analytical services/Routine analysis
- Access through the NML to the best characterisation sites in the world
- Being close to the development edge in new equipment
- Testing and standardisation of new equipment

In addressing this infrastructural requirement, two aspects will be developed: a new facility for the NML as well as a new centralised facility for R&D using forefront analytical and characterisation equipment for the entire research community of South Africa in the field of materials characterisation, macromolecular research and analytical work.

7.1.3.5 A Micro- and Nano-processing Facility

If South Africa wishes to be competitive in nanotechnology and microfabrication, it should establish infrastructure to support processing R&D at the micron and nanometer dimension level. Such a laboratory will make available tools providing a broad platform for the development and testing of new ideas in micro- and nanotechnology. In the past, clean room facilities existed for micro-electronic processing development at the University of Pretoria (the Carl and Emily Fuchs Institute for Micro-electronics (CEFIM)), the CSIR and SAMES (South African Micro-electronic Systems, a private company). These facilities were never upgraded to support processing at submicron level. Of these only the CEFIM facility is still active as a microprocessing clean laboratory. Line widths are limited to 1.5 to 2 micron and submicron work (approaching the nanoscale) can only be done with smart etching techniques in non-standard environments. New device dimensions require sophisticated electron and ion beam processes.

The ***Micro- and Nano-processing Facility*** proposed would be a clean laboratory of sufficient grade (typically Class 10 in laminar flow areas and Class 100 in open areas; a 10 times improvement on existing facilities) to support nanoprocessing. This typically includes laminar flow environments, various lithography technologies, mask design and mask making, ion beam and electron beam lithography, ion beam milling, reactive ion beam etching and ion beam scribing, laser scribing, wet and plasma processing and ultraviolet lithography.

A practical approach would be to take an existing facility at a university (e.g. CEFIM at the University of Pretoria) and revamp it to present such a facility. It will require significant investment in clean room facility, low vibration floors, ultra-clean air flow, accurate temperature and humidity control and proper clean lab management protocols.

The communities that will benefit from such a facility include:

- Micro- and nano-electronics research at HEIs and research institutions
- MEMS R&D and manufacturing
- Nanotechnology scale device R&D

The use of lasers in microfabrication is a field that has been investigated by the National Laser Centre. In micromachining using lasers, addressing the markets with products as outlined in Table 7 will be possible thorough having access to a laser microfabrication facility:

Table 7: *Products that are possible via microfabrication in various markets*

Market	Product
Aerospace	Accelerometers Sensors MEMS
Automobile	Tyre pressure sensors Accelerometers Engine component profiles Engine management sensors
Communications	Fibre-Bragg Gratings Optical MEMS (MOEMS) Stripping of optical fibre
Computers and Peripherals	Print Heads Displays Imaging Systems
Electronics	Resistor Trimming Thermistor Trimming Ceramic package etching PC Board fabrication Direct write waveguides
Data Storage	Magnetic disks Flash Memory
Defence	Electronic warfare components Missile components Smart munitions Battlefield sensing Guidance and control
Jewellery	Mould manufacturing Surface patterning Gemstone cutting
Materials	Ceramics machining Plastics machining Semiconductor patterning Thin film patterning Superconductor patterning Metals machining Ultra-hard materials machining Ablation Composites machining

Market	Product
Medical	Bio-absorbable stents Stent grafts Skiving/excising of delivery devices Angoplasty devices Catheters Embolic filters Drug delivery devices Nanobots Intravascular radiation delivery devices Femoral closures Electrophysiology diagnosis Micofluidics Genosensors Neurology devices

Joining such a laser microfabrication facility with a nanofabrication facility makes sense in the case of hybrid devices that are utilising both nano- and microprocessing technologies such as MEMS (Micro Electromechanical Systems).

The estimated cost of a functional nanofabrication facility including a new clean laboratory, the various etching and trimming technologies and testing equipment is of the order R 100 million.

Centralisation is desirable for a Micro- and Nanoprocessing Facility. South Africa does not have modern facilities for lithography, and most definitely not at the nanoscale. To make and demonstrate many of the devices required in micro-fabrication and nanotechnology, such a facility is required. A specific emphasis could be MEMS research, a topic of importance to the defence, aerospace and automotive industries.

7.1.4 Resourced-based Industries

The areas that will be addressed under Resource Based Industries include Deep Mining and Metals and Minerals. The latter area overlaps with the light materials initiative and metals and minerals market sector in the AMTS which were highlighted under the discussion on manufacturing.

7.1.4.1 Deep mining

Mines will continue to go deeper and new technologies are required to operate at these extreme environments. Furthermore, deep mines could be used as a laboratory in its own to study, for example, the sources of earthquakes. These experiments are often done by overseas R&D institutions, without South Africa being part. To position the geological knowledge of earthquake processes competitively, South African researchers should be enabled to take part in these "mine laboratories." These laboratories could also be used to study biological life at great depths. Some species only occur in these extreme conditions and are called extremolites.

The specific rock types and ores make it difficult to use mechanisation in South Africa. Many challenges exist for the development of remote mining tools, automation, mechatronics, sensors and telemetry. Future developments include innovative thinking such as ropeless shafts utilising skips with magnetic levitation. The standard equipment used for rope testing is very old, but still applicable and has been upgraded with time. The rope testing facility at Cottlesloe should be maintained to provide risk free testing services. Although the half life of knowledge in mining is still very long (about 30 years, compared to an average mine life time of 40 to 50 years) many of the standard test and analysis facilities such as currently housed by CSIR (Natural Resources and the Environment: Mining) needs to be maintained. The installed base for rock testing is about R 100 million and the installed base for rope testing about R 50 million. Most of the equipment is custom designed and built locally and should be maintained.

7.1.4.2 Metals and Minerals

The Advanced Metals Initiative includes focus areas on:

- Precious Metals and Platinum Group Metals (PGMs)
- Light Metals
- New Metals
- Speciality Steels

Competitive infrastructure requirements have been identified in the fields of Precious Metals and Light Metals/New Metals. The field of Speciality Steels is very mature and any new innovations will be high risk and very expensive.

7.1.4.3 National Centre for Precious Metals Research

Several R&D activities already taking place in precious metals research could benefit from being integrated in a ***National Centre for Precious Metals Research***. South Africa is the largest producer of platinum group metals (Gold, Platinum, Palladium, Rhodium, Iridium, Osmium, Ruthenium). For many years questions have been asked on why the country is not a leading R&D force in the downstream beneficiation of these metals. Mining houses often reacted by stating that any value-added activities may result in conflict with the market. Yet, it is believed that the country should excel in R&D that could add value to these precious metals and that the economy of mining them should be extended by downstream value addition into highly sophisticated products such as catalytic converters, jewellery, pharmaceuticals and fuel cells.

Johnson Matthey[40] is a speciality chemicals company focused on core skills in catalysts, precious metals and fine chemicals. Principal activities include the manufacture of autocatalysts and pollution control systems, catalysts and components for fuel cells, pharmaceutical compounds,

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[40] http://www.matthey.com/

process catalysts and fine chemicals; the refining, fabrication and marketing of precious metals; and the manufacture of colours and coatings for the glass and ceramics industries. Johnson Matthey has a large manufacturing plant for autocatalysts in South Africa, but its entire R&D is being conducted in the United Kingdom, Europe and Japan. The reason why South Africa is not on the list may be because of a lack of competitive infrastructure for R&D as well as capacity in R&D human resources. Mintek and some universities have been involved in R&D and characterisation of PGMs, but at a very limited scale. Creating a National Centre for Precious Metals Research may change the critical mass aspects and provide visibility to the fact that South Africa is serious about generating knowledge and innovation on beneficiating its flagship metals. By having such a competitive R&D base, South Africa would become attractive for attracting foreign direct investment in R&D.

The Centre should also focus on new applications of some of the less known PGMs such as Rhodium, Iridium, Osmium and Ruthenium.

The following R&D activities could be integrated in such a National Centre for Precious Metals Research over an infrastructure range that will address the entire value chain:

- Metallurgical characterisation including equipment such as metallurgical microscopes, X-ray analysis, High Resolution SEM, Atomic Force Microscopy, advanced sample preparation laboratories, etc.
- Modelling of new precious metals applications and linkages with the CHPC via SANReN.
- Processing, including design and development and demonstration of multi-use infrastructure.
- Manufacturing of products in the various application markets, such as energy, jewellery, pharmaceuticals, electronics, biolabelling, etc.
- Fuel cell R&D
- A biolabelling laboratory
- Nanotechnology applications of PGMs
- Linkage with the Centralised Advanced Characterisation Facility via SANReN

Such a centre will integrate some existing activities and make provision for many new activities to be supported by a parallel national flagship programme on precious metals research. The involvement of industry in co-funding such a centre should be investigated. The critical mass in skills and knowledge that such a sector will bring, together with the intention of the government to make visible the importance of precious metals beneficiation should be driven as a national project.

It is estimated that the establishment of the infrastructure for a National Centre for Precious Metals Research would cost of the order of R 100 million.

7.1.4.4 Centre for Light Metals and New Metals Research

Light metals research into the value chain beneficiation of primarily Magnesium, Aluminium and Titanium should focus on finding new alloys and new manufacturing techniques. Light metals are of specific interest to the Aerospace and Automotive industries. A ***Centre for Light Metals and New Metals Research*** is proposed.

The infrastructure should support the following areas:

- Modelling facilities for new alloy development, linked via SANReN to the CHPC
- Materials characterisation facilities linked to metallurgical characterisation in the National Centre for Precious Metals Research and the Centralised Advanced Characterisation Facility via SANReN
- New extraction plant demonstrators (Mg and Ti)
- New manufacturing processes such as the development of innovative and new casting technologies and processes and metal forming
- Powder metallurgy plants, vacuum melting and forging, working with ultra-fine grain materials
- Equipment and facilities for developing new joining techniques
- Linkages with Aerospace component design and analysis and testing

It is estimated that the infrastructure budget for such a facility may be of the order R 50 million.

7.2 Frontier Science and Technology

7.2.1 Nanotechnology

The National Nanotechnology Strategy[41] states about infrastructure that a key initiative is to: "Create the physical infrastructure to enable first-class basic research, exploration of applications, development of new industries, and commercialisation of innovations". It proposes a budget to support R&D Infrastructure in the form of Characterisation Centres to the value of R 130 million over three years.

Such dedicated nanotechnology Characterisation Centres could be developed on a regional basis with strong links to the Centralised Advanced Characterisation Facility where state-of-the-art world class equipment such as High Resolution TEM/SEM and Atomic Probe Microscopy will be present. The linking of such regional centres with the Centralised Advanced Characterisation Facility via SANReN could create a "collaboratory" model. It is not unlikely, and in fact desirable, that the regional centre where the Centralised Advanced Characterisation Facility will be should be co-located in the National Measurement Institute, since nanometrology is an important aspect of nanotechnology development. It is likely that two regional characterisation centres will be developed, one in Gauteng and one in the Western Cape.

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[41] http://www.dst.gov.za/publications/reports/Nanotech.pdf

Access to advanced modelling infrastructure, computing power and broad band data services is a crucial element in nanotechnology R&D. Here SANReN and the CHPC will play a major role.

The regional characterisation centres should ensure efficacy of communication, data distribution, international liaison and even sample courier services.

The application of nano-materials, and nano-science and –technology in the manufacturing of nano-devices should be linked to the Micro- and Nano-processing Facility.

The entire infrastructure support environment for nanotechnology can be visualised as is shown in the diagramme in Figure 11.

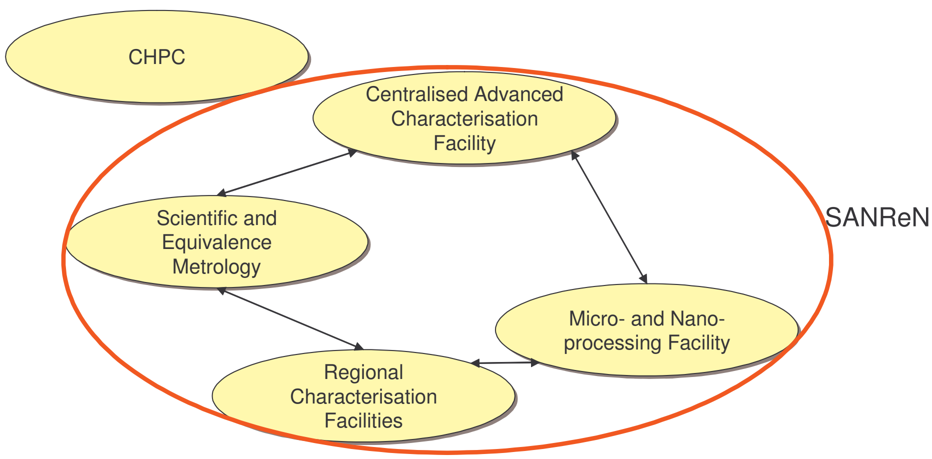

Figure 11: *Infrastructure supporting Nanotechnology*

The linking of small enterprises that may spin out from nanotechnology initiatives based on publicly funded research to this infrastructural network should be an imperative once such commercialisation activities begin to emerge.

7.2.2 Hydrogen Energy and Fuel Cells

The positioning of South Africa for the so-called hydrogen economy is addressed by an R&D strategy in Hydrogen Energy and Fuel Cells that is under development. A central management facility has been proposed that will implement the strategy and manage the linkages among research groups locally and internationally. Infrastructure will rely heavily on what is being proposed for the Resourced-based Industries, Advanced Manufacturing and Energy Technologies. The current Centre of Excellence in Catalysis will play a crucial role in a competitive position in the hydrogen economy as well as the development of new fuel cell materials, including nanotechnology.

R&D focus areas will most likely include:

- Beneficiation of South African mineral resources (specifically platinum, other platinum group metals, gold, vanadium and zirconium)
- Hydrogen generation by South African relevant means (coal, nuclear and renewable energy such as solar)
- Niche applications for Hydrogen and Fuel Cells (e.g. rural electrification, mine vehicles)

It is clear that competitive infrastructure components already identified will make a major impact on competitive R&D in the area of hydrogen energy and fuel cells. These are very similar to the nanotechnology environment and include:

- The Centralised Advanced Characterisation Facility
- The National Centre for Precious Metals Research
- Catalysis Centre of Excellence (at UCT)
- Specialised (regional) Hydrogen Energy and Fuel Cell R&D Centres

The aim of centralising R&D activities, at least on a regional level, is to build and demonstrate critical mass in activity and skills.

Flagship projects could also be selected that link with many of the other NSI initiatives that will require new energy sources where fuel cells could play a role in future such as:

- Transport
- Stand-alone power sources
- South African built micro-satellites
- Powering environmental observation stations such as sea buoys used for climatological sensing
- Developing new equipment to be used in Southern Ocean and Antarctic research
- Powering remote research bases
- Powering on-board equipment in remote vessels such as submarines and research ships

The Hydrogen Energy and Fuel Cell strategic planning is still in its preliminary phases and is the longest term strategy that South Africa has ever embarked upon. The principle of linking energy solutions from this new field to energy requirements for infrastructural components of the science and technology systems as identified here should be considered.

