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White Paper on
Science, Technology and Innovation

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"Scientific inventions, at all conceivable levels, should enrich human life …"

Chief Albert Luthuli (first African winner of the Nobel Peace Prize), December 1961, Oslo.

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ACRONYMS

AU	African Union
BRICS	Brazil, Russia, India, China and South Africa
DHET	Department of Higher Education and Training
DST	Department of Science and Technology
dti	Department of Trade and Industry
GDP	Gross domestic product
GERD	Gross expenditure on research and development
ICT	Information and communications technology
M&E	Monitoring and evaluation
NACI	National Advisory Council on Innovation
NDP	National Development Plan
NRF	National Research Foundation
NSI	National system of innovation
OECD	Organisation for Economic Co-operation and Development
R&D	Research and development
SADC	Southern African Development Community
SET	Science, engineering and technology
SME	Small and medium enterprise
SOE	State-owned enterprise
STI	Science, technology and innovation

GLOSSARY OF TERMS

Circular economy: Looking beyond the current "take, make and dispose" extractive industrial model, the circular economy is designed to restore and regenerate. Underpinned by a transition to renewable energy sources and system-wide innovation, it aims to redefine products and services to reduce waste and negative impacts.

Emerging researchers: People who are generally younger than 40 years and have not yet completed their PhDs or established themselves as active researchers, although they are employed in knowledge-based institutions.

Established researchers: People who have established themselves as independent researchers and have an active research track record. They produce the bulk of the research output and play an important role in training and mentoring younger and less experienced researchers.

Grassroots innovations: Grassroots innovations are innovations undertaken by individuals, particularly the poor, in the informal economy and outside the realms of formal institutions of innovation.

Human capabilities: A non-instrumental notion of human development, where developing the knowledge and skills of people has intrinsic value and goes beyond the narrowly defined science, engineering and technology skills required for the National System of Innovation. The development of

science, engineering and technology skills is done in the broader context of addressing issues such as nutrition and access to the Internet, and fostering a culture that values scientific achievement.

Megatrends: Global megatrends are social, economic, technological, environmental or geostrategic forces that are shaping our world in profound ways. The implications of these forces are broad and varied, and present tremendous opportunities and risks.

National Development Plan: The National Development Plan is a long-term South African development plan, developed by the National Planning Commission in collaboration with South Africans from all walks of life. It serves as an action plan for securing the future of South Africans as charted in the Constitution. It is founded on six pillars that represent the plan's broad objectives to eliminate poverty, reduce inequality and ensure a decent standard of living for all South Africans by 2030.

National System of Innovation: There is no single accepted definition of a National System of Innovation. What is important is the web of interaction in the system, as underscored in the following two excerpts: "The network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies";[33] and "that set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies".[34]

Next Industrial Revolution: The Next Industrial Revolution has been defined as technological developments that blur the lines between the physical, digital and biological spheres. It integrates cyber-physical systems and the Internet of Things, big data and cloud computing, robotics, artificial intelligence-based systems and additive manufacturing. Compared to previous industrial revolutions, this one is evolving at an exponential rather than a linear pace.

Next-generation researchers: Students who have not completed their studies and are not yet employed in knowledge-based institutions.

Office of Technology Transfer: An Office of Technology Transfer tends to be located at a university or science council and is focused on facilitating the identification, protection and use of intellectual property that emanates from research and development for social and/or economic benefit. Researchers are the creators of this intellectual property. By managing and protecting it appropriately, the technology transfer function helps researchers translate their intellectual property into useful and innovative products and services, creating an additional layer of impact for their research. It also gives industry access to this intellectual property to further develop and use it commercially or otherwise.

Open Innovation: The basic premise of Open Innovation is to introduce more actors into the innovation process so that knowledge can circulate more freely and be transformed into products and services that create new markets, fostering a stronger culture of entrepreneurship.

Open Science: Open Science refers to an approach to research based on greater access to public research data enabled by information and communications technology tools and platforms, broader collaboration in science, including the participation of non-scientists, and the use of alternative copyright tools for diffusing research results.

Policy nexus: New institutional arrangements to facilitate collaboration in specific areas. Arrangements are based on written agreements that specify how to harmonise policy and coordinate the implementation of action plans.

Quadruple helix: The quadruple helix approach is grounded in the idea that innovation is the outcome of an interactive process involving government, academia/the research sector, the private sector and civil society, each contributing according to its "institutional" function in society. Inclusion of the fourth helix (i.e., civil society) is critical as science, technology and innovation is increasingly evaluated by its social robustness and inclusivity. The fourth helix highlights new discoveries and innovations that improve social welfare such as eco-innovation. Moreover, government, academia, industry and civil society are key actors that promote a democratic approach to innovation through which strategy development and decision-making are exposed to feedback from key stakeholders, resulting in socially accountable policies and practices.[35]

Research infrastructures: Research infrastructures are facilities, resources and services used by the science community to conduct research and foster innovation.

Science diplomacy: Science diplomacy refers to scientific cooperation and engagement with the explicit intent of building positive relationships with other governments and societies. The Royal Society and the American Association for the Advancement of Science identify three main types of activities related to science diplomacy:

- Science in diplomacy: Informing foreign policy objectives with scientific advice.
- Diplomacy for science: Facilitating international science cooperation.
- Science for diplomacy: Using scientific cooperation to improve international relations between countries.[36]

Technology Balance of Payments: The technology balance of payments is a subdivision of the balance of payments used to collate invisible transactions relating to trade in technical knowledge and technology-related services between partners in different countries.[37] It registers the commercial transactions related to international technology and know-how transfers. It consists of money paid or received for the use of patents, licences, know-how, trademarks, patterns, designs and technical services (including technical assistance), and for industrial research and development carried out abroad, among other things.

Transdisciplinarity: Transdisciplinary research is defined as research efforts conducted by investigators from different disciplines working jointly to create new conceptual, theoretical, methodological and translational innovations that integrate and move beyond discipline-specific approaches to address a common problem.

EXECUTIVE SUMMARY

This White Paper sets the long-term policy direction for the South African government to ensure a growing role for science, technology and innovation (STI) in a more prosperous and inclusive society. It focuses on using STI to accelerate inclusive economic growth, make the economy more competitive and improve people's everyday lives. It aims to help South Africa benefit from global developments such as rapid technological advancement and geopolitical and demographic shifts. Examples of these "megatrends" include the Next Industrial Revolution, the rise of China and India as economic powers, rapid urbanisation, and the growing proportion of young people in Africa's population. These megatrends hold both opportunities (such as rapid economic growth) and threats (such as the loss of traditional and low-skilled jobs). The extent to which South Africa will thrive in the world of the future will depend on policies and programmes put into place to prepare for change.

This White Paper is not an implementation plan. The policy actions proposed here will be implemented according to decadal plans informed by technology foresight studies and consultation with all implementation partners (across government, business, academia and civil society) to ensure policy coherence and certainty. The decadal plans will detail technology focus areas, programmes to be initiated, institutional arrangements and funding required for these programmes, and ways to evaluate their performance. They will be reviewed and updated every five years, or as deemed appropriate by the Department of Science and Technology.

Since 1996, when the White Paper on Science and Technology was adopted, a solid foundation has been laid to achieve the ambitions outlined here. Recent reviews of the South African National System of Innovation (NSI) show that significant progress was made between 1996 and 2016. This included expanding the STI institutional landscape, a three-fold increase in publications, significant growth in the participation of black people and women in the research and development workforce, and a rise in doctoral graduation rates.

However, challenges remain. The NSI is still not fully inclusive, and since 1996 South Africa's innovation performance (measured in patents and products) has been relatively flat. There is potential to increase the impact of STI in South Africa. STI can be instrumental in improving public service delivery and decision making for public policy; increasing the competitiveness of existing firms; forming new technology-based firms; modernising existing industries such as agriculture and mining; developing emerging industries such as those linked to the Next Industrial Revolution; exploiting new sources of economic growth such as green growth; improving the quality of life of South Africans, particularly in poor communities, through improved educational and health outcomes; and promoting environmental custodianship to safeguard the future. Furthermore, the production of knowledge through scientific enquiry develops an empowered citizenry and equips children with the thinking skills they need in a technologically advanced world.

For STI to be a powerful driver of growth and development in South Africa, a number of long-standing problems in the NSI need to be addressed. Therefore, in addition to expanding successful initiatives to grow the research system and skills base of the economy, and improve innovation performance, the White Paper introduces a number of policy shifts. These include:

- Increasing the focus on inclusivity and transformation.
- Enhancing the innovation culture in society and government.
- Including and supporting civil society and business in government planning and funding.
- Increasing the focus on local, particularly city-based, innovation ecosystems.
- Supporting grassroots innovation.
- Prioritising a pan-African STI agenda.
- Institutionalising approaches to improve policy coherence and programme and budget coordination in the NSI.
- Increasing investment in the NSI and optimising the productivity of those investments.
- Endorsing open data, Open Science and Open Innovation approaches.
- Supporting inter- and transdisciplinary approaches to knowledge development.

CHAPTER 1: INTRODUCTION

Science, technology and innovation (STI) embodies some of the best qualities of humanity: curiosity, creativity, aspirational thinking and resilience. STI should therefore be nurtured to improve South Africans' quality of life and the country's competitiveness. In 1996, with the adoption of the White Paper on Science and Technology, the South African government committed to using STI to develop the country and overcome the legacy of apartheid.

Twenty years later, building on achievements since 1996 and using South Africa's abundant natural and human resources, STI can significantly contribute to realising the National Development Plan (NDP) 2030 and help citizens thrive in a rapidly changing world.

This White Paper sets the medium- to long-term policy direction for government to ensure a growing role for STI in a prosperous and inclusive society in which the potential of all South Africans is realised. It proceeds from the starting point that as Africans we share a common history and, as humankind, a common future.

"No modern society has scaled the heights of social progress without science and technology … harnessing the force of science and technology to meet South Africa's developmental needs is among the surest ways out of the current quagmire of under-development … research has shown that nations such as Japan, South Korea and Germany put science, technology and innovation in the service of their societies, with commendable results."

(Kgalema Motlanthe, former president of South Africa, addressing the 2013 South African Science, Technology and Innovation Summit)

1.1 Why a new White Paper on STI?

There are two reasons for South Africa renewing its STI policy. First, global megatrends such as demographic shifts, technological change and environmental degradation render even the near future uncertain and require new STI policy approaches. Second, recent reviews indicate that South African society has not yet fully realised the potential of STI to address the country's challenges.[2, 14, 15] The next three sections examine these reasons in more detail.

1.2 The evolution and performance of the National System of Innovation, 1996 to 2016

1.2.1 South African STI policy since 1996

In 1994, the newly elected government inherited a fractured society, a fiscally drained state and an unsustainable and resource-intensive economic growth path. The pre-1994 STI system was small, exclusive and in line with the narrow agenda of the apartheid state, rather than oriented towards economic efficiency, broad development needs and social equity. It was noted that "at an institutional level the apartheid years saw the rapid decline of coherent science and technology programmes … and indeed policy".[1]

The democratic government began a period of comprehensive STI policy development. It adopted the 1996 White Paper on Science and Technology, the 2002 National Research and Development Strategy,

and the Ten-Year Innovation Plan for South Africa (2008–2018). Various sectoral and cross-cutting STI strategies were also adopted, for example, for advanced manufacturing technology, biotechnology and human resource development. The aim was to transform the STI system to serve all South Africans, counter STI policy fragmentation, expand and transform human resources, provide more support for researchers, build the required STI institutions, expand knowledge infrastructure, and increase innovation to support economic growth and socioeconomic development.

1.2.2 Performance of the National System of Innovation, 1996 to 2017

This section provides an overview of the performance of the National System of Innovation (NSI) over the past two decades. It highlights progress made in developing the NSI, expanding skills and research performance, facilitating innovation performance and increasing financial resources for the NSI. It also introduces the remaining challenges (the reasons for these challenges are discussed in more detail from Chapter 3 onwards).

Developing the NSI

The 1996 White Paper adopted the NSI as an organising framework for STI policy and implementation. Since then, significant progress has been made in developing existing and setting up new institutions such as the Technology Innovation Agency, the National Intellectual Property Management Office, and the Department of Science and Technology (DST). Partnerships have been strengthened and public support to business is growing (for example, through the research and development [R&D] Tax Incentive). STI is increasingly being incorporated into government plans, both at sectoral level (for example, in Operation Phakisa for mining and the oceans economy) and country level (for example, in the Nine-Point Plan for the economy). The most significant indication that STI is being integrated into government planning is the central role of STI in the NDP. While challenges remain (for example, the South African STI system is still too small and some fragmentation of STI programmes persists), the government's effort in setting up institutions, building NSI relationships and facilitating coherence of STI programmes is beginning to see results.

Expanding the research system and developing high-level skills

Various instruments have been introduced to expand the research system, including the South African Research Chairs Initiative and Centres of Excellence. Among the positive impacts of these instruments was that they enabled the concentration of investment in South African research in areas of strategic importance. For instance, investment was targeted at knowledge to modernise South Africa's mining and agricultural sectors and to exploit South Africa's geographical advantage, as well as at emerging (at the time) areas such as biotechnology and nanotechnology, creating a strong science base for the NSI. As a result, South African scientists are among the best in the world in a number of fields such as theoretical physics, minerals processing, materials processing, environmental technologies, astronomy, health sciences, software engineering, development studies and poverty and inequality studies.

South African researchers have established productive international networks. Between 1996 and 2014, research output tripled (a two-fold per-capita increase). PhD student enrolment has increased by 350 percent.[30] These are striking statistics, given that challenges remain in growing the system (for example, undergraduate enrolments in science, engineering and technology (SET) fields increased by only 30 percent and the number of full-time researchers did not increase significantly).[30]

The participation of black people and women in the research system has grown substantially. In 2013/14, women comprised 44 percent of the R&D workforce and black people 52 percent. However, inequality persists, especially at the higher levels. Black women and men form less than 5 percent and 20 percent of the full professoriate, respectively.[30] This represents significant potential for making the research system more inclusive, diverse and, hence, resilient.

Advancing South Africa's innovation performance

While South Africa's innovation performance has been relatively flat over the period, there are encouraging recent trends. The 2016 Global Innovation Index noted that South Africa is strong in market sophistication and investment, and aspects of knowledge absorption and knowledge impact.[10] Although patenting is not performing well and South Africa remains a net importer of technology, a recent survey of Offices of Technology Transfer showed a quadrupling in start-up companies. Although this growth is off a low base and the sustainability of the companies is yet to be proven, this positive statistic[31] represents potential to grow innovation outputs to serve a technologically advanced economy, positively affect South African technology balance of payments and address social challenges such as service delivery.

Furthermore, an analysis of the uptake of the R&D Tax Incentive shows that for the period up to February 2017, an annual average of 85 firms have applied for the first time. . The total number of approved applications represented an estimated R41 billion in R&D expenditure in South Africa. . Government's technology localisation programme is also contributing to the competitiveness of local firms, particularly small and medium enterprises (SMEs).

Increasing the financial resources of the NSI

The positive performance of the NSI over the past two decades (discussed above) would not have been possible without an increase in investment in STI. Gross expenditure on research and development (GERD) as a percentage of gross domestic product (GDP) has not yet reached the required levels, but it has held steady at about 0.7 percent in a challenging economic environment. Moreover, since 1996, business has been the largest performer of R&D in South Africa.[6] Public resources for both public- and private-sector STI have increased significantly (for example, the DST's expenditure has increased nine-fold).

Remaining challenges in the NSI

According to recent reviews, the main factors constraining NSI performance are a lack of policy coherence and coordination, insufficient involvement of business and civil society, inadequate high-level SET and technical skills for the economy, a too-small research system, a business environment that does not sufficiently enable innovation, and underfunding. This White Paper addresses these factors by proposing ways to optimise the role of innovation in achieving South Africa's goals for society and the economy.

1.3 The policy context

The 2017 White Paper has to respond to a challenging and shifting context. This section summarises the local socioeconomic context and how South African STI policy needs to take note of global trends (see Chapter 2 for an examination of the implications of megatrends for STI).

1.3.1 South Africa's socioeconomic landscape

Despite progress over the past two decades, poverty and unemployment still afflict the majority of the population. South Africa has one of the highest inequality rates in the world. In 2014, 21.5 percent of South Africans lived below the poverty line.[16] Black South Africans continue to bear the brunt of poverty. Unemployment in 2017 is at 36 percent and remains racially skewed. Youth unemployment increased from 30 percent in 1994 to 40 percent in 2013, leaving many young people, most of them black, on the margins of society.[16]

The South African government responded to the low economic growth caused by the global financial crisis of 2008/9 by focusing on several specific initiatives to increase growth (the so-called Nine-Point Plan). Although the drop in oil and commodity prices has weakened (but, crucially, not ended) the "Africa growth" narrative, recent growth in the mining sector is promising.

South Africa's weak economic outlook coincides with the emergence of what is loosely termed the Next Industrial Revolution. There is a need to develop labour market support measures that integrate skills development, basic education, tertiary education and skills adapted to the demands of the new workplace.

Despite steady increases in enrolment at schools and universities,[16] a study by the Human Sciences Research Council shows that South Africans continue to underperform in mathematics and science compared with other countries. The skills base is not expanding fast enough to drive economic growth and create jobs.

The decreasing contribution of the productive sectors to South Africa's GDP offers opportunities for innovation in the services sector. While this shift towards services is a global phenomenon, it remains necessary over the short to medium term for South Africa to strengthen productive sectors such as manufacturing, mining and agriculture to absorb large numbers of low-skilled workers.