Preliminary budgetary figures for dedicated R&D infrastructure in the Draft Hydrogen Energy and Fuel Cell strategy are of the order R 60 million over three years.

7.2.3 Energy technologies, especially renewable energy

Research infrastructure is required to address the many areas of energy research undertaken in the country.

7.2.3.1 South African Energy Research and Development Strategy

The Energy R&D Strategy exists in draft form. It identifies energy infrastructure to be a critical aspect of sustainable, reliable and competitive energy supply for the future. Looking for alternatives to fossil fuels in the energy mix of the future is an important aspect to guide R&D. The so-called hydrogen economy will for a long time be driven by a mix of more conventional fossil fuels, hydrogen and renewable energies such as wind and solar.

Drivers were identified by the Draft Energy R&D Strategy to collectively shape South Africa's energy R&D requirements. These are:

- Wealth creation through growing a globally competitive economy
- Expanding the development opportunities of the Second Economy
- Global efforts aimed at protecting the environment
- The constraints and opportunities of South Africa's natural energy resource base
- The pressing need for regional cooperation and development
- Innovation
- The need to develop human capital and promote social and economic transformation

These can be matched against the identified R&D focus areas which include:

- Energy infrastructure optimisation
- Energy efficiency and demand side management
- Secondary beneficiation of minerals resources
- Expanding socio-economic and development opportunities of the Second Economy
- Clean coal development
- Renewable energy
- Energy planning and modelling
- Energy policy research

The strategy is not specific on competitive R&D infrastructure. It focuses more on the coordination of what is existing and a major component is the creation a South African National Energy Research Institute (SANERI); an important instrument to implement this strategy. SANERI may do its own R&D based on gaps recognised in analysing the energy R&D environment. SANERI is mandated by the strategy to:

- Undertake a techno socio-economic study of each identified energy R&D theme in order to develop its understanding and to identify three or four topics per theme that will lead to the highest net research benefit for the country
- Expand and refine the project selection and prioritisation principles to facilitate the selection of research topics
- Develop its first energy R&D Agenda. This R&D Agenda will be the overall plan for activities to be funded by SANERI.

In contemplating infrastructure for energy R&D one should consider the R&D demands and energy realities in South Africa as discussed below.

At a high level two aspects of energy are important:

- Energy as input into the economy
- Energy with export potential

7.2.3.2 South African Energy Advantage Areas

Coal

South Africa has a major natural advantage in its coal reserves. The competitive edge of coal has not been explored. New R&D by industry in for example in situ beneficiation of coal to reduce environmentally unfriendly emissions from coal and to make the exploitation process cheaper is underway. R&D into these processes will require some analytical infrastructure as well as modelling and design of new processes. The possibility of a ***National Coal Research Institute*** should be explored by SANERI. The activities of such an institute should be aligned with work done on climate change.

Hydropower

The effective utilisation of massive hydropower sources in mid-Africa (e.g. the Congo delta) necessitates R&D into optimising ultra-long distance transmission lines, most often based on DC transmission.

Energy metering

South Africa has been a world leader in energy metering technology development. This technology holds major potential as an export product and should be strengthened through R&D and commercialisation of these energy metering solutions.

End-use technologies

The development of effective end-use technologies should continue and will impact on second economy environments both for living and business creation.

Solar and Photovoltaic

With its abundance of solar energy, South Africa should be focusing on solar thermal water heating and electricity generation. This could be a clean source for electricity in remote areas where transmission line infrastructure is incomplete.

Infrastructure required for the development of new generations of solar cells has been invested in via the Innovation Fund and industry (local and foreign) at the University of Johannesburg. The knowledge of, and infrastructure support to demonstrate commercialisation of photovoltaic energy is an important aspect of competitiveness.

Energy modelling

Energy modelling and planning research is an important component and the institutes that are currently active in this area should be supported on a continuous basis. High performance computing and SANREN will play a major role in this area as well.

SANERI, once operational, should be tasked to develop a detailed energy R&D infrastructure plan.

7.2.3.3 Current interventions in generic energy R&D

The government has called for proposals to establish energy research chairs and post-graduate research programmes in renewable energy research. It was recently announced that the post-graduate programme on renewable and sustainable energy will be hosted at the University of Stellenbosch.

Linkages of current energy research activities with SANReN and CPHC, as well as with the Centralised Advanced Characterisation Facility are crucial.

Infrastructure will probably be networked and not centralised in energy research.

7.2.3.4 Nuclear Energy

The major development around nuclear energy is the Pebble Bed Modular Reactor (PBMR) programme. The PBMR is a High Temperature Reactor (HTR), with a closed-cycle, gas turbine power conversion system. Although it is not the only HTR currently being developed in the world, the South African project is internationally regarded as the leader in the power generation field. Very high efficiency and attractive economics are possible without compromising the high levels of passive safety expected of advanced nuclear designs[42]. The technology development around the PBMR requires significant access to competitive R&D infrastructure.

Currently most of the large manufacturing contracts are done overseas since the infrastructure and know-how often do not exist in South Africa. Long qualification times are involved which makes it difficult to develop such infrastructure here. Existing technology is used as far as possible in the design. The principle is also adopted to purchase all fuel material. However, a programme is in place to further develop the pebbles locally. For this crucial infrastructure includes:

[42] http://www.pbmr.co.za/

- Materials development
- Access to world class characterisation (radio-active and non-radioactive)
- Access to neutron flux

Nanotechnology is also considered for high temperature turbine blade development and new generation ceramics are required for heat processing and heat exchange. Biotechnology methods are considered for minimising radioactive waste. Modelling includes the physical construction of a micro-model. Heat transfer testing facilities exist at the University of the North West. Micromachining with lasers is being conducted by the NLC. The process heat from the reactor is an ideal source to create hydrogen which has an impact on the hydrogen energy and fuel cell industry. Radiation damage studies are required, using accelerated protons. The Separated Sector Cyclotron at iThemba LABS is thus useful infrastructure to apply. In general R&D on graphite is required.

It is thus clear that several of the infrastructure components identified impact on needs of the PBMR development. These are:

- Centralised Advanced Characterisation Facility (Surface and structural analysis)
- Micro- and Nano-processing Facility (Micromachining)
- Separated Sector Cyclotron (Radiation damage studies with proton beams)
- CHPC and SANReN (Modelling)
- The SAFARI Reactor at Pelindaba (Neutron fluxes)

7.2.4 Micro-satellite engineering

Micro-satellite engineering is practiced mainly by a private company, SunSpace (Pty) Ltd based in Stellenbosch as well as the Faculty of Engineering at the University of Stellenbosch. Several other pockets of expertise support this skills base, such as the CSIR, HMO (Hermanus Magnetic Observatory) and several small private micro-fabrication and mechanical engineering firms, mainly in the Stellenbosch area.

In ensuring an infrastructure that would lead to a competitive satellite and space industry presence for South Africa, the following should be maintained and funded:

- SunSpace (Pty) Ltd
- The University of Stellenbosch Engineering Faculty
- The Houwtech test facility
- HMO
- CSIR measurement and testing facilities
- Electro-optical systems capability (CSIR and universities)
- The Satellite Applications Centre for tracking satellites

The Overberg Test Range (better known as OTB – "Overberg Toetsbaan") is not seen as a critical component of the micro-satellite capacity, but will play a role in the larger space debate in

South Africa (see also comments relating to the National Space Agency in sections 6.1.1 and 6.2 above). At present OTB is not linked to the space programme. Given the cost formula for launching a micro satellite (about $2 million to $9 million for a launch), it is not important for a local micro-satellite programme to have a local launching facility that a recognised launching country such as e.g. Russia can use as platform; the costs for the satellite manufacturer may be the same. However, to position South Africa as a visible role player in the space industry, it may be advisable to have the full value chain in launching, from building a satellite, to launching it and tracking it. A national space agency will also boost the image of the space industry and indicate a commitment by government that it wants to be seen as a serious player.

Of particular importance is the identification of a few well defined satellite flagship projects with the product as the end point. It is of critical importance that the capability to design and build and commercialise micro-satellites be maintained in South Africa. The best vehicle to ensure that this capability is maintained and expanded is for government to become the effective client of a range of satellites. It is suggested that government orders about 3 to 5 satellites over a period of 3 years. The satellite industry could then provide collateral investment by winning international orders of the same magnitude. This will build the industry from a sub-critical one to a competitive one. It is seen that the critical mass is about 100 to 150 people.

An average micro-satellite can be built in South Africa for about R 100 million. A three year plan of a minimum of R 300 million should thus be able to sustain and grow the expertise base in the country.

The following immediate infrastructure establishment and upgrades are required:

- ***Space optics testing facility*** - Vacuum optics test equipment (R 40 million to R 50 million).
- Upgrade of Houwtech facilities to align testing capacity with satellite functionality and international accreditation requirements.

Despite the developments of a Space Policy for South Africa and a National Space Agency, the satellite industry is operating in a directional vacuum and the development of a National Strategy for Space Innovation is suggested.

The flagship projects should focus on large, high cost projects such as:

- Agriculture and land use
- Intelligence
- Climate change

To accommodate the micro-engineering small business sector that supports the micro-satellite industry, a small "***Mechanical Engineering Hub***" should be established on the Stellenbosch TechnoPark in close proximity to SunSpace facilities.

Currently a project to build the second satellite (after SunSat I) to be launched towards the end of 2006 is underway. An amount of R 26 million has been made available for this project by the DST. This project is known as "Pathfinder" or ZA002 and is a technology demonstration project with a limited number of students (5 to 6) being trained on it. Adequate funding for such a project is estimated around R 70 million to R 80 million. A strong case could be made for a multi-spectral satellite to be used by agriculture in South Africa. Such a satellite would cost around R 150 million and negotiations with the Department of Agriculture are underway.

By investing in micro-satellite development via ***flagship satellite building projects***, critical infrastructure will be developed and maintained. The result will be that South Africa will be a more competitive contender for international micro-satellite projects based on a track record of flying operational satellites. New science and technology in the field will be expanded and new products could be offered to the space markets.

the dti in South Africa also views a micro-satellite capacity as an important building block towards creating future high value industries. Such developments could lead to a satellite infrastructure for earth observation that is crucial for any country. *the dti* is driving the development of the National Space Policy.

In terms of international accreditation, an audit may be required on the state of South African facilities that are crucial to a space programme. Optical, radar and communications infrastructure components need to be integrated well with a developing satellite building capacity in South Africa. Accreditation of existing infrastructure needs to be given attention to, since no formal accreditation has been done yet for the major players in the emerging satellite industry.

Attention should be given to liability for losses linked to satellites or satellite services, should they occur. Insurance is normally taken to cover risk of losing the payload during a launch (15% of cost of launch for rocket failure; 10% of cost of launch for loss of business after one year). Liability for loss of services for clients while the satellite is in orbit should be covered.

South Africa is also involved in discussion with Africa on an African Resource Monitoring (ARM) Constellation of three satellites. The purpose of such an agreement is to ensure complimentarity when satellites are launched by African countries and to get maximum benefit from sharing in such a constellation. The Nigerian Government has recently announced a 25-year plan to venture into space technology by locally manufacturing and launching its own satellite[43]. The plan has the objective to launch a satellite manufactured in Nigeria by between 2018 and 2030. Other potential players are Algeria and Kenya.

In developing a local technology platform via infrastructure development, attention should be given to the market needs, such as that for intelligence, and matching that with what the local micro-satellite manufacturing capacity could provide.

[43]http://www.itweb.co.za/sections/hardware/2006/0605150910.asp?S=IT%20in%20Manufacturing&A=ITM&O=FRGN

7.2.5 Health: Vaccine technologies

Vaccine production as a Frontier Science and Technology issue has been discussed together with the Biotechnology Missions (see section 7.1.2.6)

7.3 High Value Industries

High value industries were identified by *the dti*. Competitive infrastructure requirements already exist for these sectors.

7.3.1 Defence

The defence R&D activities focus mainly on key capabilities in defence:

- Military Communications
- Interception
- Cryptography/Information Security Systems

In supporting infrastructure, industry and existing institutions are relied on very heavily. These include:

- CSIR
    - DPSS (Defence, Peace, Safety and Security) (Aerospace and Maritime Applications, expertise in line with key focus areas for defence research)
    - Optronics
    - Radar (Traditional and no Phased Array Radar) and Electronic Warfare
    - Information Warfare
    - Modelling and simulation for decision support
    - Medium Range Wind Tunnel

- IMT (Maritime R&D)
    - Naval Mine Warfare (including mine countermeasures)
    - Submarine Warfare (including torpedoes)
    - Surface Warfare
    - Target characterisation above water (radar, infrared)
    - Target characterisation subsurface (acoustics, magnetics)
    - Battlefield characterisation (understanding the maritime environment)
    - Decision Support

- HEIs
    - Specific expertise
        - Knowledge
        - Products

Competitive infrastructure in the defence industry includes:

- Test laboratories and test equipment
- R&D facilities in the key focus areas
- Advanced processing facilities

Links with the technology missions include:

- ICT, excluding military communications
- Advanced Materials
- Advanced Manufacturing
- Nanotechnology
- Aerospace

A requirement is identified for the following infrastructure that will support defence R&D

- Infrastructure to support an R&D programme on MEMS (Micro Electro-Mechanical Systems), focusing on inertial sensors for navigation and orientation. Ideally such a MEMS capability should be synchronised with needs of the automobile sector, such as micro-sensors for automotive air bags. This will be satisfied with the establishment of a Micro- and Nano-processing Facility.
- Facilities for micro-fabrication, micro-machining and atomic manipulation. This will be satisfied with the establishment of a Micro- and Nano-processing Facility.
- Nanolithography and nanoelectronics processing facility. This will be satisfied with the establishment of a Micro- and Nano-processing Facility.
- Test and characterisation equipment to support the development of all new technologies. This need will be addressed by the establishment of a Centralised Advanced Characterisation Facility.
- The wind tunnel. (See Aerospace, section 7.3.2)

The testing and processing facilities need to be centralised to compensate for the high cost of such facilities and equipment.