Compared with most African countries, the South African economy is relatively diverse. It has the potential to increase productivity through skills development, innovation, regulatory reform, investment in infrastructure and information and communications technology (ICT). These changes will also help modernise and green the rural economy, improving its competitiveness.

1.3.2 The NDP

The NDP 2030 was introduced in 2012 to serve as South Africa's long-term planning framework. At the heart of the plan lies the vision to create a "virtuous cycle of growth and development", with success "measured by the degree to which the lives and opportunities of the poorest South Africans are transformed in a sustainable manner".[8] The NDP envisages STI playing a central role in achieving

its vision for 2030. Three areas stand out as important STI outcomes: increasing employment through faster economic growth; improving the quality of education, skills development and innovation; and building the capacity of the state.

The NDP acknowledges that economic development takes time and that innovation should grow in importance in years to come. In the first phase (2012–2017), the focus should be on "intensifying research and development spending, emphasising opportunities linked to existing industries". In the second phase (2018–2023), the "country should lay the foundations for more intensive improvements in productivity" and "innovation across state, business and social sectors should start to become pervasive". As 2030 approaches, "the emphasis should be on consolidating the gains of the second phase, with greater emphasis on innovation, improved productivity, more intensive pursuit of a knowledge economy, and better utilisation of comparative and competitive advantages in an integrated continent".

The NDP also supports the Sustainable Development Goals adopted by the global community in 2015. STI is key to realising the vision of the NDP and achieving the Sustainable Development Goals.

1.3.3 The evolution of the global STI policy environment

South Africa must take cognisance of the global STI environment. An analysis of policy trends in the Organisation for Economic Co-operation and Development (OECD) group of countries highlighted a number of implications for South African STI policy. Foremost among these is that OECD countries are shifting the composition of their STI funding by increasing public financial support to firms (at the expense of public research), amid a projected stabilisation of public R&D budgets. The OECD group is focusing on immediate economic priorities and policy efficiency gains (public research capacity, business innovation and entrepreneurship, governance, and framework conditions), rather than long-term issues (structural adjustment, sustainability and green growth). However, it is also policy to advance more Responsible Research and Innovation.

R&D funding has become increasingly competitive and countries are developing their research systems accordingly. Increased investment in research is necessary to ensure that South Africa remains competitive. Any strategy to attract foreign R&D funding would have to take the shifting patterns of global funding into account, particularly the increasing role of large firms in the national R&D effort (meaning that international collaborative efforts will have to shift to firms). South Africa needs to concentrate on increasing the research capacity of domestic firms and strengthening their competitiveness in global value chains. It also needs to increase its focus on Responsible Research and Innovation if local researchers are to collaborate and compete with their foreign counterparts in a world where ethics (for example, fair trade) and environmental concerns (such as emission standards) are increasingly influencing competitiveness.

1.4 The vision and objectives of the White Paper

The vision of this White Paper is:

Science, technology and innovation enabling inclusive development in a changing world

1.4.1 Looking to the future

As discussed in Chapter 2, a number of megatrends, coupled with significant technological changes, are making the future uncertain. These changes present opportunities and threats (for example, a changing manufacturing environment can lead to economic growth but also the loss of traditional jobs). The degree to which countries are able to prepare for these changes will determine whether they thrive.

Examples of these often intersecting megatrends are:

- Social: Rising populations, demographic shifts and rapid urbanisation in the developing world.
- Economic: Increased consumption driven by an expanding middle class in emerging economies, rising inequality, youth unemployment and social unrest.
- Geopolitical: The rise of China and India, and the declining economic influence of the United States and Europe.
- Environmental: The natural environment is under increasing pressure, giving rise to the need to make economies more sustainable, for example, by using clean energy and minimising waste.

These megatrends are creating market opportunities for technology. For example, the growth of a middle class in emerging economies and the high proportion of young people in national populations (the so-called "youth bulge") in Africa are stimulating manufacturing, widening markets for mobile telephones, and creating job opportunities for ICT-enabled young entrepreneurs in the services sector. South Africa can benefit from these emerging market opportunities by using technology to modernise sectors such as agriculture and mining and increase exports to growing markets in Africa and other emerging economies. Innovation is required to address needs arising from these megatrends, such as protecting the environment and improving service delivery.

Rapid technological change is driving some of these megatrends to shape a world that will look very different in the near future. The lines between physical, digital and biological systems are becoming blurred, and governments around the world are strategising for the impact of the Next Industrial Revolution. In particular, it is necessary to prepare for the ways in which artificial intelligence and advances in ICT will change the way society and the economy function.

Already, traditional jobs are being lost to automation and traditional commerce is being disrupted by the move to online, just-in-time personalised services and products. The role of cryptocurrencies in

the digital economy is uncertain. The possibilities are exciting and the implications vast. Only countries that are prepared for these changes will thrive.

STI lies at the heart of this preparation. South Africa needs to build on progress in biotechnology, nanotechnology, advanced manufacturing, and ICT research and innovation. This White Paper proposes policy interventions to accelerate skills development, leverage ICT, commit to openness, and support interdisciplinary research. It also puts in place foresight mechanisms on which to base institutionalised collaborative planning for STI in South Africa.

1.4.2 Objectives and theory of change of the White Paper

The premise of this White Paper is that innovation can shape a different South Africa. For South Africa to take advantage of opportunities for innovation, new policy instruments need to be developed and successful policies strengthened. Efforts to leverage STI fully to attain the goals of the NDP are constrained by exclusion in the system, insufficient linkages, lack of coherence in the NSI, gaps in the institutional landscape, insufficient human resources and investment in STI, and inadequate transformation.
The White Paper proposes policy actions to address these problems, according to the following conceptual logic:

- The White Paper's point of departure is the significant shifts facing the world that have an impact at the global, continental and local level. This context is characterised by the emergence of new technologies, megatrends such as demographic and political shifts, the global commitment to the Sustainable Development Goals, and locally the NDP to address South Africa's socioeconomic reality. **(Chapters 1 and 2).**

- Within this shifting and challenging environment, STI is central to helping South Africa address its socioeconomic challenges and navigate the world of the future with success. But it is only through the collaboration of business, government, academia and society that the potential impact of STI will be achieved. While there has been significant progress in building the NSI since 1996, renewed focus on inclusion and collaboration is needed. **(Chapters 2 and 3).**

- Coherent, evidence-based and collaborative policy action on STI issues will therefore help South Africa realise the NDP's vision for 2030. Such positive STI policy action requires the setting of a whole-of-government STI agenda, the collaboration of all NSI partners in pursuing this agenda, and all stakeholders to reflect on and learn from the implementation of policy and specific STI initiatives **(Chapter 3)**.

- However, for such positive policy action to fully realise the potential benefit of STI to South Africa, specific STI-related challenges such as insufficient skills and funding, as well as constraints in the business environment for innovation need to be addressed. Moreover, if these challenges are addressed effectively, STI can significantly accelerate progress towards the NDP Vision 2030 and beyond **(Chapters 4, 5 and 6).**

- A society that values knowledge and understands the impact of innovation on national development priorities, a society permeated by a culture of creativity and entrepreneurship, and a government that anticipates change and regularly reflects on the implications of this change for its policies are essential for promoting innovation **(Chapters 3, 4 and 5).**

Against this background, the high-level objectives of the White Paper are the following:

- **Take advantage of opportunities presented by megatrends**
  The proposed policy actions address gaps and opportunities arising from significant global and local changes. These changes include the emergence of new technologies, demographic and political shifts, a global commitment to the Sustainable Development Goals, and the priorities of achieving South Africa's NDP.

- **Expand what has worked and propose new approaches where necessary**
  The proposed policy actions fall into five categories: addressing NSI linkages, inclusivity and coherence; strengthening and transforming NSI institutions; expanding human capabilities in the NSI; enhancing the enabling environment for innovation, and improving the direction and management of NSI funding. These categories have been identified as the most important for using STI to help South Africa achieve its goals.

- **Promote inclusivity**
  Inclusivity is an important goal of the NSI both in terms of social justice and to foster a system where creativity and learning can flourish. The White Paper addresses inclusivity from a broad perspective, including demographic representation, greater participation of historically disadvantaged universities in research production, support for grassroots innovation, and the formal involvement of civil society.

1.5 The implementation of the White Paper

This White Paper is an enabling policy document that sets the medium- to long-term policy direction for the NSI. It is informed by analysis of evidence from a number of reviews of the NSI, experience gained in the implementation of STI policy over the past 20 years, and consultation with NSI partners – both state actors, such as STI-intensive government departments, universities and science councils, and non-state actors, such as civil society, labour and business.

The White Paper is not an implementation plan. Its implementation will be provided through decadal plans, informed by foresight studies and consultation with all implementation partners to ensure policy coherence. The decadal plans will be reviewed every five years, or as deemed appropriate by the DST.

The decadal plans will detail aspects such as the programmes to be initiated, the institutional arrangements needed to align policies and frameworks across government, the funding required, how to mitigate implementation risks and how to evaluate the performance of the proposed initiatives.