Defence R&D is rooted in the national S&T system. The use of infrastructure in the national S&T system would be advantageous, although defence research is still organised in Defence and Evaluation Institutions (DERIs). The SADERI consists of:

- ARMSCOR
- CSIR
- IMT

The DoD Vote allocation to R&D is R 300 million per annum

7.3.2 Aerospace

"The aerospace industry is expected to achieve the levels of economic growth and vibrancy that are similar to those of the automotive industry by 2014.[44]" World-wide the aeronautical and space manufacturing industries generate the highest added value items of all industries (of the order of 50%), and can therefore provide a large revenue stream for a successful industry. A sustainable and growing aerospace industry can thus be a significant building block for the economic prosperity of South Africa. Stimulating the aerospace industry through R&D is one of the objectives of the AMTS. In government, the DST works closely with *the dti* in the development of the aerospace industry. *the dti* has formed an Aerospace Industries Support Initiative (AISI). A technology road-mapping initiative has been done based upon the initial work undertaken to develop the ASSEGAI strategy (A Strategy for a Sustainable, Economical and Growing Aerospace Industry).

The aerospace industry is that industry which covers the research, design, manufacture, support, maintenance, conversion and upgrade of[45]:

- Rotary and fixed wing aircraft
- Satellites and satellite launch and tracking systems
- Air traffic control systems
- Unmanned aircraft
- Weapons systems
- The relevant subsystems and components

This industry is very close to the Light Metals Initiative which has been addressed as an infrastructure component in this report see section 7.1.4.4). Access to a Centre for Light Metals and New Metals Research is crucial for technology development in this sector.

Focus is given on integrating R&D activities in the industry with international OEMs such as Airbus Industries.

The infrastructure required by the aerospace sector has been identified as:

- Wind tunnels
- National Aerospace Centre of Excellence

7.3.2.1 Wind Tunnels

The CSIR manages 7 wind tunnels of varying size and speed. Wind tunnels, especially the larger ones such as the medium speed wind tunnel are expensive to maintain and may cost around R 3 million to R 4 million per annum to run. The major cost is for electricity. The Medium Speed

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[44] Keynote Address: Minister Mosibudi Mangena at the Launch of the AMTS Aerospace Network , April 2006, http://www.dst.gov.za/media/speeches.php?id=88&print=1

[45] *A S S E G A I - A Strategy for a Sustainable, Economical and Growing Aerospace Industry*, Philip Haupt and Paul Hatty

Wind Tunnel has a 30 MW motor. The cost of testing in the Medium Speed Wind Tunnel may add up to R 1.5 million per test. This is a transonic wind tunnel and can handle speeds up to Mach 1.5 and is of the closed loop type. A smaller Supersonic Wind Tunnel exists and is an open design. Speeds up to Mach 4.5 can be achieved. The model sizes differ though, and when the same air frame needs to be tested in the two tunnels, the model size has to be reduced for supersonic testing and the algorithms adapted to compare the design at various speeds.

It is estimated that it will cost approximately R 150 million to replace the current wind tunnel infrastructure. It is constantly upgraded and maintained, but the high cost of operation makes its use very selective. To build a larger Supersonic Wind Tunnel may cost up to R 80 million. The Aerospace Strategy that is under development will comment on detail infrastructure requirements. It is, however, already clear that the wind tunnel infrastructure should be maintained and upgraded on a regular basis to support the Aerospace Initiative in South Africa.

Hand-in-hand with experimental wind tunnel work goes computational analysis and modelling. Connectivity with the CHPC through SANReN is critical for real time processing of large data streams form the wind tunnel experiments.

Currently the wind tunnels are not optimally used and capacity utilisation is below 20%. The facilities should be positioned for access to higher education institutions, SMEs and industry. The first two categories could possibly be subsidised, given the high cost of operation.

7.3.2.2 National Aerospace Centre of Excellence

An important infrastructural component for the support of the aerospace industry is the establishment of the National Aerospace Centre of Excellence (NACoE) at the University of the Witwatersrand as an environment of national collaboration between government, industry, academia and scientists for the provision and co-ordination of specialised services for the South African Aerospace Industry.

The vision of the NACoE is that it will be recognized and supported by all role-players (locally and internationally) as a valuable and integral part of South Africa's aerospace industry. The NACoE is to conduct leading edge commercially significant technology research and development for the Aerospace industry in South Africa that would not have otherwise happened, and enhances the competitiveness and sustainability of the industry. Key outputs of the NACoE include new or more competitive technologies/products, new knowledge, highly skilled human resources and technology transfer. Outputs are achieved in accordance with a long-term development strategy as a collaborative, multi-disciplinary effort between government, industry, academia and research institutions. The scope of activity is focused on the South African Aerospace Industry, with aerospace defined to be "the technology of flight in any of its forms", and includes space and aeronautics technology, as well as support systems and technologies.

A major contribution by this CoE is design work on structural composites components of the Airbus A400M cargo carrier. This work makes a global contribution to the development of this airframe in terms of a defined work share for South Africa.

No infrastructural investment needs were identified for the short term and the CoE is adequately funded by *the dti*.

7.3.3 Nuclear industry and radiation science

The global trends driving the nuclear industry can be summarised as:

- Finding security of energy supply.
- Managing climate change and CO_2 footprints.
- The nuclear energy safety case needs to be made more convincing by the entire industry.
- The global geopolitical environment has become multi-polar after the Cold War and South Africa could be seen as a fully compliant player.

In terms of addressing nuclear infrastructure in South Africa, three possible scenarios could be considered:

- Maintain the status quo. This means that development on the PBMR continues and that no more Light Water Reactors (LWRs) such as Koeberg are purchased. The current Vaalputs nuclear waste storage site is maintained. South Africa remains a major supplier of radio-isotopes.
- ESKOM agrees to purchase up to 25 PBMR units which will deliver about 4 GW additional power as required according to projections. One PBMR generates 165 MW. It will thus require about 6 PBMRs to provide the equivalent generation power of 900 MW of one Koeberg reactor (the power station has two reactors). These 25 PBMRs will thus provide equivalent generation capacity to two full LWRs such as Koeberg. In this scenario local Uranium conversion could be considered. This type of capacity will require 1 500 to 2 000 ton of Uranium per annum, which means a 10 kiloton per annum conversion[46] plant. Enrichment[47] processes have developed significantly and a choice is

[46] After the yellowcake is produced at the mill, the next step is conversion into pure uranium hexafluoride (UF_6) gas suitable for use in enrichment operations. During this conversion, impurities are removed and the uranium is combined with fluorine to create the UF_6 gas. The UF_6 is then pressurized and cooled to a liquid. In its liquid state it is drained into cylinders where it solidifies after cooling for approximately five days. The UF_6 cyclinder, in the solid form, is then shipped to an enrichment plant. http://www.nrc.gov/materials/fuel-cycle-fac/ur-conversion.html

[47] Uranium found in nature consists largely of two isotopes, U-235 and U-238. The production of energy in nuclear reactors is from the `fission' or splitting of the U-235 atoms, a process which releases energy in the form of heat. U-235 is the main fissile isotope of uranium. Natural uranium contains 0.7% of the U-235 isotope. The remaining 99.3% is mostly the U-238 isotope which does not contribute directly to the fission process (though it does so indirectly by the formation of fissile isotopes of plutonium). Uranium-235 and U-238 are chemically identical, but differ in their physical properties, particularly their mass. The nucleus of the U-235 atom contains 92 protons and 143 neutrons, giving an atomic mass of 235 units. The U-238 nucleus also has 92 protons but has 146 neutrons - three more than U-235, and therefore has a mass of 238 units. The difference in mass between U-235 and U-238 allows the isotopes to be separated and makes it possible to increase or "enrich" the percentage of U-235. All present enrichment processes, directly or indirectly, make use of this small mass difference.

available from centrifugal, Molecular Laser Isotope Separation (MLIS) and vortex technologies.

- South Africa agrees to international partnerships and becomes a supplier of enriched Uranium. The country has 10% of the world's resources in Uranium (current price about $40/lb). It is number four as a resource owner after Australia, Russia and Kazakhstan. The re-establishment of a conversion capability will be easy, though re-establishment of an enrichment capability will not be easy, since a totally new technology will have to be used.

A major infrastructural development may include the expansion of the Vaalputs storage site and an expanded radioactive water management programme once several PBMRs operate in the country. There is 9 gram of Uranium in a PBMR "pebble". The primary material of the pebble is graphite. Such a programme could focus on separating the graphite and Uranium to re-use the graphite. This could possibly be done with transmutation of nuclear waste, using accelerators.

7.3.3.1 Nuclear Reactor

The current SAFARI reactor that is 41 years old is maintained and according to estimates could work efficiently for another 20 years. It has only recently been used at high capacity of 20 MW.

In eventually replacing a reactor such as SAFARI it would be wise to be knowledgeable about new generation reactor projects such as Thorium reactors and accelerator/reactor combinations. It will be necessary to maintain a reactor research group that has knowledge about these new reactor configurations as well as keeping track of what is happening on the fusion side.

7.3.3.2 South African Nuclear Research Institute

Management structures to synergise nuclear science R&D in iThemba LABS and the SAFARI reactor R&D group should be investigated. The eventual creation of a ***South African Nuclear Research Institute*** may be required as an umbrella organisation to preside over nuclear R&D. The merging of the accelerator community may also be added to finding such synergy.

7.3.3.3 Isotope Production

The commercial aspects of NECSA and iThemba LABS, especially in isotope production should also be synergised. A broad spectrum of isotopes is being manufactured by utilising the neutron-rich reactor environment and the neutron-poor accelerator environment.

7.3.3.4 Fluorochemicals

NECSA has on-site capacity to manufacture fluorochemicals. Current infrastructure that exists includes:

- HF (Hydrogen Fluoride) plant
- F_2 (Fluorine) plant
- Smaller plants for fluorine derivatives

- Production of NF_3 (Sodium Fluoride Gas) (for BOC-Edwards)
- Fluorine inorganic compounds for the semiconductor industry

This infrastructure can support the development of the downstream Fluorochemical sector which in turn may add to the development of a continuous value chain for Fluorspar, a mineral of which South Africa has large resources.

Future infrastructure requirements to stimulate the Fluorochemical industry could involve the upgrading of the HF plant to supply HF to take UF_6 production from 4.5 kiloton per annum to 10 kiloton per annum. Such an upgrade may not be feasible on the Pelindaba site and could be done as a PPP (Public-Private-Partnership) with industry in an industrial development zone such as Richards Bay or Coega.

7.3.3.5 Synchrotron

Investigations into the possibility of developing a synchrotron for South Africa and the African continent have been going on for a considerable time. Such a development will only be justified if a sizable user community has been established. Australia invested in such a facility with a user community of 60 people, and now has 300 users. Such a minimum target of 60 users may be feasible for South Africa as well. A synchrotron is attractive since it provides a broad platform for research in biochemistry, biotechnology, mining, forensics and physics. However, before such an expensive project can be justified, the country should focus on the development of user capacity. For this reason a few scientists are supported to conduct "suitcase science" to access synchrotrons elsewhere in the world. The long term goal should remain for Africa to have a synchrotron.

7.3.3.6 Radioactive Beam Facility

For iThemba LABS policy decision is required to commence with the construction of an accelerator for dedicated radiation medicine for the proposed Major Radiation Medicine Centre (MRMC), and with a new dedicated 200 MeV cyclotron for isotope production. This will mean that the existing Separated Sector Cyclotron may exclusively be used for Sub-Atomic research and technology development. In such a case, an upgrade of the facility is required to bring it to the forefront of international competitiveness.

Internationally, the forefront of nuclear physics research is steadily focusing on the great unknown of nuclear physics: the properties of the so-called neutron rich nuclei - artificially produced nuclei with many more neutrons than protons compared to those encountered in nature. To produce neutron rich nuclei, a radioactive beam facility is required. Approximately twenty such facilities exist or are under construction worldwide.

iThemba LABS in South Africa and as an African facility is limited to stable beams and hence the forefront of nuclear physics research is no longer accessible to South African researchers.

An upgrade of the iThemba LABS facility to a ***Radioactive Beam Facility*** is proposed to allow the production and exploitation of radioactive beams[48]. The benefits of such a facility extend into other fields such as solid state physics, laser physics and electronics.

There are two methods of producing radioactive beams, both have different strengths and weaknesses and both are in continuous state of development and improvement. They are Projectile Fragmentation (PF) and Isotope Separation On-Line (ISOL).

In Projectile Fragmentation a primary, stable beam is accelerated to relativistic energies and is broken up into fragments by colliding it with a thin production target. Because of the relativistic energies, the fragments pass through the target and continue in the original direction and thus a radioactive secondary ion beam is created. The different fragment species are separated and directed onto a yet another target to study the neutron rich nuclei.

In Isotope Separation On-Line a primary, non-relativistic beam is directed on a thick production target such as Uranium, which is fissioned to produce neutron rich nuclei. In contrast to projectile fragmentation, the fission products are stationary, and must be re-accelerated by a second, post-accelerator to be directed on to a target for further study.

In both approaches the reaction of the primary beam with the production target produces a cocktail of radioactive ion species from which the desired species must be separated. This is usually accomplished by combinations of electric and magnetic fields, but for ISOL, the Resonant Laser Ionization technique, which has extremely high efficiency, is also available.

iThemba LABS proposes developing both ISOL and PF facilities to produce radioactive beams. The primary beam for both methods can be delivered by the existing 200 MeV Separated Sector Cyclotron of iThemba LABS.

Projectile Fragmentation requires the construction of a separator and an upgrade of the existing beamlines. The use of beams of relativistic energies requires a large acceptance spectrometer and accompanying detector systems.

ISOL requires the development of a resonant laser ion-source. Expertise for the development of the resonant laser ion-source already exists in South Africa, as a similar technology was used by NECSA to enrich uranium for nuclear fuel. The ISOL technique also requires a post-accelerator for the radioactive beams. The standard solution to this requirement is a combination of RFQ (radio frequency quadrupole) and LINAC (Linear Accelerators) accelerators. To exploit the new beams additional new detector systems are also required, many of which can be shared.

A new accelerator technology in its infancy is emerging. This is Laser Acceleration of ions. Given the obvious synergy with the development of a resonant laser ion-source and the expertise available in South Africa, iThemba LABS proposes a research facility into laser acceleration.

[48] A Radioactive Beam Facility at iThemba LABS, R Bark, J J Lawrie, , J F Sharpey-Schafer

An amount of R 460 million is required over a period of 10 years for these upgrades. A recurring budget of R 50 million per annum will be required to run these facilities.

7.3.3.7 Synergised governance for Nuclear Science and Technology

In addition to looking at a synergised nuclear R&D and isotope production environment, it would be useful to also consider a synergised governance structure for "SA Nuclear Inc." Reconcilliation among the various departments responsible for nuclear science and technology is required:

- Department of Minerals and Energy (DME): NECSA and the Nuclear Regulator
- Department of Public Enterprises (DPE): PBMR
- Department of Science and Technology (DST): iThemba LABS
- Department of Education (DoE): Universities with accelerator infrastructure and nuclear research

There should also be an investigation into which entities in the nuclear industry could be corporatised along the example of PTP (Pelindaba Technology Products) and Flurochemicals.