CHAPTER 2: LOOKING INTO THE FUTURE

The world is rapidly changing. Our future is being shaped by powerful and complex forces. As noted in Chapter 1, these megatrends are social, economic, environmental and geopolitical, and are being driven by rapid technological change.

The potential of STI lies in helping South Africa and its NSI respond to opportunities offered by the changing world. All countries are grappling with how to transform sociotechnical systems to meet new challenges and build resilience in a fragile world. The next section examines the drivers of change, before discussing the implications for the NSI.

2.1 Drivers of global change

2.1.1 Social

The global population could reach 9.6 billion people by 2050 and 10.9 billion by 2100. In 2000, for the first time, there were more people over the age of 60 in the world than children under five. By 2050, four-fifths of older people will live in developing countries, where 80 percent of them will have no regular income. Youth unemployment is also growing. In 2012, 15- to 24-year-olds made up 40 percent of the total unemployed population. Other notable longer-term trends include rapid urbanisation and the "youth bulge" (i.e., a large pool of young people) in Africa, migration, and the pervasiveness of technology.

By 2050, most northern regions are expected to be at least 84 percent urban, while Africa's urban dwellers are projected to make up 62 percent, and Asia 65 percent. In Asia and Africa, rapid rural-to-urban shifts are taking place. Urbanisation is a key engine of economic growth, but it comes with the risks of marginalisation, conflict and exploitation. Furthermore, the international mobility of highly educated individuals at different stages of their professional careers is a significant driver of knowledge circulation worldwide. Countries and institutions are engaged in a global competition for talent to build their own centres of global scientific excellence. Digital technologies increasingly help ease the strains of mobility, enabling individuals to maintain regular contact with friends and families, further facilitating greater mobility.

2.1.2 Technological

The technological revolution is blurring the lines between physical and digital spheres, with legal, ethical and socioeconomic consequences. It influences human and social behaviour, reorganises the workplace, has consequences for public services and civic engagement, presents opportunities for generating income and online learning, and changes the ways in which we produce and consume. Researchers and innovators should analyse this new human-technology nexus, particularly complex innovation dynamics that can help create prosperous, inclusive, stable and resilient economies and societies.

2.1.3 Economic

A growing middle class and increasing consumption in emerging economies will increase demand for innovative consumer goods worldwide. In 2012, 71 percent of the world's population was reported to live in nations where income inequality is increasing. Inequality stifles economic growth and affects health, educational outcomes and security. Youth unemployment remains stubbornly high in many countries (including South Africa) and young people are increasingly exposed to the risk of income poverty. Technologies can directly promote social inclusion and economic growth, but they can also cause the loss of many traditional jobs, for example, through automation. This is a dire prospect for South Africa, given its high unemployment rate and high proportion of low-skilled workers.

2.1.4 Environmental

Natural systems are under enormous pressure, with serious consequences for the world's most vulnerable people. The challenges of climate change, degradation of the natural environment and loss of biodiversity will become increasingly dominant themes in future national STI agendas. The concept of a circular economy will likely shape future innovation agendas and will require new technologies, processes, services and business models.

Energy technology innovation will be key to limiting the average global temperature increase to 2°C. A comprehensive portfolio of low-carbon technologies, including solutions for decarbonisation, will be needed to achieve policy climate goals. Governments will need to be proactive in promoting green innovation, funding R&D, using tax incentives and innovative procurement, and introducing standards and regulation. Onshore wind and solar photovoltaics are ready to be mainstreamed, but will require further innovation in energy storage and smart grid infrastructure to increase their ability to adapt to variable weather.

2.1.5 Geopolitical

The axis of the world's economic and geopolitical power is shifting from west and north to east and south. Although Europe, Japan and North America still dominate aggregate STI investment globally, their shares are declining and the international landscape is increasingly multipolar. In 2012, the BRICS countries (Brazil, Russia, India, China and South Africa) were reported to be responsible for more than 25 percent of the world's GDP, based on purchasing power parity, and to account for 40 percent of the global population.

Changes in the geopolitical landscape will create opportunities for South Africa, but the country and its neighbours will need to develop their own infrastructure to fully benefit from new alliances. Inclusive, long-term modernisation of the region is essential. Such a programme has already been outlined in several documents, including the recently approved Southern African Development Community (SADC) Industrialisation Strategy and Roadmap, which addresses one of the biggest challenges that Africa faces, namely, the transition from a commodity-driven region to a value-adding region. It is anchored on three pillars: industrialisation to drive economic and technological transformation; competitiveness as an active process to move from comparative advantage to competitive advantage; and regional integration as the context for industrial development and economic prosperity. All the pillars depend on STI capability and human resources.

The critical role of STI is also recognised by two African Union (AU) planning frameworks, namely Agenda 2063 and the Science, Technology, and Innovation Strategy for Africa. The former is the AU strategic framework for socioeconomic transformation over the next 50 years, building on and accelerating the implementation of existing initiatives for growth and sustainable development. The latter responds to the demand for STI to play a role in critical sectors such as agriculture, energy, environment, health, infrastructure, mining, security and water.

2.2 Implications of the drivers of change for innovation in South Africa

The drivers of global change have significant implications for South Africa's STI policy. The remainder of this chapter defines the main ways in which policy should respond to these changes.

2.2.1 Deepening African collaboration

The SADC and AU strategies highlight the potent role of STI in achieving the goals of SADC and the broader objective of pan-Africanism. South Africa's cultural, political, social and economic linkages with the rest of Africa present opportunities to build and consolidate national, regional and continental systems of innovation. South Africa's cooperation strategies in Africa should prioritise efforts to strengthen its and partner countries' STI systems to promote and facilitate cross-border research networks, shared technology innovation platforms, mutual learning and an integrated Africa research, development and innovation agenda that encourages development and competitiveness. Greater African collaboration will assist in developing knowledge networks, funding partnerships and collaborative research efforts, and optimally circulating ideas, information and people.

South Africa's strategic science diplomacy focus has already recognised STI as an important means by which to drive the developmental agendas of the AU and SADC. For instance, major minerals beneficiation projects, as highlighted in the SADC Industrialisation Strategy, will depend on cross-border cooperation in energy and transport infrastructure and input supply, and on the development of globally competitive industry sectors. This White Paper takes these aspects of international cooperation even further (see Section 5.9).

2.2.2 Exploiting the pivotal role of ICT

To realise the goals of the United Nations Sustainable Development Agenda and the NDP, South Africa will need to exploit the increasing convergence, sophistication and reach of ICT. Inclusive innovation – not only *for* the poor but *by* the poor – will require resources for improving digital infrastructure. ICT can thus play a critical role in reducing poverty, decreasing inequality, increasing employment and promoting economic growth.

This view is supported by the NDP, which sees ICT underpinning a dynamic, inclusive and prosperous knowledge economy, in which seamless information infrastructure and systems will meet the needs of citizens, business and the public sector. Such a situation, in which advances in ICT are used to strengthen economic competitiveness, generate youth employment and enable an enhanced quality of life, can be described as a "digital advantage". The attainment of digital advantage is important if South Africa is to participate in the Next Industrial Revolution.

ICT is already playing an important role in transforming the educational system. More changes are expected in terms of new models for open access, mobile, lifelong and ubiquitous learning beyond the traditional classroom. Integrating digital technologies in the provision of government services (e-government) and the management of cities (smart cities) has the potential to transform the scope and efficiency of public services. Local and regional innovation systems will play a critical role in modernising cities. Chapter 4 details how South Africa can exploit these opportunities.

2.2.3 Achieving the Sustainable Development Goals

The Sustainable Development Goals speak to a broad range of directions the world needs to take to promote economic, environmental and social wellbeing. The ambitious agenda of the goals presents an opportunity to experiment with and foster new forms of innovation for sustainable development.

STI plays three main roles in the Sustainable Development Goals. First, STI is a goal in itself as a driver of economic growth and job creation. Second, science is central to the implementation of other goals, for example, new technological solutions can help address challenges around energy and food security. Third, scientific knowledge can help translate targets into national policies and evaluate their impact.

The tremendous potential of ICT will accelerate the attainment of the Sustainable Development Goals through e-education, e-health, e-agriculture, smart grids and smart cities, among other ventures. Mobile access, including satellite mobile, will be the first way to access broadband-enabled services. 4G access technology, and soon 5G, along with the reduced cost of devices such as smartphones and tablets, is putting unprecedented computing power in the palms of ordinary citizens. The use of big data, open data, cloud computing and the development of the Internet of Things can accelerate the attainment of the Sustainable Development Goals.

The idea of a circular economy is linked to the Sustainable Development Goals, but is mentioned separately for its particular relevance as a source of new growth across the globe. The concept implies systemic change, moving to a zero- or low-waste, resource-efficient society, and entails major changes to methods of production and consumption.[17] Beyond the potential to save materials and leave a smaller footprint on the environment, a circular economy would create economic opportunities as new services and business models emerge, transforming the relationship between producer and consumer, and a product and its user.[18] Chapter 4 provides more detail on policy actions relating to the circular economy.