7.3.3.8 Nuclear engineering and manufacturing

Nuclear engineering and design is mostly practiced in South Africa by a public company, IST (Ltd). These engineering and design skills at nuclear specification level are essential capabilities for South Africa. The capacity for a local manufacturing capability to adhere to nuclear specification should be enhanced. This will also result in more manufacturing contracts from the PBMR to the local industry. Infrastructure may be required in the form of a ***Nuclear Manufacturing Centre of Excellence*** and a demonstration centre.

7.3.3.9 Public Understanding of Nuclear Science and Technology

In terms of public understanding of nuclear science and technology, the development of a ***National Nuclear Science Centre*** should be considered.

7.3.4 Cross-cutting Infrastructure

Three infrastructural components were identified that could serve as providing cross-cutting support to competitiveness:

- National Systems Engineering Initiative
- Foresighting and Roadmapping and Technology Demonstration
- Innovation Space on The Innovation Hub

These could be managed as a collection of initiatives or by setting up some centralised physical infrastructure to provide visibility and to build critical mass of human resources and skills.

7.3.4.1 National Systems Engineering Initiative

There is concern that South Africa is losing its competitive edge in systems engineering that it used to have in the old missions of defence, energy and nuclear applications. A major driver for growing and maintaining such skills on Systems Engineering is the "big science" projects such as:

- SALT
- SKA
- KAT
- PBMR

In addition to these the following initiatives also require systems engineering:

- Aerospace Industry Support Initiative (AISI)
- Advanced Manufacturing Technology Strategy (AMTS)
- National Space Initiative
- SANReN
- CHPC

These projects require concentrated systems engineering input. Suggestions have been put forward[49] to address the widening gap between demand and supply of systems engineering competence by interventions such as: on-the-job training; demonstration projects; certification support; research; access to world experts and access to the international community via the International Council on Systems Engineering (INCOSE). Most of the infrastructure components discussed in this report require a significant input from systems engineering to design, build, maintain and operate them.

7.3.4.2 Foresighting and Roadmapping and Technology Demonstration

The need to look forward and to convert strategy into demonstratable action has been recognised by DST. Centralised skills and a critical mass are required to scan trends and to relate these findings to policies. Demonstrating the future use of technologies on an unfolding technological and economical landscape has become crucial to competitiveness. A shared vision needs to be demonstrated and optimised. Such activities would be ideally grouped with a future demonstration laboratory. The cost of creating such a ***Foresighting and Road Mapping Institute*** will be of the order R 30 million.

7.3.4.3 Innovation Space on The Innovation Hub

Several activities require innovation space on The Innovation Hub in the City of Tshwane. These include discussions regarding the establishment of an ICT Precinct where organisations such as the Meraka Institute, The Innovation Hub, InnovationLab (Pty) Ltd and multinationals

[49] Towards a National Systems Engineering Initiative, J Strydom, F Anderson, A G Smit, March 2006, CSIR

interested in bringing their R&D to South Africa have indicated the intention to collaborate to enhance ICT R&D in South Africa. InnovationLab (Pty) Ltd is a private black economic empowered company that facilitates the demonstration of future business solutions based on emerging and advanced technologies originating from a variety of technology R&D sources, including universities and science councils. Such an ***Innovation Space*** will further house an Innovation Showcase as well as several future worlds of business demonstrators under development by InnovationLab (Pty) Ltd. Interest has been expressed by the AMTS and the Aerospace Industries Support Initiative as well as the Future Industries initiative of *the dti* to collocate in such an Innovation Space. The Innovation Space could also include the Foresighting and Road Mapping Institute. This infrastructural requirement includes a building that is designed specifically to create space for the futures demonstrators, business solutions R&D, innovation showcasing, public briefing and R&D space of about 6 000 m^2 and will mean a capital investment of R 120 million.

8 Infrastructure/Mission Matrix

In analysing the impact of required infrastructure on the various missions, a matrix approach is used to indicate which infrastructure is existing, which is required as new infrastructure and which should be expanded upon or upgraded.

The infrastructure *vs.* Science Missions is shown in Figure 12. The crosses indicate impact and the colours indicate whether the infrastructure exists, needs upgrading or does not exist yet.

Infrastructure	2nd Generation Instrumentation	Upgrades at Sutherland and Cape Town	Additional KAT Dishes	HESS 2 Demonstrator	VLBI Antennas	Lunar Laser Ranging	Dual Frequency GPS Receivers	Geodesy Station	Instrumented Anchored Buoys	Satellite Dishes	SAC Databank	Near-shore Research Vessel	Manned Submersible and ROV	Marine Research Instrumentation	Modelling Capacity	Marine Aquaculture Research Facility	SAEON/LTER Sites	Face-type Instrumented Field Sites	ECOTRON-type facility	Airborne Survey Facility	NZG Research Infrastructure	BioBank Facility	National History Collections	Replacement of Agulhas	Marion Base	Geo-analytical and Characterisation	Dating	CT Scanner and Tomography	Accelerator Mass Spectrometer (AMS)	Surveillance Sites	IKS
Space Science																															
Astronomy	x	x																													
Radio-astronomy			x																												
Hess 2				x																											
Geodesy					x	x	x	x	x																x						
Space Physics						x			x															x							
Satellite Applications Centre										x	x																				
Biodiversity																															
Marine Biodiversity									x			x	x	x	x	x					x	x	x	x					x		
Terrestrial Biodiversity															x		x	x	x	x	x	x	x		x				x		
Antarctica and Southern Oceans																															
Oceanography									x						x									x					x		
Biodiversity															x				x	x		x	x	x	x				x		
Space Physics									x															x		x	x				
Earth Science, including Marine Geology															x					x				x		x	x	x	x		
Palaeo-sciences																													x		
Poverty Reduction and Health															x		x													x	x
Indigenous Knowledge																	x													x	x
Earth Observations					x					x	x				x		x	x		x										x	

Key	
Exsiting	(green)
Existing, but needs upgrade	(yellow)
Not existing	(red)

Figure 12: *Science Infrastructure/Mission matrix showing cross impacts and current status*

The infrastructure *vs.* Technology Missions or Frontier Science and Technology or High Value Industry or Cross-cutter matrix is shown in Figure 13. The crosses indicate impact and the colours indicate whether the infrastructure exists, needs upgrading or does not exist yet.

Infrastructure	Centre for Human Language Technology	Centre for High Performance Computing	Wireless test bed	SANREN	TENET	UbuntuNet	Centre for Monitoring and Evaluation	Biotechnology Hubs	National Bio-informatics Network	Biobank	National Preclinical Institute	Centralised Advanced Characterisation Facility	Micro- and Nano-processing Facility	National Centre for Precious Metals Research	Centre for Light Metals and New Metals Research	Regional Nanotechnology Characterisation Facilities	Regional Hydrogen Energy and Fuel Cell R&D Centres	SANERI	Flagship satellite projects	Space optics testing facility	Vaccine/Bio- Manufacturing Facility	Wind Tunnels	South African Nuclear Research Institute	Synchrotron	Radioactive Beam Facility	Nuclear Manufacturing Centre of Excellence	National Nuclear Science Centre	National Systems Engineering Initiative	Foresighting and Road Mapping Institute	Innovation Space Building
Technology Mission																														
ICT	x	x	x	x	x	x	x						x						x			x						x	x	x
Biotechnology		x		x	x	x		x	x	x	x	x	x								x							x	x	x
Manufacturing Technology		x		x	x	x						x	x	x		x	x		x		x	x	x			x		x	x	x
Resource-based Industries		x		x	x	x						x	x	x	x	x	x	x					x					x	x	x
Financial Instruments																														
Frontier Science and Technology																														
Nanotechnology		x		x	x	x						x	x	x		x		x			x								x	x
Hydrogen		x		x	x	x						x	x	x		x	x	x	x				x						x	x
Energy Coal & Renewable		x		x	x	x						x	x	x			x	x										x	x	x
Microsatellite Engineering		x	x	x								x	x				x		x	x		x						x	x	x
Vaccine technologies		x		x				x	x			x	x								x								x	x
High Value Industries																														
Defence	x	x	x	x								x	x			x	x		x			x						x	x	x
Aerospace		x	x	x								x	x		x		x		x			x						x	x	x
Nuclear		x		x								x	x	x									x	x	x	x	x	x	x	x

Key	
Exsiting	
Existing, but needs upgrade	
Not existing	

Figure 13: *Technology Infrastructure/Mission matrix showing cross impacts and current status*

8.1 Prioritisation

Prioritising the infrastructure is not straightforward, as it would be very difficult to design objective criteria that will discriminate fairly between science missions and technology missions and high value industries in such a prioritisation process. For this reason three principles for prioritisation have been identified but applied separately for the science missions and the technology missions. The three principles of prioritisation identified for consideration are:

- Impact on multiple missions/frontier science and technology areas/high value industries by a specific infrastructure component.
- Risk of infrastructure or science and technology activity seriously threatened as a result of non-investment.
- Infrastructure that can leverage foreign R&D investment or substantial foreign direct investment (FDI) in South Africa.

8.2 Multiple mission impact

The first level of prioritisation concerns the number of missions impacted on by the proposed infrastructure. The matrices presented in Figure 12 and Figure 13 are analysed for multiple occurrences of cross-impact of a particular infrastructural component.

8.2.1 Illustrative prioritisation of infrastructure for Science Missions

Prioritisation for the Science Infrastructure is done on the basis of weight of impact across missions and is shown in Figure 14.

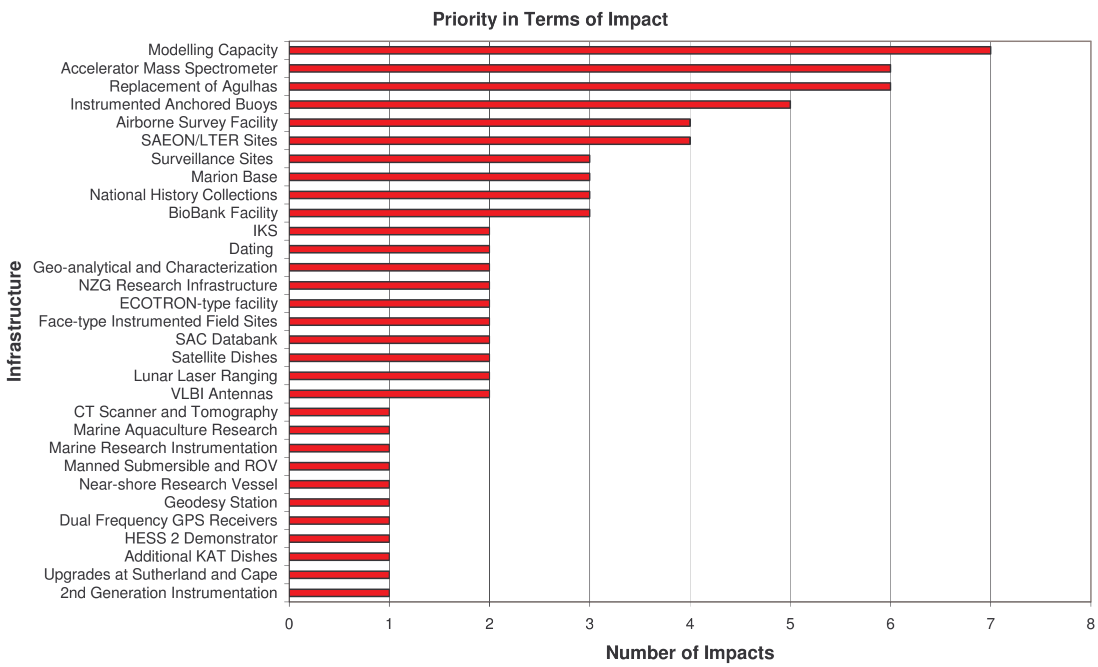

Figure 14: *Prioritisation of infrastructure identified for the Science Missions*

Figure 14 shows clear groupings of priorities based on multiple cross impacts of the infrastructure on the missions. The infrastructure components in these groupings are not in any hierarchy and are of equal importance.

8.2.2 Illustrative prioritisation of infrastructure for Technology Missions, Frontier Science and Technology and High Value Industries

Prioritisation for the Technology Infrastructure is done on the basis of weight of impact across missions and is shown in Figure 15.

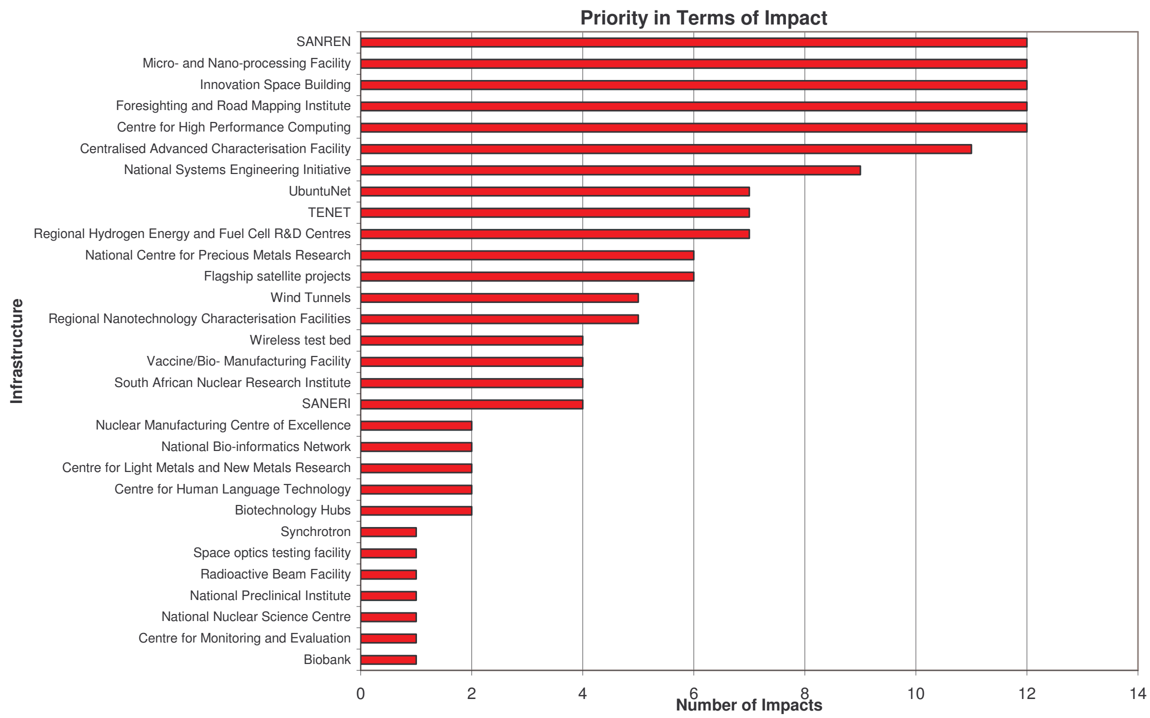

Figure 15: *Prioritisation of infrastructure identified for the Technology Missions, Frontier Science and Technology and High Value Industries*

Figure 15 shows clear groupings of priorities based on multiple cross impacts of the infrastructure on the missions. The infrastructure components in these groupings are not in any hierarchy and are of equal importance.