2.2.4 Harnessing the Next Industrial Revolution

The "Fourth Industrial Revolution" (referred to as the Next Industrial Revolution in this White Paper), is based on three sets of megatrends: physical, digital and biological.[19] Building on digital technologies and infrastructure, the Next Industrial Revolution involves a convergence of technologies and disciplines, non-linear growth, and a re-emergence of digital into physical domains. These changes are having a multisystem impact, as illustrated below.

The future of "digital work" is expected to change the work environment in innovative ways, as online jobs, crowd-sourcing and the ability of general workers and specialists to choose when, where and

how long they work might replace traditional employment models. Technological progress will also leave many people behind, but there has never been a better time for workers to acquire special skills or education to enable them to use technology to create and capture value. Retraining and educating today's workers will be crucial in preventing skill mismatch, mass unemployment and growing inequality.

The manufacturing sector is an important part of the South African NSI. Exploiting the potential of the Next Industrial Revolution will play a key role in enhancing South Africa's manufacturing capacity so that it can compete in high-value products in global markets (see Chapter 4).

2.2.5 Changing sociotechnical systems

Schot, Kanger and Verbong state that current systems are not able to respond adequately to the "world in transition" described in this chapter.[20] The authors contend that for the necessary transition to take place, the current focus on individual systems has to shift to entire sociotechnical systems and the values underlying them.[i]

The new value systems involve changing a set of deeply embedded meta-rules shared among several sociotechnical systems to address the current interconnected social, economic and ecological challenges facing humanity. Such a transition entails a greater focus on smart, sustainable and inclusive development, the circular economy, renewable energies and more Responsible Research and Innovation. Finding better alternatives to the current systems for energy, healthcare, mobility, food and other resources, and addressing societal aims, such as the United Nations' Sustainable Development Goals, are a starting point for STI endeavours to help change methods of system provision, for example, in our health, food and energy sectors.

In South Africa, which is still grappling with the legacies of its apartheid past, a focus on the evolution of sociotechnical systems and their underlying values is acutely relevant. Many South African institutions are still exclusionary. For example, apartheid spatial development patterns continue to obstruct the development of inclusive systems of mobility that are needed to enhance productivity and protect human dignity.

These insights have profound implications for South African STI policy. They apply to how programmes are conceived and implemented across sectors as well as how impact is evaluated. Optimising the positive evolution of sociotechnical systems requires a paradigm shift in experimentation, openness and transdisciplinary science. The latter two topics are discussed in the next section (experimentation is addressed in Chapter 4).

2.2.6 Realising Open Science and Open Innovation

Open Science and Open Innovation represent the next frontier. Increasing access to public science has the potential to make the entire research system more effective, participative and productive by

[i] The current focus is on individual systems, for instance, a transport system. However, because of increasing inter-connectedness, this focus should shift from individual systems to entire sociotechnical systems, which in this example would be a system of mobility (rather than a system of transport). A sociotechnical system links a number of individual systems such as fuel infrastructure, vehicle production, cultural practices and norms regarding public transport, road infrastructure and traffic systems, maintenance and distribution systems, and industry structures.

reducing duplication and the costs of creating, transferring and re-using data. Open Science is a new practice, where research data, laboratory notes and other research processes are freely available, under terms that allow people to re-use, redistribute and reproduce the research and its underlying data and methods.[21]

Fostering digitally enabled open and collaborative innovation is also key. What is novel in collaborative innovation is the greater use of the Internet, digital technologies and social networks to foster learning, enable the co-creation of (codified) knowledge and provide wide access to tools, data and resources. Such innovation approaches draw on and recombine multiple sources and forms of knowledge, especially through digitally enabled open collaboration. Open access to scientific knowledge and innovation in fields such as health can drive more inclusive growth.

The basic premise of "open innovation" is to make the innovation process accessible to all active players so that knowledge can circulate more freely.[23] Open Innovation represents, at least in part, a re-invention of the organisational models that we have come to take for granted. In a networked world, it is no longer possible to ring-fence what we know or have invented and to create new value through internal means alone. This assumes that firms can and should use both external and internal ideas as they seek to improve their performance.[24] Policies to stimulate Open Science and Open Innovation are discussed in Section 5.6.1.

2.2.7 Breaking silos in science and embracing transdisciplinarity

Technological change is transforming research systems. More than ever before, research is data-driven. This means that not only is the volume of data available to conduct research growing exponentially, but research subjects, methods and practices, and visibility are changing irrevocably. New research fields will develop around data mining, machine learning, privacy and database interoperability to enable big data science. Big data analytics should open new research avenues and create new business models.

Interdisciplinary research teams and the integration of knowledge from different disciplines are necessary to deal with the complexity of South Africa's development challenges. This is increasingly being viewed by scholars and policy makers as "science for the future", and as an example of strengthening the relationship between science and society by putting social concerns at the core of scientific research. Mainstreaming Open Science will allow universities, research centres and society to take advantage of the benefits of collaborative, transdisciplinary approaches to knowledge development and sharing. Interdisciplinarity is further addressed in Chapter 5.

2.2.8 Expanding scientific knowledge development

An increased investment in science is critically important since it is this investment in science that has enabled knowledge breakthroughs in, for example, the next industrial revolution, biotechnology, artificial intelligence, nanotechnology, synthetic biology, and in the basic sciences more broadly. Moreover, benefiting from technological change and the megatrends described in this chapter requires that the scientific knowledge base of the NSI should be expanded across all scientific disciplines.

Currently, our nation has to compete with international competitor countries who have been pouring resources into scientific investment, and who understand long-term horizons. If South Africa wants to craft an innovative edge, create meaningful jobs and realise economic growth, then we must make funding for scientific research a national priority. Basic research is an essential building block for the South African economy, keeping it competitive globally. To this end, it is vital to commit resources to, and fully implement, the DST's Basic Sciences Development and Support Framework.

As the leading STI countries around the globe are all expanding their scientific base in order to remain at the forefront of knowledge development (see Chapter 1), the competition for high-level skills and for investment in science projects will increase exponentially. South Africa's expat scientists remains a vastly untapped resource. Hence, South Africa needs to look beyond the brain drain and take advantage of its expat scientists by strengthening international networks of expat scientists. Knowledge networks through which diaspora scientists organise scientific exchanges, educational programmes, networking and other opportunities that build capacity and encourage innovation and knowledge production in both the scientists' home country and the host country needs to be supported. Properly leveraged, these 'brain circulation' networks could help drive innovation and knowledge generation in South Africa, and improve science diplomacy between countries.

CHAPTER 3: A COHERENT AND INCLUSIVE NATIONAL SYSTEM OF INNOVATION

As discussed in Chapters 1 and 2, the future holds both threats and opportunities, and countries that prepare for these will thrive in our rapidly changing world. The NSI is central to South Africa's preparation for the future. This chapter focuses on how to improve the coherence and inclusiveness of the NSI, thereby realising its potential to transform society and shape a bright future for all South Africans.

3.1 Progress, gaps and focus areas in developing the NSI

The 1996 White Paper conceptualised the NSI 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". It adopted the NSI approach to provide a coherent and integrated framework for national activities, with a focus on innovation, rather than just research.

3.1.1 Progress in building the NSI and remaining gaps

Over the past two decades, meaningful progress has been made in establishing the institutions required for a modern system of innovation, including the DST, the South African National Space Agency, the Technology Innovation Agency, and the National Intellectual Property Management Office. Furthermore, legislation governing intellectual property resulting from publicly funded R&D has been promulgated.

However, the 2012 Ministerial Review of the STI Institutional Landscape found that the NSI is too small and that, while the public STI institutions are well governed, there is room for improvement. For example, improvements can be made in transformation, serving emerging research areas, and aligning mandates of public research institutions to national priorities and the mandates of relevant government departments.[2]

Relationships between STI-intensive departments have been strengthened. For example, the DST is working closely with the Department of Higher Education and Training (DHET) on human capital development; with the Department of Trade and Industry (the dti) on including STI in government's plans to industrialise the South African economy; with the Department of Human Settlements on addressing challenges of informal settlements as a result of rapid urbanisation; and with the Department of Water and Sanitation on using STI to address the country's water needs. However, there is room for improving the incorporation of STI in the strategies of lead departments.

Although there has been progress (for example, increased support for industry via the R&D Tax Incentive and the Sector Innovation Funds), the level of collaboration between all NSI actors needs to increase. In particular, civil society has to be brought into the formal NSI structures and networks, and support for and collaboration with business have to be enhanced. A nuanced approach is required to address the unique needs of business sectors, and small and large firms.

3.1.2 Approach to developing the NSI

South Africa was one of the first countries to formally adopt the NSI approach. The NSI is still a valuable organising concept for STI in South Africa, but it will be made more inclusive, with an emphasis on mutual learning, policy coherence and collaboration.

The field of knowledge on innovation systems has grown significantly over the past few decades. For the next iteration of the NSI to benefit from these advances, a better balance will be sought between business interests, economically useful knowledge, benefit to the environment, and the inclusion of a wider range of actors in the social innovation space and their development needs. Greater emphasis will be placed on the potential of innovation to improve government service delivery, particularly access to basic services.

It is recognised that innovation often happens on the basis of non-directed scientific inquiry. Therefore, in developing the NSI, and in optimising the impact of innovation on South African challenges, the need to expand the science base of the NSI is recognised. In particular, scientific knowledge development to respond to megatrends facing the world (such as rapid and profound technological change and environmental degradation) will be expanded, and measures will be put in place to safeguard scientific excellence.

This chapter contains policy actions to address the above-mentioned reasons for the remaining gaps, while building on the successes since 1996. These actions aim to improve the systemic functioning of the NSI by:

- Bringing more and different actors across society into the NSI fold to make it more inclusive.
- Intensifying interactions, partnerships and enhancing coherence among NSI actors in pursuing a broadly common agenda.
- Improving the governance of STI institutions on the basis of evidence from institutional reviews and other studies.
- Strengthening the monitoring, evaluation and learning function of the NSI.

Policy intents and actions

3.2 Policy intent: Improve the inclusivity and interactivity of the NSI

The themes of inclusivity and interactivity run through the White Paper and are addressed in various ways in each chapter. Here, a number of overarching issues are highlighted.

3.2.1 Inclusivity

The NSI concept will be retained as an organising framework, and a quadruple helix model of innovation will be adopted to facilitate interactions and partnering between business, government, public research institutions (higher education institutions and science councils) and civil society.

In particular, civil society is recognised as a link between the formal and informal parts of the NSI. It serves to strengthen and incentivise collaboration with and between non-governmental organisations, public benefit organisations, publicly funded R&D institutions and science councils in piloting and distributing technology for public use. The White Paper therefore explicitly brings civil society into the NSI fold.

In further pursuit of an inclusive NSI, and building on the progress over the past 20 years, improving the representation of black people and women, as well as people with disabilities, in the NSI remains a priority. Chapters 4 and 5 emphasise the need to shift the demographic representativeness of the NSI at all levels: among undergraduates, in management positions in research programmes, in new technology-based firms and in the professoriate.

Specific measures will be introduced to address the gender imperative, expanding the focus beyond demographic representativeness of researchers and students. These include:

- Improving gender representativeness in NSI institutions and the monitoring and evaluation (M&E) mechanisms for gender initiatives.
- Ensuring that the research agenda serves the needs of women, alongside those of men.
- Providing targeted support to women researchers and techno-entrepreneurs.

3.2.2 Interactivity

To increase interactions and collaboration, a more open approach to science, data and innovation will be adopted (see Chapter 5).

Formal mechanisms will, however, also be institutionalised to improve interaction among actors (for example, sector-based planning instruments). Requirements for interaction and collaboration will also be built into the shareholder compacts of relevant government entities such as science councils and higher education institutions.

To illustrate, the White Paper introduces strategies to enable both large businesses and SMEs (in both the service- and resource-based industries) to play a full role in the NSI. Additional support for the business sector will be provided to improve collaboration with government. Support for the business sector is discussed in more detail in Chapter 4.

Furthermore, government will continue to use and strengthen, where appropriate, platforms designed to finance and execute interactive and collaborative R&D involving private and public research institutions such as Centres of Competence, the Technology and Human Resources for Industry Programme, and Sector Innovation Funds.

3.3 Policy intent: Enhance the policy coherence and programme coordination in the NSI

The White Paper proposes coherence and coordination at different levels: overall governance (priority setting and planning), STI policy coordination across state actors, funding, research performance and M&E. (Research performance is discussed in Chapter 5 and funding in Chapter 6.)

3.3.1 Coherence of the NSI at the system level

An inter-ministerial committee on STI, chaired by the Minister of Science and Technology, will be established to improve system coherence at the national level. The committee will focus on setting a high-level agenda for the NSI, approving decadal plans on innovation for South Africa, committing resources to innovation (national, provincial and local government) and reviewing reports on the performance of the NSI over three-year cycles.

The issues affecting the enabling environment for innovation fall within the ambit of various government departments, such as those dealing with trade and competition policy, immigration and labour, procurement policies and STI. As such, all these departments need to commit to supporting innovation in their policies and programmes to encourage long-term private investment. A whole-of-government innovation approach will therefore be adopted to ensure that the various policies that affect innovation are aligned. The inter-ministerial committee on STI will lead this initiative.

To support the inter-ministerial committee on STI in carrying out its mandate, government recognises the need for a high-level body representing all stakeholders. The National Advisory Council on Innovation (NACI) will be reconstituted as this body and will include representatives from provincial structures.

NACI will act as the consultative body on innovation policy frameworks (for example, for decadal plans) to be presented to the inter-ministerial committee on STI. NACI legislation will be amended to allow for this new role and to facilitate the other new functions assigned to it in this White Paper (such as those related to monitoring, evaluation and learning, and drafting STI investment frameworks; see Section 3.5 for more detail on M&E, and Section 6.4 on STI investment frameworks).

The DST will work with the Presidency and the National Treasury to facilitate the integration of the STI agenda and plans approved by the inter-ministerial committee on STI into government planning, under the auspices of the inter-ministerial committee on STI.

As coherence is strengthened when values, information and competencies are shared, several additional initiatives (discussed throughout the White Paper) will be launched to increase appreciation for how to use STI to transform the economy and to improve the performance of the state. Examples include digitising the state and making information freely available, experimentation, training officials, and increasing the mobility of employees among government, business, science councils and higher education institutions.

3.3.2 Coherence in critical policy areas

There are areas where it is particularly important to build policy coherence and strong collaborative STI relationships. As recommended by the Ministerial Review Committee (2012), a number of well-functioning "core" policy nexuses will therefore be established, each structured through a formal agreement spelling out how policy can be harmonised and implementation plans coordinated. The

role of the relevant clusters, such as the Social and Economic Clusters, will be optimised in these arrangements. These policy nexuses include[ii]:

- **Post-school education:** This nexus will focus on education and training involving the DHET, the DST, the Department of Basic Education and the Department of Labour.
- **Economy:** This nexus will focus on business and enterprise development, involving at least the DST, the dti and the departments of Economic Development and Public Enterprises.
- **Social:** The focus of this nexus will be on social development and social innovation, involving the DST and departments concerned with social and rural development, and the social security-health-education complex.

3.3.3 Horizontal and sector/thematic coordination

Innovation has the potential to modernise sectors of South Africa's economy such as agriculture, manufacturing and mining. Examples include smart agriculture and biotechnology to increase yields. Innovation therefore drives the development of high-technology exporting firms on the basis of investments already made by government and business (in fields such as biotechnology, nanotechnology, ICT R&D, sensors and robotics), as well as those investments that will be made in the technologies of the future. Realising the full potential of innovation will require innovation strategies for various sectors to be developed and/or revitalised.

Government recognises the need to deploy public funding to strengthen the performance and productivity of key sectors of the economy by supporting and collaborating with business in national innovation priorities. Such an approach will be important in sectors that are absorbing significant labour, contributing to exports and likely to be affected by technological change in the near future. Examples are manufacturing, agriculture and mining, as well as the integrated value chains that link these to the services sector.

Integrated STI planning for priority sectors such as mining, agriculture and education will be adopted (as done for Operation Phakisa). Government instruments such as inter-ministerial committees and clusters will be used to support coordination. The DST will drive coordination on STI issues with relevant government departments.

For each priority sector, a sector innovation programme (including a sector research, development and innovation plan) will be drawn up and used to coordinate the research effort across industry, science councils and universities, and concentrate funding in priority sectors. The development and implementation of these sector plans will be driven by a committee involving all stakeholders, specifically business. The DST, in collaboration with the relevant line department, will manage this committee.

Sectoral research, development and innovation plans will be supported by financial and non-financial instruments. Sector Innovation Funds, which have been introduced mainly in the agriculture

[ii] Policy nexuses around ICT, environmental sustainability and the Next Industrial Revolution are discussed in later chapters of the White Paper.

subsectors, and initial funding for extending the life of mines through R&D, will be enhanced and expanded to include other priority sectors.

Sector science councils will continue to report to their line departments. This will allow councils to conduct research and innovation to help the relevant sectors modernise and enhance their competitiveness. The councils will increasingly help the country translate research into products and services, demonstrate the use of knowledge in transforming society, and inform government policy related to the sectors.

All STI-intensive departments will be encouraged to set up STI units to facilitate coordination with the DST, industry, and other government departments and organisations, and to improve the STI planning competence of these departments. STI units will serve as sites of experimentation and help build a stronger innovation culture across government.

3.4 Policy intent: Strengthen the governance of public NSI institutions

While South African STI institutions are generally well governed, the 2012 Ministerial Review did identify problems such as overlapping mandates and duplication of work, depleting the scarce resources of the NSI. Moreover, studies by the DST have shown that while sector-specific science councils necessarily focus on the needs of sector line departments, there have been instances where the science base of these councils has been neglected.