8.3 Infrastructure threatened by lack of funding

Infrastructure threatened by lack of funding identified during the course of this investigation include the natural history collections in museums which are dealt with in some detail in section 6.3.2.5, as well as collections of live tissue culture, many of which have been established as a result of specific research foci of individual researchers. With a change of research focus such collections are often destroyed or are poorly maintained. The importance of live tissue cultures lies in the study of plant disease and the potential of mining specific chemicals for application and technology development. Included in this category is also the funding for the 2nd generation instrumentation for SALT, as lack of financing in proportion to South Arica's shareholding will result in a decrease of South Africa's share in SALT and hence also observation time.

8.4 Infrastructure that can leverage foreign R&D investment or substantial foreign direct investment (FDI) in South Africa

An example under this category is an investment of R 6 million by South Africa to build components for the HESS 2 prototype locally. The prototype will be the forerunner of the proposed 7 square km array with an estimated infrastructure investment of about R 800 million. Although the HESS 2 will be built in Namibia, there are bound to be opportunities for South African industry to participate in the building of the telescopes for this array and thereby benefit in one way or another from the proposed investment in future. The reasoning here is akin to the motivation for construction of the KAT.

The creation of an Innovation Space on The Innovation Hub holds potential for attracting FDI in R&D in South Africa. The notion of building an "InnovationLab" on the hub has already resulted in a prominent multinational ICT company investing in setting up an international R&D activity and facility on The Innovation Hub. By creating such innovation space, more multinationals will be attracted to invest in R&D.

9 Monetary Value of Infrastructure and Estimated Budget

The monetary value indicated for infrastructure in the discussion in this report refers to the bulk sum required to place the infrastructure over time. It is thus not an immediate investment and some infrastructural components could be established over extended periods of up to 10 years.

9.1 Science Missions

The tables below summarise the indicative capital and running (recurring) cost of the identified science infrastructure.

Table 8: *Cost of Infrastructure of the Space Science Mission*

Science Mission	Sub-mission	Infrastructure	Capital Cost (R million)	Running Cost (R million)
Space Science	Astronomy	2nd Generation Instrumentation	20	1
		Upgrades at Sutherland and in Cape Town	20	
	Radio-astronomy	Additional KAT dishes	(200)	
	Hess 2	Contribution to demonstrator	6	
		Participation cost		0.5
	Space Geodesy	New generation VLBI antennas (4 @ R10 m)	40	
		NASA SLR2000		
		Lunar Laser Ranging	22	
		6 Dual Frequency GPS Receivers @ R250 000	1.5	
		New Geodesy Station	39	4
	Space Physics	Low Altitude HR Radar	3	
		Ionosonde	1.6	
		Dual Frequency GPS Receivers ▪ Islands and vessels ▪ 5 Anchored buoys	 1.5 30	
		Smaller instruments and HMO infrastructure	2	
	Satellite Application Centre (SAC)	New generation smart dishes at SAC on Hartebeesthoek	50	
		Data storage facility	10	
		Operation as a National Facility		18
Sub-Total			**246.5**	**23.5**

Table 9: *Infrastructural requirements for the Biodiversity Mission*

Science Mission	Sub-mission	Infrastructure	Capital Cost (R million)	Running Cost (R million)
Biodiversity	Marine Biodiversity	Near-shore Research Vessel	150	20
		50% contribution to Research vessel for Regional GEF programmes	150	15
		Manned Submersible	10	1
		Remotely Operated Support Vehicle (ROV)	6	1
		Research Instrumentation ▪ Data logging and listening devices ▪ Acoustic Doppler Current Profilers	 50 50	
		Anchored Buoys – See Space Science		
		Modelling capacity – SAEON node		
		Marine Aquaculture research facility	50	7.5
	Terrestrial Biodiversity	5 SAEON/LTER sites including instrumentation	35	7.5
		4 x FACE-type instrumented experimental field sites	20	4
		"Ecotron"-type national research facility	100	15
		NZG Research infrastructure	15	
		Airborne survey ▪ Operating expenses ▪ Instrumentation	 7	 8.6
		National BioBank facility ▪ Laboratories and storage ▪ Research equipment ▪ Operations	 50 2.5 	 4.5
		Natural History Collections ▪ Storage ▪ Support staff & running	 40 	 5
		Specialised Analytical Equipment ▪ Genotyping Facility ▪ Isotopes and Trace Elements (Atmospheric Chemistry)	 7 4	 1 1
Sub-Total			**746.5**	**91.1**

Table 10: *Cost of Infrastructure for the Antarctic and Southern Ocean Mission*

Science Mission	Sub-mission	Infrastructure	Capital Cost (R million)	Running Cost (R million)
Antarctica and Southern Ocean		Research Vessel, replacement of SA Agulhas Instrumentation Operation	650 75	47
		H F Radar Connectivity		0.5
		Marion Base ▪ Equipment, well found laboratory ▪ Support staff, operating and connectivity	10	1
		Landscape Dynamics	2	
		Oceanography HR capacity: 2 Research Chairs		6
		5 Anchored Buoys (See Space Science)		
Sub-Total			**737**	**54.5**

Table 11: *Cost of Infrastructure for the Earth Science Mission*

Science Mission	Sub-mission	Infrastructure	Capital Cost (R million)	Running Cost (R million)
Earth Science		Geodata storage and Retrieval	5	2
		Analytical and characterisation ▪ Standard set (XRD, XRF, etc) ▪ QEMSEM ▪ SIMS	25 5 25	
		Dating >2.5 million years SHRIMP	40	2
		Infrastructure access		3
		Marine Geology (See Antarctic and Southern Oceans, Instrumentation on Research vessels)		
Sub-Total			**100**	**7**

Table 12: *Cost of Infrastructure for the Palaeo-science Mission*

Science Mission	Sub-mission	Infrastructure	Capital Cost (R million)	Running Cost (R million)
Palaeo-sciences		National Collections ▪ Storage ▪ Curation	 40 	 16
		Characterisation: Imaging ▪ Upgrading of existing equipment ▪ CT Scanner for large samples ▪ Operations	 11 25 	 1
		Characterisation: Dating < 2.5 million years. ▪ AMS at iThemba (Gauteng) ▪ QUADRU: Luminescence	 10 3	 1 1
		Stable Isotopes		
Sub-Total			**89**	**19**

Table 13: *Cost of Infrastructure for Poverty Reduction and Health, Indigenous Knowledge and Earth Observations*

Science Mission	Sub-mission	Infrastructure	Capital Cost (R million)	Running Cost (R million)
Poverty Reduction and Health		5 Surveillance Sites ▪ Buildings ▪ Support staff and running	 25 	 17.5
Indigenous Knowledge		7 IK Centres ▪ Offices, recording labs ▪ Operations	 10.5 	 7
Earth Observations		South African Earth Observation System		18
Sub-Total			**35.5**	**42.5**

From summing the subtotals in the tables above, it can be seen that the ***total capital amount*** required to finance the competitive infrastructure components of the science missions is about ***R 1 955 million***.

In addition to this capital amount, a ***recurring running amount*** of about ***R 238 million*** should be made available for funding the supporting staff and operations to ensure optimum application of this infrastructure.

A summary of the costs at the high levels is given in Table 14. Here additional costs for start-up are included. Start-up cost includes:

- Feasibility studies
- Strategy planning
- Training of people in new fields of science and infrastructure management

Table 14: *Summary of costs for Competitive Infrastructure for the Science Missions*

Science Mission	Capital Cost (R million)	Running Cost (R million)	Start-up Cost (R million)	Total Cost (R million)
Space Science	246.6	23.5	24.7	294.8
Biodiversity	746.5	91.1	42.7	898.3
Antarctic and Southern Ocean	737.0	54.5	11.2	802.7
Earth Science	100.0	7.0	1.0	108.0
Palaeo-sciences	89.0	19.0	8.9	116.9
Poverty Reduction and Health	25.0	17.5	2.5	45.0
Indigenous Knowledge	10.5	7.0	1.1	18.6
Earth Observation		18		
Total	**1 954.6**	**237.6**	**92.0**	**2 284.2**

The total start-up cost for the science missions is thus ***R 92 million***.

The ***total financial impact*** of the competitive infrastructure for the science missions is thus ***R 2 284 million***.

9.2 Technology Missions

The tables below summarise the indicative cost of the identified technology infrastructure and add the cost for the mission or frontier science and technology or high value industry as well as the cross-cutter activities.

Table 15: *Cost of infrastructure in the ICT mission*

Technology Mission	Sub-mission	Infrastructure	Capital Cost (R million)
ICT	HLT	Centre for Human Language Technology	50
	HPC	Centre for High Performance Computing	120
	Wireless & satellite	Wireless test bed	20
	Networks	SANREN	300
		TENET	-
		UbuntuNet	-
	Generic ICT	Centre for Monitoring and Evaluation	-
	HCI		-
	Geo-information Science		-
	Futureweb		-
Sub-Total			490

Table 16: *Cost of infrastructure in the Biotechnology mission*

Technology Mission	Sub-focus	Infrastructure	Capital Cost (R million)
Biotechnology	BRICs	Biotechnology Hubs	240
	Networks	National Bio-informatics Network	-
		Biobank	60
	Clinical testing	National Preclinical Institute	180
Sub-Total			480

Table 17: *Cost of infrastructure in the Manufacturing Technology mission*

Technology Mission	Sub-focus	Infrastructure	Capital Cost (R million)
Manufacturing Technology	Advanced Materials	Centralised Advanced Characterisation Facility	300
		Micro- and Nano-processing Facility	100
	Advanced Metals		
	Generic Manufcaturing	National Centre for Systems Engineering	-
Sub-Total			400

Table 18: *Cost of infrastructure in the Resource-based Industries mission*

Technology Mission	Sub-focus	Infrastructure	Capital Cost (R million)
Resource-based Industries	Deep mining		-
	Metals and Minerals		-
	Precious Metals (including PGMs and Gold)	National Centre for Precious Metals Research	100
	Light metals	Centre for Light Metals and New Metals Research	50
	New metals		
	Speciality Steels		-
Sub-Total			150

Table 19: *Cost of infrastructure in the Frontier Science and Technology Programmes*

Frontier Science and Technology	Sub-focus	Infrastructure	Capital Cost (R million)
Frontier Science and Technology Theme	Nanotechnology	Regional Nanotechnology Characterisation Facilities	130
	Hydrogen	Specialised (Regional) Hydrogen Energy and Fuel Cell R&D Centres	60
	Energy Coal & Renewable	SANERI	-
	Microsatellite Engineering	Flagship satellite projects	300
		Space optics testing facility	50
	Vaccine technologies	Vaccine/Bio-Manufacturing Facility	120
Sub-Total			660

Table 20: *Cost of infrastructure in the High Value Industries*

High Value Industries	Sub-focus	Infrastructure	Capital Cost (R Million)
High Value Industry Sector	Defence		-
	Aerospace	Wind Tunnels	80
	Nuclear	South African Nuclear Research Institute	-
		Synchrotron	-
		Radioactive Beam Facility	460
		Nuclear Manufacturing Centre of Excellence	-
		National Nuclear Science Centre	-
Sub-Total			540

Table 21: *Cost of infrastructure in the Cross Cutters*

Cross-Cutting Infrastructure	Sub-focus	Infrastructure	Capital Cost (R million)
Cross-cutters	Systems Engineering	National Systems Engineering Initiative	-
	Foresighting, Road Mapping and Demonstration	Foresighting and Road Mapping Institute	30
	Innovation Space	Innovation laboratories on The Innovation Hub	120
Sub-Total			150

From summing the subtotals in the tables above, it can be seen that the ***total capital amount*** required to finance the competitive infrastructure components of the technology missions, frontier science and technology areas, high value industries and cross-cutting areas is ***R 2 870 million***.

In addition to this capital amount, a ***recurring running amount*** of about ***R 287 million*** should be made available for funding the supporting staff and operations to ensure optimum application of this infrastructure.

A summary of the costs at the high levels is given in Table 22. Here additional costs for start-up are included. Start-up cost includes:

- Feasibility studies
- Strategy planning
- Training of people in new fields of science and infrastructure management

Table 22: *Summary of costs for competitive infrastructure at the high level missions*

Infrastructure Area	Capital Cost (R million)	Running Cost (R million)	Start-up Cost (R million)	Total Cost (R million)
Technology Missions	1 520	152	91	1 763
ICT	490	49	16	555
Biotechnology	480	48	22	550
Manufacturing Technology	400	40	40	480
Resource-based Industries	150	15	13	178
Frontier Science and Technology	660	66	38	764
Nanotechnology	130	13	3	146
Hydrogen	60	6	6	72
Energy Coal & Renewable	0	0	0	0
Microsatellite Engineering	350	35	18	403
Vaccine technologies	120	12	12	144
High Value Industries	540	54	41	635
Defence	0	0	0	0
Aerospace	80	8	4	92
Nuclear	460	46	37	543
Cross-Cutting Infrastructure	150	15	17	182
Systems Engineering	0	0	2	2
Foresighting, Road Mapping and Demonstration	30	3	3	36
Innovation Space	120	12	12	144
Total	2 870	287	187	3 344

The ***total financial impact*** of the competitive infrastructure for the technology missions, the frontier science and technology activities and the high value industries and cross-cutting aspects is thus ***R 3 344 million***.

9.3 Combined financial implication

The combined financial implication for the science and technology missions is thus as outlined in Table 23.

Table 23: *Total Financial Impact of Competitive Infrastructure Requirements*

Mission	Capital Cost (R million)	Running Cost (R million)	Start-up Cost (R million)	Total Cost (R million)
Science Missions	1 955	238	92	2 285
Technology Missions	2 870	287	187	3 344
Total	4 825	525	279	5 628

9.4 Factors determining infrastructure roll-out decision making

No single methodology for prioritisation should be used, and a combination of the three priority considerations is required. These factors determining infrastructure roll-out are subsequently discussed.

9.4.1 Multiple mission impact of infrastructure, linkages and funding distribution over expenditure terms

The impact of the various infrastructure components on multiple missions was taken into account in prioritising the infrastructure for both missions as discussed in Section 8.2, as well as the distribution of funding required over several expenditure terms. This new representation shows that although some items may appear low in terms of multiple impact prioritisation, if the other prioritisation criteria (Section 8.1) are applied, they may enjoy preference in terms of funding priority. An analysis of the condensed infrastructure components as used in the impact prioritisation is given for the science missions in Table 24 and for the technology missions in Table 25 for 3 consecutive Medium Term Expenditure Frameworks (MTEF). Each MTEF period is 3 years, thus a funding period of 9 years is suggested for addressing the competitive infrastructure scenario in full.