To address these concerns, a policy framework will be developed, under the guidance of the DST, that describes the purpose, functions and governance of public research institutions relevant to national development as guided by the NDP, taking into account the role of all stakeholders. This will involve clarifying the strategic mandates of the DST and other line departments regarding public research institutions and taking into consideration the current capacities of these institutions.

As the mandates of public research institutions are refined according to this policy framework, an appropriate evaluation framework will be put in place (including assessing the system of institutional reviews) to enable objective assessment of efficiency levels. This will be a prelude to interventions to improve productivity across the focus areas of public research institutions.

The evaluation criteria will include requirements for expanding collaboration with civil society, industry and international partners (for example, to establish international research institutes). In particular, the requirement to maintain and expand the science base will be incorporated. The ambitions underpinning this White Paper – excellence, inclusion, collaboration and pan-African collaboration – will be built into the evaluation framework.

3.5 Policy intent: Expand the NSI

3.5.1 Establishment of new public STI institutions

The expansion of the NSI would require, among others, the establishment of additional research institutions in areas of strategic importance to South Africa's economic competitiveness to expand research in emerging areas linked to for instance the Next Industrial Revolution.

Periodic reviews of the STI institutional landscape will be undertaken by the DST to determine the need for new public research institutions and to provide the evidence base for channelling public funding towards supporting the establishment of these, as well as to incentivise the establishment of public-private research institutions and research partnerships.

3.5.2 Expansion of the scientific knowledge base of the NSI

The DST and DHET will collaborate in implementing overarching measures to expand the science base of the NSI, including increased public investment in scientific research.

The DST will specifically target the expansion of selected strategic, emerging and underdeveloped STI areas to improve the competitiveness of South Africa through long-term and cross-cutting research, with a specific focus on post-graduate research. The DST will undertake the high-level coordination of the STI programmes related to these areas (in collaboration with line departments and industry), and will coordination support for the foundational aspects such as human capital development and infrastructure provision related to these STI priority areas.

The DST will also, in collaboration with the DHET and sector departments, support sector-specific research and technology transfer in relatively mature domains, where such activities relate to building South Africa's competitiveness.

3.6 Policy intent: Upgrade the monitoring, evaluation and policy capacity of the NSI

Agenda-setting and oversight of the NSI require good M&E. Policy implementation needs to be improved by monitoring the progress of initiatives and assessing their impact to enable early corrective action. An effective M&E system will keep all stakeholders informed about what is and is not working. Processes need to be established to ensure that M&E information feeds into policy development and planning.

3.6.1 Institutionalised M&E for the NSI

NACI will be reconfigured to act as the national STI M&E institution charged with analysing STI information and undertaking work to inform government planning on STI.

Good performance information forms the bedrock of any effective M&E system. NACI will therefore implement knowledge management systems (for example, a national STI information portal) to enhance the analysis of NSI performance and support evaluation work informing strategies. In this, NACI will draw on the work of existing specialist centres collecting STI-related information. Existing institutional arrangements for data collection (for example, innovation and R&D surveys) will be maintained and strengthened and, where necessary, expanded.

3.6.2 Skills for M&E in the NSI

The DST and the Department of Planning, Monitoring and Evaluation will cooperate with the higher education sector to expand the STI-related M&E skills base of the NSI.

3.6.3 New M&E framework for the NSI

South Africa will intensify its work on international STI measurement guidelines. Particular attention will be given to the Sustainable Development Goals, innovation for inclusive development and the NDP objectives.

Furthermore, NACI will develop a framework of indicators to monitor South Africa's NSI performance (see box below). The DST will work with NACI, the Department of Planning, Monitoring and Evaluation, and the National Treasury to ensure that the framework delivers useful information that can drive the management of STI funding and initiatives across government.

NSI M&E framework

The framework will include both quantitative and qualitative measures, as well as indications of how South Africa is progressing relative to the rest of the world. In terms of scope, system-level STI M&E will cover at least the following:

- Responsible Research and Innovation indicators.
- Investments/inputs into the NSI (funding sources and spending, people, infrastructure, partnerships/linkages) to indicate how the size, shape and strength of the NSI is evolving.
- The performance of the NSI (innovation activities, including R&D, outputs in terms of knowledge, products, technology transfer and applications).
- The behaviour of NSI actors.
- How the STI system is transforming the economy.
- The systemic impact of sustained investment in specific programmes/fields.
- A composite South African Innovation Index will be developed, responding to the specific needs of the country, for example, in terms of skills development, inclusive economic growth and transformation.

3.5.4 An enhanced policy advisory function

In addition to measures to strengthen NACI, Centres of Excellence, the Academy of Science of South Africa and science councils will be expected to use their research expertise to support government in using knowledge to inform policy.

The NSI's absorptive capacity for policy advice will be strengthened through policy units in relevant government departments and an NSI policy liaison function in the DST. This will encourage the sharing of policy-relevant information among departments and other NSI partners.

CHAPTER 4: AN ENABLING INNOVATION ENVIRONMENT IN SOUTH AFRICA

Innovation has significant transformative potential. For developing countries, innovation can support economic growth and employment, create livelihoods at grassroots level, and improve government performance and service delivery. While innovation is not the only factor in faster economic growth, industrialisation and inclusive development, it remains a significant and vital catalyst. Innovation can enhance South Africa's development and improve the quality of life of its citizens. It has the potential to:

- Improve public service delivery and decision making for public policy
- Increase the competitiveness of existing firms
- Form new technology-based firms
- Renew and modernise existing industries
- Develop new and emerging industries
- Exploit new sources of economic growth
- Improve the quality of life of South Africans, at local level, particularly in poor communities
- Promote environmental custodianship.

4.1 Performance, gaps and innovation focus areas

In 2016, the World Intellectual Property Organisation Global Innovation Index noted that South Africa's strengths lie in market sophistication and investment, as well as some aspects of knowledge absorption and knowledge impact. The World Economic Forum's Global Competitiveness Index (2017) shows South Africa moving up two places to 47 out of 138 countries. This progression is mostly due to enhanced competition, better use of talent and an increase in primary school enrolment. Although there is room for improvement, both of these indices point to strengths and progress in aspects related to innovation.

Although knowledge generation does not necessarily lead to innovation, it is noticeable that despite significant increases in knowledge generation, South African patent applications granted in the United States between 1996 and 2016 have not grown significantly, nor have Patent Cooperation Treaty applications. Over the same period, there were significant increases in trademark applications – but, although these represent goods and services in the market, they cannot be viewed as a proxy for innovation performance.

There are indications that this situation is changing. A recent survey titled *The South African National Survey of Intellectual Property and Technology Transfer at Publicly Funded Research Institutions*,[31] covering the period 2008 to 2014, shows progress made by South African higher education institutions and science councils to advance an innovation agenda. All institutions responding to the survey confirmed that they had established an Office of Technology Transfer. In terms of outputs, the number of disclosures received by this office more than doubled during the survey period. Significantly, comparative statistics with the United States revealed that a higher percentage of disclosures were converted into provisional patent applications in South Africa. The number of start-up companies in South Africa quadrupled over the period. Although this increase occurred off a low base, this is a

positive development, as is the fact that 75 percent of these companies were based on publicly financed intellectual property. While the sustainability of these technology start-ups has yet to be proven, this positive statistic suggests growth in the sector and potential to improve the South African technology balance of payments.

Despite these encouraging growth trends, an analysis of the average rate of conversion of intellectual property disclosures to commercialisation/use by these institutions is about 7 percent.[iii] International benchmarking shows that the conversion rate from disclosures to licences for a mature system ranges between 15 percent and 30 percent. In terms of this benchmark, the South African public innovation system appears to still be developing. This conclusion is supported by the fact that South Africa's high-technology exports have not increased in the recent past.

However, there has been progress in employing military technologies for civilian applications such as the fluorine initiative and the retention and rebuilding of the satellite programme. Using innovation for decision making has made slow but steady progress, for example, using satellite data produced by the South African National Space Agency in elections. There is potential for innovation to play a greater role in improving government service delivery, for example, via e-government. Therefore, despite isolated areas of progress, South Africa's innovation performance has been mostly flat between 1996 and 2016. This highlights the potential for deepening the role of innovation in the economy and heralds the need for new policy approaches.

This chapter addresses the following causes of unsatisfactory innovation performance. The proposals aim to:

- Ensure an inclusive innovation system
- Integrate innovation strategies into local and regional economic development planning
- Tap into new sources of innovation and growth
- Foster an innovation culture across South African society
- Improve collaboration across the quadruple helix to drive innovation
- Achieve an entrepreneurial state that hosts a set of diverse and harmonised policy instruments to support business
- Stimulate learning and support the conversion of ideas to commercialisation.