The tables also indicate all the government departments (other than the DST) that are co-responsible for the infrastructure under discussion.

Possible linkages in terms of institutions that would be positioned best for leading the roll-out of the infrastructure are also given in the tables for each item.

Table 24: *Detailed costs, linkages and distribution of costs over MTEF periods for Science Missions*

Priority (Multiple Mission Impact)	Science Mission	Sub-focus	Infrastructure	Capital Cost	Running Cost	Start-up Cost	Total Cost	Government Department(s)	Linkages	MTEF Period		
				R Million						1	2	3
										R million		
7	Biodiversity	Marine	Modelling Capacity & Earth Observation Systems		18.0	2.0	20.0	DST	SAEOS/ SAEON/ SANBI/ Universities	6.7	6.7	6.7
6	Antarctica and Southern Oceans	Research Vessel	Replacement of SA Agulhas	725	47.0	10.0	782.0	DEAT/DST	SANCOR/ SANAP/NRF/ CGS	391.0	391.0	
6	Palaeo-sciences	Dating	Accelerator Mass Spectrometer (AMS)	10	1.0	1.0	12.0	DST	iThemba LABS/ Universities/ NECSA/ Museums	12.0		
5	Space Science	Space Physics	Instrumented anchored buoys	38.1	0.0	3.8	41.9	DST	DEAT/HMO/ SAWS/ Universities	21.0	21.0	
4	Biodiversity	Terrestrial Biodiversity	SAEON/LTER sites	35	7.5	3.5	46.0	DEAT/DST	SAEON/ SANBI	23.0	23.0	
4	Biodiversity	Terrestrial Biodiversity	Airborne survey facility	7	8.6	0.7	16.3	DST	SAWS/NRF/ Universities/ CSIR	16.3		
3	Biodiversity	Terrestrial Biodiversity	BioBank facility	52.5	4.5	5.3	62.3	DST	NZG/NRF/ BRICs/ BiobankSA	20.8	20.8	20.7
3	Biodiversity	Terrestrial Biodiversity	Natural History Collections	40	5.0	4.0	49.0	DST/ DAC	Museums/ SANBI/NRF	49.0		
3	Poverty Reduction and Health	Centre	Surveillance Sites	25	17.5	2.5	45.0	DST/ DoH	Universities/ INDEPTH/ MRC	22.5	22.5	
3	Antarctica and Southern Oceans	Bases and Oceanography	Marion Base, SANAE and Oceanography	12	7.5	1.2	20.7	DEAT/DST	SANCOR/ SANAP/NRF	20.7		

Priority (Multiple Mission Impact)	Science Mission	Sub-focus	Infrastructure	Capital Cost	Running Cost	Start-up Cost	Total Cost	Government Department(s)	Linkages	MTEF Period		
										1	2	3
				R Million						R million		
2	Biodiversity	Terrestrial Biodiversity	"Ecotron"-type facility	100	15.0	10.0	125.0	DEAT/DST	NRF/ Universities/ SANBI			125.0
2	Earth Science	Analytical	Geoanalytical and characterisation	100	7.0	1.0	108.0	DST	CGS/ Universities		54.0	54.0
2	Space Science	Satellite Applications Centre (SAC)	Satellite dishes	50		5.0	55.0	DST	CSIR/SAC		27.5	27.5
2	Palaeo-sciences	Collection	Dating & National Collections	43	17.0	4.3	64.3	DST/ DAC	Museums/ Universities/ CSIR/ iThemba LABS	64.3		
2	Space Science	Space Geodesy	New generation VLBI antennas	40	0.0	4.0	44.0	DST	HartRAO		22.0	22.0
2	Biodiversity	Terrestrial Biodiversity	FACE-type instrumented field sites and Specialised Analytical Equipment	31	6.0	3.1	40.1	DST/ DPE	ESKOM/ Universities	13.4	13.4	13.3
2	Space Science	Space Geodesy	Lunar Laser Ranging	22	0.0	2.2	24.2	DST	HartRAO/ NASA	12.1	12.1	
2	Biodiversity	Terrestrial Biodiversity	NZG Research infrastructure	15	0.0	1.5	16.5	DST	NRF/SANBI/ SANPARKS/ Universities	16.5		
2	Indigenous Knowledge	Centre	IK Centres	10.5	7.0	1.1	18.6	DST	HSRC/ Universities/ MRC	6.2	6.2	6.2
2	Space Science	Satellite Applications Centre (SAC)	SAC Databank	10	18.0	1.0	29.0	DST	CSIR/SAC	29.0		
1	Biodiversity	Marine	Near-shore Research Vessels	300	35.0	5.0	340.0	DEAT	SANCOR/ SAIAB	113.3	113.3	113.3
1	Biodiversity	Marine	Research Instrumentation	100		1.0	101.0	DEAT/DST	SANCOR/ SAIAB	33.7	33.7	33.7
1	Biodiversity	Marine	Marine Aquaculture research facility	50	7.5	5.0	62.5	DEAT/DST	SANCOR/ SAIAB/ Rhodes		31.3	31.3
1	Space	Space	New Geodesy Station	39	4.0	3.9	46.9	DST	HartRAO		23.5	23.5

Priority (Multiple Mission Impact)	Science Mission	Sub-focus	Infrastructure	Capital Cost	Running Cost	Start-up Cost	Total Cost	Government Department(s)	Linkages	MTEF Period 1	2	3
				R Million						R million		
	Science	Geodesy										
1	Palaeo-sciences	Imaging	CT Scanner and Tomography	36	1.0	3.6	40.6	DST	NECSA/ Universities/ Museums	20.3	20.3	
1	Space Science	Astronomy	2nd Generation Instrumentation	20	1.0	2.0	23.0	DST	SAAO	23.0		
1	Space Science	Astronomy	Upgrades at Sutherland and in Cape Town	20	0.0	2.0	22.0	DST	SAAO	22.0		
1	Biodiversity	Marine	Manned Submersible and ROV	16	2.0	1.6	19.6	DEAT/DST	SANCOR/ SAIAB	12.6		
1	Space Science	HESS 2	Contribution to HESS demonstrator	6	0.5	0.6	7.1	DST	NWU	7.1		
1	Space Science	Space Geodesy	Dual Frequency GPS Receivers	1.5	0.0	0.2	1.7	DST	HartRAO	0.8	0.8	
1	Space Science	Radio-astronomy	Additional KAT dishes			0.0	0.0	DST	HartRAO	0.0	0.0	
	Totals			1954.6	237.6	92.0	2284.2			967.9	840.9	475.3

Table 25: *Detailed costs, linkages and distribution of costs over MTEF periods for Technology Missions*

Priority (Multiple Mission Impact)	Technology Mission	Sub-focus	Infrastructure	Capital Cost	Running Cost	Start-up Cost	Total Cost	Government Department(s)	Linkages	MTEF Period		
										1	2	3
				R Million						R million		
12	ICT	Networks	SANREN	300	30	6	336	DST	Meraka	112	112	112
12	ICT	HPC	Centre for High Performance Computing	120	12	2	134	DST	UCT/UWC/Meraka	45	45	45
12	Cross-cutters	Innovation Space	Innovation laboratories on The Innovation Hub	120	12	12	144	DST	The Innovation Hub	144		
12	Manufacturing Technology	Advanced Materials	Micro- and Nano-processing Facility	100	10	10	120	DST	UP/CEFIM	60	60	
12	Cross-cutters	Foresighting, road mapping and Demonstration	Foresighting and Road Mapping Institute	30	3	3	36	DST	DST	36		
11	Manufacturing Technology	Advanced Materials	Centralised Advanced Characterisation Facility	300	30	30	360	DST	NML	180	180	
9	Cross-cutters	Systems Engineering	National Systems Engineering Initiative	0	0	2	2	DTI	CSIR/DPSS/Universities	2		
7	Frontier Science and Technology Theme	Hydrogen	Specialised (Regional) H_2 Energy & Fuel Cell R&D	60	6	6	72	DST	Universities/Mintek		36	36

Priority (Multiple Mission Impact)	**Technology Mission**	**Sub-focus**	**Infrastructure**	**Capital Cost**	**Running Cost**	**Start-up Cost**	**Total Cost**	**Government Department(s)**	**Linkages**	**MTEF Period**		
				R Million						**1**	**2**	**3**
										R million		
			Centres									
7	ICT	Networks	TENET	0	0	0	0	DST	HESA			
7	ICT	Networks	UbuntuNet	0	0	2	2	DST	Meraka	2		
6	Frontier Science and Technology Theme	Microsatellite Engineering	Flagship satellite projects	300	30	15	345	DST	Sunspace	115	115	115
6	Resource-based Industries	Precious Metals (including PGMs and Gold)	National Centre for Precious Metals Research	100	10	10	120	DME	Mintek		60	60
5	Frontier Science and Technology Theme	Nanotechnology	Regional Nanotechnology Characterisation Facilities	130	13	3	146	DST	Universities/CSIR/Mintek	146		
5	High Value Industry Sector	Aerospace	Wind Tunnels	80	8	4	92	DoD	CSIR/DPSS			92
4	Frontier Science and Technology Theme	Vaccine technologies	Vaccine/Bio-Manufacturing Facility	120	12	12	144	DoH	MRC/BRICs		144	
4	ICT	Wireless & satellite	Wireless test bed	20	2	2	24	DST	Meraka	24		
4	Frontier Science and Technology Theme	Energy Coal & Renewable	SANERI	0	0	0	0	DME	CEF			
4	High Value Industry Sector	Nuclear	South African Nuclear Research Institute	0	0	5	5	DME	NECSA/ iThembaLABS/ Universities	5		
2	Biotechnology	BRICs	Biotechnology Hubs	240	24	12	276	DST	BRICs		138	138
2	ICT	HLT	Centre for Human	50	5	3	58	DST	US	58		

Priority (Multiple Mission Impact)	Technology Mission	Sub-focus	Infrastructure	Capital Cost	Running Cost	Start-up Cost	Total Cost	Government Department(s)	Linkages	MTEF Period		
				R Million						1	2	3
										R million		
			Language Technology									
2	Resource-based Industries	Light metals & New Metals	Centre for Light Metals and New Metals Research	50	5	3	58	DST	CSIR/MSM		29	29
2	Biotechnology	Networks	National Bio-informatics Network	0	0	0	0	DST	NBN			
2	High Value Industry Sector	Nuclear	Nuclear Manufacturing Centre of Excellence	0	0	5	5	DTI	DTI/NECSA/DST	5		
1	High Value Industry Sector	Nuclear	Radioactive Beam Facility	460	46	23	529	DST	Ithemba LABS			529
1	Biotechnology	Clinical testing	National Preclinical Institute	180	18	9	207	DoH	MRC		207	
1	Biotechnology	Networks	Biobank linked to Biotech Hubs	60	6	1	67	DST	NZG		34	34
1	Frontier Science and Technology Theme	Microsatellite Engineering	Space optics testing facility	50	5	3	58	DST	CSIR/DPSS/Sunspace	58		
1	ICT	Generic ICT	Centre for Monitoring and Evaluation	0	0	1	1	DST	Meraka	**1**		
1	High Value Industry Sector	Nuclear	Synchrotron	0	0	3	3	DST	NECSA/ iThemba LABS/ Universities	3		
1	High Value Industry Sector	Nuclear	National Nuclear Science Centre	0	0	1	1	DME	NECSA	1		
	Totals			2 870	287	187	3 344			995	1 159	1 189

9.4.2 Total expenditure over three MTEF periods

The total expenditure over the three suggested MTEF periods of roll-out of competitive infrastructure is given in Table 26.

Table 26: *Total expenditure over the MTEF periods per mission and average annual expenditure per MTEF period*

Mission	MTEF Period		
	1	2	3
Science Missions (R million)	968	841	475
Technology Missions (R million)	995	1 159	1 189
Total (R million)	1 963	2 000	1 664
Average per annum (R million)	654	667	555

From the average annual expenditure it can be seen that the total budget for addressing competitive infrastructure is of the order R 500 million to R 700 million per annum.

9.4.3 Shared responsibilities for funding

It should be kept in mind that not all the required costs are new and some are already catered for in other strategies as indicated in the report. and summarised in Table 27.

In the Science Missions, it is only the Earth Observation Systems that is represented by a strategy. All other missions lack a strategy.

Table 27: *List of infrastructure in Technology Missions for which costs are covered in other strategies*

Infrastructure	Funding of Infrastructure provided for in Strategy
Centre for High Performance Computing	ICT R&D
SANREN	ICT R&D
Regional Nanotechnology Characterisation Facilities	Nanotechnology
Specialised (Regional) Hydrogen Energy and Fuel Cell R&D Centres	Hydrogen Energy and Fuel Cell
SANERI	Energy R&D

The shared responsibility of the different departments as indicated in Table 24 and Table 25 should also lower the burden on the DST budget.

9.4.4 Stratification of infrastructure

The multiple mission impact prioritisation done in Section 8.2 could be grouped into layers or strata of infrastructure that are important in terms of its total envisaged impact on the NSI. These groups are shown in
Table 28.

The table should be read from the bottom, showing the baseline infrastructure that will influence more than one mission, leading to the top where infrastructure components having an impact in only one mission are shown. These are not necessarily less important as pointed out in the roll-out schedule according to the MTEF phasing as discussed in Section 9.4.1.

Table 28: *Strata of infrastructure according to groups based on multiple mission impact priorities (starting at 1 as most critical infrastructure)*

	Science Missions
7	Additional KAT dishes Dual Frequency GPS Receivers Contribution to HESS demonstrator Manned Submersible and ROV Upgrades at Sutherland and in Cape Town 2nd Generation Instrumentation CT Scanner and Tomography New Geodesy Station Marine Aquaculture research facility Research Instrumentation Near-shore Research Vessels
6	SAC Databank IK Centres NZG Research infrastructure Lunar Laser Ranging FACE-type instrumented field sites New generation VLBI antennas Dating & National Collections Satellite dishes Geoanalytical and characterisation "Ecotron"-type facility
5	Marion Base Surveillance Sites Natural History Collections BioBank facility
4	Airborne survey facility SAEON/LTER sites
3	Instumented anchored bouys
2	Accelerator Mass Spectrometer (AMS) Replacement of SA Agulhas
1	Modelling Capacity & Earth Observation Systems

	Technology Missions
9	National Nuclear Science Centre Synchrotron Centre for Monitoring and Evaluation Space optics testing facility Biobank linked to Biotech Hubs National Preclinical Institute Radioactive Beam Facility
8	Nuclear Manufacturing Centre of Excellence National Bio-informatics Network Centre for Light Metals and New Metals Research Centre for Human Language Technology Biotechnology Hubs
7	South African Nuclear Research Institute SANERI Wireless test bed Vaccine/Bio- Manufacturing Facility
6	Wind Tunnels Regional Nanotechnology Characterisation Facilities
5	National Centre for Precious Metals Research Flagship satellite projects
4	UbuntuNet TENET Specialised (Regional) H2 Energy 7 HFC R&D Centres
3	National Systems Engineering Initiative
2	Centralised Advanced Characterisation Facility
1	Foresighting and Road Mapping Institute Micro- and Nano-processing Facility Innovation laboratories on The Innovation Hub Centre for High Performance Computing SANREN

10 Conclusions and Recommendations

This section proposes certain government interventions to be taken in enabling the establishment of the competitive infrastructure requirements identified for the NSI. It is proposed that NACI recommends to the Minister of Science and Technology that the entire spectrum of infrastructure requirements identified be given serious consideration by the DST. The estimated period for implementation should be over a number of years, both from a budget scaling point of view and from a practical perspective of implementation. The prioritisation process suggested revealed certain clusters of infrastructure that have wider impact than others. These could be given preference in terms of sequence and scale of roll-out, as should those where existing infrastructure is under serious threat or has the potential to facilitate foreign direct investment in R&D. Some of these infrastructure components, especially in the technology missions are being implemented already and their listing in this study should be seen as support for faster implementation or increased support.

10.1 Government Interventions

It is recommended that the following interventions are initiated by NACI to enable the Minister and DST to have a competitive advantage in motivating for infrastructure funding from National Treasury:

- Consider the entire infrastructure landscape and cost estimates as revealed by this study.
- Give due consideration to the priorities for infrastructure that:
    i. Maximises benefit to as many missions as possible,
    ii. Those that are under threat if not given immediate attention, and
    iii. Those with potential to facilitate foreign direct investment, including in R&D.
- Motivate for competitive infrastructure funding from National Treasury by substantiating the proposals with a fully costed budget and life-cycle planning. The guideline given in this study is that the recurring cost of supporting infrastructure with technical staff, operators, management, upgrades and maintenance costs as well as making the infrastructure accessible to users is of the order 10 to 15 % of the capital investment. This recurring cost component does not include salaries of researchers, R&D project costs, bursaries and travel and subsistence costs. In national facility context this figure could readily be escalated by another 5 % of total capital expenditure to additionally include a critical mass of permanent professional R&D staff working in the national facility.
- Following successful allocation of competitive strategic infrastructure funding from National Treasury, commission detailed business plan development for infrastructural components. This business planning phase should include a consultative process where the specific needs of users will be incorporated in capacity planning, service costing, access, management planning, technical specification, extension and upgrade planning, and include planning of staffing, marketing and branding of the infrastructure. Ownership and placement issues will be addressed at this stage. This phase should also take cognisance of recommendations regarding the planning and governance of

expensive research equipment as outlined in the National Key Research and Technology Infrastructure Strategy[5].

- Implement the infrastructure development plans by establishing appropriate management structures and instruments (see section 10.6).
- Create management systems and governance systems to optimise the use and benefits of the newly established infrastructure.

10.2 Funding Mix

A large scale infrastructure plan such as the one proposed in this document will require a mix of funding at various stages. This funding will have to cover the following phases:

- Develop the required supporting strategies or adapt existing strategies to recognise the role R&D infrastructure could play to make the science and technology system globally competitive (very little detail about R&D infrastructure exists in current strategies). In some cases, especially in the science missions, no strategies exist at all. In the case of the technology missions, several strategies exist, but are not synergised with each other. This is dealt in more detail in section 10.3 below.
- Develop detailed business plans for each infrastructural component before it is funded and deployed. Some of the projects are large and the knowledge gained with some of the other "big science" projects such as SALT and KAT may be of great value.
- Motivate for the approximate R 5 billion in capital required to be spread over a number of years, preferably less than 10 years, taking the necessary escalations into account, as well as the trading position of the currency. This spread may not be even and to ensure delivery of the envisaged competitive infrastructure over the envisaged period, it may be necessary to spend the entire budget in the first 6 to 7 years. This means an average of about R 0.75 billion per annum in additional capital funding.
- The recurring funding for technical and maintenance support and support staff should be spread with a peak towards the later years of the 7 year period of competitive infrastructure capitalisation and would on the average be an additional R 54 million per annum.

10.3 Proposed Strategies and Flagship projects

For many of the technology missions Government approved strategies exist or strategies are close to being finalised. This enabled this research infrastructure assessment exercise to be contextualised and in some cases to be linked to flagship projects. This is however not always the case as several strategies do not adequately address R&D infrastructure.

For the science missions, on the other hand, no approved strategies exist, apart from Earth Observations for which Cabinet has approved implementation of a South African Earth Observations Systems strategy recently, but for which a strategy document on the basis of which this decision was taken is not as yet in the public domain. There are however some draft strategies such as "African Origins" for the palaeo-sciences in existence, as are some extensive draft programme proposals such as the Astronomy Frontiers Programme and SEAchange which could readily be reconceptualised into strategies.

It is crucial that strategies be developed where infrastructure planning takes place in a strategy vacuum as pointed out in this study and where existing strategies do not address R&D infrastructure adequately. Without them individual scientists or teams of scientists within the respective communities will continue to pursue what they believe to be relevant and important in the respective priority areas.

In addition to these strategies, a portfolio of flagship projects in the various science and technology missions should be developed as it is often the flagship projects that define the infrastructure requirements and which will add to clarity in terms of the detailed business plans and specifications. Coordination of the different science and technology strategies is essential, as the infrastructure requirements can often be considered and prioritised in this context. Such an approach of identifying flagship projects within the context of strategic planning may, in addition, identify infrastructure needs not identified in this needs analysis.

10.4 Cross-departmental responsibilities

Many science and technology activities are spread over various government departments. In some cases the lack of implementation regarding sound infrastructure proposals in the past has been the result of uncertainties regarding the responsible government department. An overview of cross-departmental R&D and S&T responsibilities should be undertaken and clarified.

From a science mission perspective this relates particularly to the DEAT regarding biodiversity and the DAC regarding the natural history collections in museums. As for the former, there is an urgent need to resolve roles and responsibilities regarding research and research funding, particularly also in the light of the statutory mandate of the newly established SANBI. Also, the present split in responsibilities regarding the Antarctic and Southern Ocean programme between DEAT (logistics and infrastructure) and DST regarding research is not an optimal arrangement and funding opportunities have been lost as a result of lack of coordination between these two departments. Ideally the establishment of a National Facility for Antarctic and Marine Research with responsibility for the infrastructure (research bases and vessels) as well as research funding needs to be reconsidered as a matter of urgency.

The natural history collections pertaining to biodiversity, palaeontology, palaeoanthropology, mineralogy and others in museums also require urgent attention. Their science focussed activities within structures that report to the Department of Arts and Culture do not contribute to the core mission of this Department and hence are not given the recognition and support they require to maintain and grow these collections.

The DST should position itself as the custodian of competitive R&D infrastructure as identified by this study and discussed in this report. As such it should liaise with other government departments to take the lead in inter-departmental interests in R&D and ideally become the sole agency for R&D infrastructure support.

10.5 Funding and Implementation

Clear funding policies should be developed and the processes for making capital available for establishing the infrastructure identified in this study to be rolled out over the foreseeable future should be different from funding research equipment in the past. In this regard the National Key Research and Technology Equipment Strategy developed by the NRF may provide some appropriate pointers. The DST should take the lead in directing the infrastructure roll-out and to outsource the management and implementation to parties with the necessary expertise. In some cases, especially for the technology missions, implementation agencies have been assigned the task of overseeing the implementation of strategies. Where infrastructure forms part of such a strategy, these agencies could manage the roll-out. Existing agencies should as far as possible be tasked or contracted to manage such roll-out.

10.6 Strategic Management Requirements

It is advisable, given the size and impact of the R&D infrastructure requirements identified, to create an infrastructure strategic management function in the DST to be coordinated at executive level. Such a function would also have the responsibility of continuously scrutinising very closely the roadmap developments locally and abroad in order to identify in which areas and how South Africa needs to position itself not only to access such infrastructure but also in order to attract large infrastructure facilities to South Africa. The significance of the impact of infrastructure on the strategies and missions and the competitive aspects of the NSI justify such a governance focus in the department.

10.7 Human Capital

For most of the science and technology missions serious concerns have been expressed regarding availability of research staff and students, and that the infrastructure when it becomes available will not be utilised optimally. This has been highlighted in the report for astronomy (section 6.2.4 above) and oceanography (section 6.4.4) but equally applies to areas such as space physics, earth science, palaeontology, systems engineering and others. There is general consensus that the human capital dimensions also need to be addressed in the development of any strategy. The approach adopted in the Energy Research and Development Strategy, i.e. the implementation of a specially funded post-graduate programme in sustainable and renewable energy, and the implementation of a number of research chairs, is considered to be very sound and one that will go a long way in addressing the problem.

10.8 Bridging the gap between secondary education and competitive infrastructure

The original request for proposal of NACI combined the notion of infrastructure for secondary education and competitive infrastructure. The task was subsequently split and conducted by two separate service providers. Although the scope of the tasks differs so much that they are best kept separate, some ideas of how bridging between the two environments may be facilitated are presented here.

- Competitive infrastructure representing "big science" or advanced technology will always have some appeal among young people interested in science, technology and engineering. Knowing that the country is well equipped in R&D infrastructure which will create more investment in R&D, also from foreign investors may entice them to opt for a career in science and technology, as career opportunities are being created for young people that have never existed before.
- By simultaneously developing access for students and the public as part of PUSET, most of the large infrastructural components mentioned in this study could become positive attractors for career deciders to move into science, technology and engineering.
- The excitement value of competitive infrastructure linked to interactive science centres that focus on specific science and technology environments, e.g. a centre for nuclear sciences at NECSA and the envisaged Life Sciences Centre at the NZG could be of more value than exposing a secondary school student to a science laboratory in the school. These "living" laboratories could do more for maths and science education than the classical educational approach.
- Science Outreach and Education should be part of the business plans for each of the competitive R&D infrastructure components, especially where new national facilities are proposed.
- Internships of young graduates in science and engineering within such facilities will also provide career guidance and show them the environments in which they can work.

11 Conclusion

This study into R&D infrastructure has revealed that significant investment will be required to elevate the NSI to the state of competitiveness that is required to be a global player in R&D and innovation. It has taken a holistic view of the NSI from both a science and a technology perspective and shown that although many strategies that are in place are facilitating a move towards competitive R&D, in some cases strategy vacuums exist and in general very little synergy exists between science and technology areas. This may partly be caused by the fact that academic research still takes place in the silos of disciplines, whereas people, markets and the environment benefit from a multidisciplinary approach. It became clear in the study that much of the infrastructure requirements could be deployed in such a way that will foster multidisciplinary research and development and thereby beneficiate strong innovation behaviour. This supports the notion that most innovation takes place at the interfaces and boundaries of disciplines.

A systematic implementation of the infrastructure requirements identified in this study will enable government to elevate science, engineering and technology in the identified priority areas, and hence also the NSI to the level of international competitiveness as envisaged. This will undoubtedly have numerous positive impacts such as making the country globally competitive as a player in R&D, in developing products and services based on science and technology that are attractive for the world markets, and in making South Africa a place of choice to do business, effecting the incubation of many small and medium sized enterprises that can grow to successful, sustainable business entities.

12 Appendices

12.1 People Interviewed

Dr Rob Adam	NECSA
Dr Neville Arendse	Department of Science and Technology
Prof Lew Ashwal	University of the Witwatersrand
Dr Johann Augustyn	Marine and Coastal Management, DEAT
Dr Margaret Avery	Iziko
Mr Johann Basson	Convenor: Hydrogen Energy and Fuel Cell Strategy
Dr Paul Bartels	Biobank
Prof Pat Berjak	University of Kwazulu Natal
Prof Marthan Bester	University of Pretoria
Dr Krish Bharuth-Ram	iThembaLABS
Prof Paulette Bloomer	University of Pretoria
Dr Hermi Boraine	NACI
Dr David Britton	University of Cape Town
Dr Lee Burger	University of the Witwatersrand
Prof Adri Burger	Northwest University
Mr Rob Calitz	Armscor
Ms Anati Canca	Department of Science and Technology
Prof Phil Charles	SAAO
Prof Anusya Chinsamy-Turan	University of Cape Town
Prof Steven Chown	University of Stellenbosch
Mr Bart Cilliers	Sunspace
Prof Jean Cleymans	University of Cape Town
Dr Tinus Cloete	Council for Geoscience
Prof Eugene Cloete	University of Pretoria
Dr Laurens Cloete	Meraka Institute

Dr Ludwig Combrinck	HartRAO
Prof Robin Crewe	University of Pretoria
Dr Frikkie De Beer	NECSA
Mr Francois Denner	the dti
Prof Paul Dirks	University of the Witwatersrand
Prof Monuko du Plessis	CEFIM, University of Pretoria
Mr Ben Durham	Department of Science and Technology
Dr Raymond Durrheim	CSIR
Prof Tony Fairall	University of Cape Town
Dr Bernie Fanaroff	SKA
Mr Chris Franklyn	NECSA
Ms Michelle Galloway	SAAVI, MRC
Dr Steve Giddings	CSIR
Dr Gerhard Graham	Council for Geoscience
Ms Nondzwakazi Gumede	Department of Science and Technology
HMO Flagship Workshop	22 participants from HMO, Department of Communications, Chief Directorate Surveys and Mapping, NRF, several universities, not already included in the list
Prof Margit Haerting	University of Cape Town
Dr Scott Hazelhurst	University of the Witwatersrand
Mr Fadl Hendricks	Cape BioTech
Dr Dai Herbert	Natal Museum
Mr Reinhard Hiller	Cape BioTech
Dr Thembela Hillie	CSIR
Prof Brian Huntley	Including 8 members of the SANBI executive team
Mr Sherrin Isaac	Meraka Institute
Ms Tina James	Trigrammic
Prof Justin Jonas	HartRAO
Mr Llew Jones	Meraka Institute

Dr H Klinger	Iziko
Prof Antoinette Kotze	National Zoological Gardens
Dr Pieter Kotze	Hermanus Magnetic Observatory
Prof Anton le Roex	University of Cape Town
Dr Steve Lennon	ESKOM
Mr Eric Lerata	Peldev, NECSA
Ms Anita Loots	SKA
Prof. Amanda Lourens	Northwest University
Dr Wynand Louw	NML, CSIR
Dr Peter Manyike	SAAVI, MRC
Dr Duncan Martin	TENET
Dr Peter Martinez	National Working Group on Space Science and Technology
Ms Pontsho Maruping	Department of Science and Technology
Dr Agatha Masemola	BioPAD
Mr Butana Mboniswa	BioPAD
Prof Terence McCarthy	University of the Witwatersrand
Prof Melodie McGeoch	University of Stellenbosch
Dr Boni Mehlomakulu	Department of Science and Technology
Dr Jonathan Miller	Trigrammic
Prof Garth Milne	Sunspace
Prof Duncan Mitchell	University of the Witwatersrand
Dr Joe Molete	Cape BioTech
Dr Sagren Moodley	NACI
Prof Harm Moraal	Northwest University
Mr Sias Mostert	SunSpace
Dr Lebs Mphahlele	Department of Science and Technology
Dr Jonas Mphepya	SA Weather Services
Prof Kevin Naidoo	University of Cape Town