Policy intents and actions

4.2 Policy intent: Adopt a broader conceptualisation of innovation beyond R&D

The White Paper adopts a broader conceptualisation of innovation and its sources. The shift will recognise that the sources and nature of innovation go beyond R&D and radical innovation, and include imitative and incremental innovation, including design and engineering activities, on-the-

[iii] National Intellectual Property Management Office IP7 database

shop-floor attempts to improve productivity, and investment in organisational learning.[25] In developing countries, indigenous knowledge and know-how are particularly relevant.

Furthermore, while the White Paper adopts an ecosystem approach to innovation, the important role played by research as a source of innovation is recognised ("supply-side" focus). The White Paper introduces a strong focus on addressing the needs of the business sector, government, communities and civil society (the "demand-side" focus).

To allow the various sources and types of innovation to come into play, closer collaboration between relevant government departments will be established, and their incentives aligned if necessary. However, a blueprint approach to innovation is neither feasible nor desirable.

As the sources of innovation are mostly outside government, the involvement of the business sector, civil society and academia in designing measures to support learning and innovation will be incentivised.

4.3 Policy intent: Adopt a whole-of-government approach to innovation

As discussed in Chapter 3, the White Paper aims to enhance the policy coherence and programme coordination in the NSI. This will require formal mechanisms such as the proposed inter-ministerial committee on STI discussed in Chapter 3, as well as infusing the whole of government and society with an innovation-enabling culture and aligning policies that impact on innovation such as immigration and competition policy (an innovation compact). To this end, a number of policy nexuses will be established (as discussed in Chapter 3 and elsewhere in this White Paper).

In priority areas such as mining and agriculture the policy nexuses will be supported by sector plans for research, development and innovation (see Chapter 3).

In addition to the general innovation compact and the policy nexuses, there is a need to strengthen the role of STI policy in enhancing the competitiveness of firms, sustaining high growth in both the productive and services sectors, and supporting the development of new firms and industries. The DST currently contributes to the Industrial Policy Action Plan, but there is room for the DST, science councils and relevant public entities across the NSI to achieve greater impact.

The current contributions of STI to the Industrial Policy Action Plan will be deepened to ensure that the programmes of the DST and NSI science councils are aligned with priority industrial sectors, as well as new growth opportunities identified by, among others, the Industrial Development Corporation. STI will be integrated into future frameworks and legislation to advance the national industrial and economic objectives. An important step towards aligning STI and industrial policy will be the establishment of the proposed policy nexus on trade and investment.

The Council for Scientific and Industrial Research, other agencies and STI-intensive departments have the opportunity to develop programmes to support national industrial policy. This has implications for the types of research carried out, technology transfer processes and the commercialisation of

research. It will also affect how knowledge and technologies are leveraged to increase the competitiveness of firms.

4.4 Policy intent: Increase support for and collaboration with the business sector[iv]

4.4.1 Supporting business R&D needs

Public funding of private-sector needs-based R&D will be increased.

A 2016 study by the National Treasury on the effectiveness of South African science councils partnering with industry found that there was significant room for improving the focus of research on industry needs.[27] Therefore, support for and partnering with industry will be made an explicit policy mandate of public research institutions, particularly science councils, and will be monitored as part of their annual performance plans. Furthermore, for instance the mining R&D hub and other instruments to support the private sector will be strengthened.

4.4.2 Targeted technology development and deployment to support firms

In line with national priorities, sectors (and potentially subsectors) in which South Africa has a competitive advantage will be identified to support R&D-led industry development and encourage high-technology exports. Where South Africa does not have a competitive advantage, it will be determined whether an in-bound technology transfer will be used to acquire technologies to be localised and diffused, or whether it would be more cost-effective to import the technologies. This information will inform R&D planning and funding, as well as procurement strategies at national, provincial and local levels.

Efforts to localise and diffuse technologies will be intensified through existing and new technology-based support interventions (including the Technology Stations Programme and the Technology Localisation Programme). Public funding will be aimed at long-term sustainability of firms supported, and information dissemination on local production opportunities will be enhanced.

4.4.3 Global value chains

The growing importance of complex global value chains provides opportunities to attract foreign direct investment and associated benefits, including technology transfer. The extent to which a country will benefit from these global value chains depends on its absorptive capacity and the level of its R&D stock. Economies with higher levels of R&D capacity are more likely to maximise technology spillovers and ensure greater technology diffusion. The absorptive capacity of enterprises may be further increased by supporting innovation and technology transfer activities.

The DST will work with relevant NSI partners to intensify support for technology transfer and absorption. This will include supporting early adopters, developing R&D capacity within firms, integrating local companies or sectors into global value chains, supporting clustering and agglomeration in key sectors, and offering incentives to attract foreign direct investment.

[iv] Recent progress on collaborating with the business sector (for instance in the Sector Innovation Funds) notwithstanding, the OECD's criticism in 2008 that the South African NSI is too supply-side driven is still relevant in certain respects. Therefore, the White Paper unambiguously emphasises support for and collaboration with the business sector.

4.4.4 Public procurement to ensure the sustainability and transformation of technology-based businesses

New and complex technology products (for example, for satellites or civilian aircraft) usually require "launch customers" to help establish customer and market confidence in the product, as well as downstream maintenance and support. In most instances, such programmes rely on a "lead market" in the form of government procurement to help position the product for future sustainability.

Public procurement can also help ensure the sustainability of new and transformed broad-based black economic empowerment firms in or outside the existing supply chains of state-owned enterprises (SOEs), as well as increase the number of SMEs in these supply chains. Therefore, the following instruments will be pursued.

Therefore, the public procurement policy will be reviewed to ensure that government is the first customer when it comes to using locally developed technologies. Government's infrastructure build programme is one example where locally developed technologies can be supported and tested.

For a fixed period, government departments and SOEs will have increased access to information on the NSI's innovation outputs to inform their procurement decisions. This will ensure these outputs can develop market traction, for example, through a database of locally developed technologies based on local intellectual property. The Preferential Procurement Policy Framework Act (2000) will be amended to make provision for local intellectual property as a requirement for local content.

Where the success of new industry development efforts (bio-economy, medical devices, ICT and environmental technologies) depends on government procurement, a formal strategy will be developed jointly by the DST and the government department responsible for procurement. Such a strategy would address issues such as price, quality and after-sales support. To ensure the development of new industries that are globally competitive, government will mostly provide infant industry development support instead of, for example, price premiums.

The role of the Public Finance Management Act (1999) in R&D-related activities will be made clear (for example, to differentiate collaboration and partnerships from procurement-related activities). Technology conditionality will be built into large procurement contracts, for example, fleet procurement such as rail, to ensure that South Africa acquires the latest technologies and that there is technology transfer in the localisation process. The Competitive Supplier Development Programme, championed by SOEs, will also be expanded to include local technologies.

4.4.5 Specific support for SMEs

Besides identified challenges such as access to finance and credit, and inadequate infrastructure, SMEs often struggle to innovate, perform R&D, access knowledge and absorb new technology. In this context, the accessing of specialised knowledge and equipment through the existing network of technology stations has proved successful, with support provided to more than 2,000 firms per year.

Therefore, the current model for providing broad-based support to SMEs (for example, walk-in support at technology stations) will be scaled up to ensure that even more SMEs can access services, equipment and support in product/technology commercialisation.

SMEs play an important role in the industrial value chain and initiatives aimed at developing and/or upgrading them as suppliers to government and larger firms will be scaled up. Tailored technological support (such as technology assistance packages) will be intensified to enable SMEs to meet the technical and commercial requirements for becoming qualified suppliers – locally and globally. Links between SMEs and larger firms will be incentivised to diffuse technology and improve the ability of SMEs to innovate.

A comprehensive support package for SMEs in priority focus areas will be developed collaboratively by relevant government departments. The existing instruments (for example, those of the DST, the dti, the Department of Small Business Development, the Economic Development Department and the Department of Public Enterprises) will be aligned to support SMEs and emerging industries. As an example, both technological and other innovation support to SMEs will be provided to develop new markets or to support systems innovation. New support instruments (for example, an R&D voucher scheme for eligible firms to cash in with registered R&D service providers) will be introduced .

In pursuit of an inclusive innovation system, particular attention will be given to supporting SMEs in informal settlements, rural areas and cooperatives. Furthermore, to support the transformation of the demographic ownership profile of technology-based firms (and in particular SMEs) in South Africa, guidelines will be developed by the DST, in cooperation with relevant NSI partners, to use intellectual property from publicly funded R&D under appropriate conditions to support women and black entrepreneurs when such intellectual property is commercialised.

4.4.6 Revitalising the role of SOEs in innovation

SOEs are important actors in the South African economy, given their role in providing infrastructure and economic services (for example, energy, water, transport and communications). SOEs serve as clusters of expertise and have important linkages to various parts of the economy, as anchor institutions in their sectors, as channels for international knowledge spillovers, and as hubs for human capital development. SOEs are funders, performers and collaborators in R&D and technological innovation. Ten such enterprises account for about 99