Mr Dhesigen Naidoo	Department of Science and Technology
Dr Johan Nell	Mintek
Prof Norman Owen-Smith	University of the Witwatersrand
Prof Norman Pammenter	University of Kwazulu Natal
Prof John Parkington	University of Cape Town
Dr Adi Paterson	Department of Science and Technology
Dr Gary Pattrick	Mintek
Dr Roger Paul	Mintek
Mr Johan Pauw	SAGEOS and SAEON
Prof Mike Perrin	University of Kwazulu Natal
Prof Kobus Pienaar	Northwest University
Dr Stuart Piketh	University of the Witwatersrand
Prof Calie Pistorius	University of Pretoria
Prof Marius Potgieter	Northwest University
Ms Marjorie Pyoos	Department of Science and Technology
Dr Mike Raath	University of the Witwatersrand
Prof Michele Ramsay	National Health Laboratory Services and Wits University
Mr Mothibi Ramusi	SAC - CSIR /DST Space Affairs Office
Prof Christo Raubenheimer	Northwest University
Dr Vijay Reddy	HSRC
Dr Tony Ribbink	SAIAB - Aquatic
Mr Kobus Roux	Meraka Institute
Prof Justus Roux	University of Stellenbosch
Prof Bruce Rubidge	University of the Witwatersrand
SANCOR Workshop	40 participants from various Universities, MCM and the Oceanographic Research Institute (ORI) in Durban
Dr Chris Scheffer	Department of Science and Technology
Dr Bob Scholes	CSIR
Prof Mary Scholes	University of the Witwatersrand

Prof Clark Scholtz	University of Pretoria
Mr Gerhard Schulze	SA Weather Services
Mr Manfred Scriba	CSIR
Prof Judith Sealy	University of Cape Town
Mr Tshepo Seekoe	Department of Science and Technology
Dr Bethuel Sehlapelo	Department of Science and Technology
Dr Yonah Seleti	DST
Dr Elias Sideras-Haddad	University of the Witwatersrand
Prof Paul Skelton	SAIAB - Aquatic
Mr Johan Slabber	PBMR
Prof Robert Slotow	University of Kwazulu Natal
Dr Rodger Smith	Iziko
Mr Johan Strydom	DPSS, CSIR
Dr Peter Sutcliffe	Hermanus Magnetic Observatory
Dr Francis Thackeray	Northern Flagship
Prof Philip Tobias	University of the Witwatersrand
Prof Steve Tollman	MRC/WITS Unit in Rural Public Health & Health Transitions Research
Mr Henry Valentine	Department of Environmental Affairs and Tourism
Dr Elma van der Lingen	Mintek
Prof Albert van Jaarsveld	University of Stellenbosch
Prof David Walker	University of Kwazulu-Natal
Dr Dave Walwyn	CSIR
Dr Patricia Whitelock	South African Astronomical Observatory
Prof Allan Wilson	UKZN
Prof Mike Wingfield	University of Pretoria FABI
Dr Stephen Woodborne	CSIR/QUADRU
Prof Pete Zacharias	University of Kwazulu Natal
Dr Peter Zawada	Geosciences

12.2 Delegates to workshops

12.2.1 Gauteng Workshop

Mr Andrew Alston	TENET
Dr Paul Bartels	Biobank
Dr Hermi Boraine	NACI
Dr Anthon Botha	TechnoScene
Prof Adri Burger	Northwest University
Mr Rob Calitz	Armscor
Ms Anati Canca	Department of Science and Technology
Dr Ludwig Combrinck	HartRAO
Prof Maarten de Wit	AEON and University of Cape Town
Prof Paul Dirks	University of the Witwatersrand
Mr Ben Durham	Department of Science and Technology
Dr Raymond Durrheim	CSIR
Dr Gerhard Graham	Council for Geoscience
Dr Dai Herbert	Natal Museum
Mr Sherrin Isaac	Meraka
Dr Steve Lennon	ESKOM
Prof Terence McCarthy	University of the Witwatersrand
Dr Sagren Moodley	NACI
Mr Imraan Patel	DST: Department of Science and Technology: Economic Impact
Prof Calie Pistorius	University of Pretoria
Ms Marjorie Pyoos	Department of Science and Technology
Dr Vijay Reddy	HSRC
Prof Bruce Rubidge	University of the Witwatersrand
Mr Manfred Scriba	CSIR

Prof Gideon Smith	SANBI
Dr Francis Thackeray	Northern Flagship
Mr Martin van Staden	NML, CSIR
Dr Gerhard von Gruenewaldt	Consultant
Mr John Wesley	CSIR Aerospace Systems
Mr Christopher Willis	SANBI
Prof Allan Wilson	UKZN
Dr Peter Zawada	Geosciences

12.2.2 Western Cape Workshop

Dr Johann Augustyn	Marine and Coastal Management, DEAT
Dr Anthon Botha	TechnoScene
Dr Lowry Conradie	iThembaLABS
Dr Kobus Lawrie	iThembaLABS
Mr Yunus Manjoo	iThembaLABS
Dr Guy Midgley	SANBI
Mr Ben Opperman	HMO
Prof Justus Roux	University of Stellenbosch
Prof Judith Sealy	University of Cape Town
Dr Chris Theron	iThembaLABS
Mr Henry Valentine	Department of Environmental Affairs and Tourism
Prof Albert van Jaarsveld	University of Stellenbosch
Dr Gerhard von Gruenewaldt	Consultant
Dr Patricia Whitelock	South African Astronomical Observatory

GLOSSARY OF ACRONYMS

ACEP	African Coelacanth Ecosystems Project
ADCP	Acoustic Doppler Current Profiler
AES	Auger Electron Spectroscopy
AFM	Atomic Force Microscopy
AFRIMETS	Inter Africa Metrology System
AISI	Aerospace Industries Support Initiative
ALC	African Laser Centre
ALICE	A Large Ion Collider Experiment
AMS	Accelerator Mass Spectrometry
AMTL	Advanced Manufacturing Technology Laboratory
AMTS	Advanced Manufacturing Technology Strategy
APAN	Asia Pacific Academic Network
ARC	Agricultural Research Council
ARM	African Resource Monitoring
ASCLME	Agulhas Somali Current Large Marine Ecosystem
ASGISA	Accelerated and Shared Growth Initiative – South Africa
ASSEGAI	A Strategy for a Sustainable, Economical and Growing Aerospace Industry
BCLME	Benguela Current Large Marine Ecosystem Programme
BENEFIT	Benguela Environment Fisheries Interaction and Training Programme
BRC	Biological Resource Centres
BRIC	Biotechnology Regional Innovation Centres
BVOC	Biogenic Volatile Organic Compounds
CGS	Council for Geosciences
CEFIM	Carl and Emily Fuchs Institute for Micro-electronics
CHAMP	CHAllenging Minisatellite Payload
CHPC	Centre for High Performance Computing
CoML	Census of Marine Life
CPU	Central Processing Unit
CT	Computerised Tomography
CTD	Conductivity-Temperature-Depth
CTP	Committee of Technikon Principals
DAC	Department of Arts and Culture
DEAT	Department of Environmental Affairs and Tourism
DERI	Defence and Evaluation Institution
DME	Department of Minerals and Energy
DoD	Department of Defence

DoE	Department of Energy
DP	Dynamic Positioning
DPE	Department of Public Enterprises
DPSS	Defence, Peace, Safety and Security
DRC	Democratic Republic of the Congo
DST	Department of Science and Technology
EASSy	Eastern Africa Submarine Cable System
ESFRI	European Strategy Forum on Research Infrastructures
ESR	Electron Spin Resonance
F_2	Fluorine
FABI	Forestry and Agricultural Biotechnology Institute
FACE	Free Air Carbon Dioxide Enrichment
FDI	Foreign Direct Investment
FEA/FEM	Finite Element Analysis/Finite Element Modelling
Gb/s	Gigabit per second
GC-MS	Gas Chromatography linked Mass Spectrometry
GEF	Global Environment Fund
GEOS	Global Earth Observation System
GEOSS	Global Earth Observation System of Systems
GIS	Global Information System
GMO	Genetically Modified Organism
GOOS	Global Ocean Observing System
GPS	Global Positioning System
HartRAO	Hartebeesthoek Radio Astronomy Observatory
HCI	Human Computer Interface
HEI	Higher Education Institution
HESA	Higher Education South Africa
HESS	High Energy Spectroscopic System
HF	High Frequency
HF	Hydrogen Fluoride
HLT	Human Language Technology
HMO	Hermanus Magnetic Observatory
HPC	High Performance Computing
HTR	High Temperature Reactor
IAEA	International Atomic Energy Agency
ICBGE	International Centre for Biotechnology and Genetic Engineering
ICPMS	Inductively Coupled Plasma Mass Spectrometry
ICT	Information and Communication Technology
IF	Innovation Fund

IK	Indigenous Knowledge
IKS	Indigenous Knowledge System
ILRI	International Livestock Research Institute
IMT	Institute for Maritime Technology
INCOSE	International Council on Systems Engineering
INPETH	International Network for the Demographic Evaluation of Populations and Their Health
IOC	Intergovernmental Oceanographic Commission
IOGOOS	Indian Ocean Global Ocean Observing System
IP	Intellectual Property
ISGEO	Institute for Space Geodesy and Earth Observation
ISOL	Isotope Separation On-Line
ISP	Internet Service Provider
ITER	International Thermonuclear Experimental Facility
KAT	Karoo Array Telescope
kb/s	Kilobit per second
LEO	Low Earth Orbiting
LINAC	Linear Accelerator
LLR	Lunar Laser Ranging
LTER	Long Term Ecological Research
LWR	Light Water Reactor
MALDI-TOF MS	Matrix-assisted Laser Desorption/Ionisation Time Of Flight Mass Spectrometry
MAST	Mega Amp Spherical Tokamak
MCM	Marine and Coastal Management
MEMS	Micro-electromechanical System
MLIS	Molecular Laser Isotope Separation
MOBLAS	Mobilisation Level Application Software
MOEMS	Optical MEMS
MRC	Medical Research Council
MRMC	Major Radiation Medicine Centre MRMC
MTEF	Medium Term Expenditure Framework
NACI	National Advisory Council on Innovation
NACoE	National Aerospace Centre of Excellence
NASA	North American Space Agency
NASSP	National Astronomy and Space Science Programme
NBCF	National Biodiversity Collections Facility
NBN	National Bioinformatics Network
NCRIS	(Australian) National Collaborative Research Infrastructure Strategy
NECSA	Nuclear Energy Corporation of South Africa

NEPAD	New Partnership for Africa's Development
NF_3	Sodium Fluoride Gas
NGO	Non-governmental Organisation
NIH	National Institute of Health
NML	National Metrology Laboratory
NMR	Nuclear Magnetic Resonance
NOAA	National Oceanic and Atmospheric Administration
NRDS	National Research and Development Strategy
NREN	National Research and Education Network
NRF	National Research Foundation
NSBA	National Spatial Biodiversity Assessment
NSF	National Science Foundation
NSI	National System for Innovation
NWU	North West University
NZG	National Zoological Gardens
OBP	Onderstepoort Biological Products
ORI	Oceanographic Research Institute
OTB	"Overberg Toetsbaan"
OVI	Onderstepoort Veterinary Institute
PASA	Petroleum Agency of South Africa
PBMR	Pebble Bed Modular Reactor
PCR	Polymerase Chain Reaction
PF	Projectile Fragmentation
PFMA	Public Finance Management Act
PGM	Platinum Group Metal
PoP	Point-of-Presence
POST	Pacific Ocean and Shelf Tracking
PPP	Public-Private-Partnership
PTP	Pelindaba Technology Products
QEMSEM	Quantitative Evaluation of Minerals by Scanning Electron Microscope
QUADRU	Quaternary Dating Research Unit
R&D	Research and Development
REN	Research and Education Network
RFI	Request for Information
RFID	Radio Frequency Identification
RFP	Requests for Proposal
RFQ	Radio Frequency Quadrupole
ROV	Remotely Operated Vehicle
RU	Rhodes University

S&T	Science and Technology
SAA	South Atlantic Anomaly
SAAO	South African Astronomical Observatory
SAAVI	South African AIDS Vaccine Initiative
SABIF	South African Biodiversity Information Facility
SAC	Satellite Applications Centre
SADA	South African Data Archive
SADERI	South African Defence and Evaluation Institution
SAEON	South African Environmental Observation Network
SAEOS	South African Earth Observation System
SAFE	South Africa Far East (Optical Fibre Cable system)
SAHRA	South African Heritage Resources Agency
SAIAB	South African Institute for Aquatic Biodiversity
SALT	Southern African Large Telescope
SAMES	South African Micro-electronic Systems
SANAP	South African National Antarctic Programme
SANBI	South African National Biodiversity Institute
SANBio	Southern African Network for Biosciences
SANCOR	South African Network for Coastal and Oceanic Research
SANERI	South African National Energy Research Institute
SANPARKS	South African National Parks
SANReN	South African National Research and Education Network
SAT-3 WASC	Southern Africa/West Africa Submarine Cable
SAUVCA	South African Universities Vice-Chancellors' Association
SCAR	Scientific Committee on Antarctic Research
SEAChange	Society, Ecosystems and Change Programme
SEM	Scanning Electron Microscope
SET	Science, Engineering and Technology
SHARE	Southern Hemisphere Aural Radar Experiment
SHRIMP	Sensitive High Resolution Ion MicroProbe
SIMS	Secondary Ion Mass Spectroscopy
SKA	Square Kilometer Array
SNP	Single Nucleotide Polymorphism
SQAM	Standardisation, Quality Assurance, Accreditation and Metrology
SuperDARN	Super Dual Auroral Radar Network
SWIOFP	South West Indian Ocean Fisheries Project
TEC	Total Electron Count
TENET	Tertiary Education Network
TIMS	Thermal Ionisation Mass Spectroscopy

UCT	University of Cape Town
UFS	University of the Free State
UK	United Kingdom
UKZN	University of KwaZulu-Natal
UP	University of Pretoria
US	United States
US	University of Stellenbosch
USA	United States of America
VLBI	Very Long Baseline Interferometry
VNTR	Variable Number Tandem Repeat
wBRC	Wildlife Biological Resources Centre
Wits	University of the Witwatersrand
WMO	World Meteorological Organisation
XPS	X-ray Photo-emission Spectroscopy
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence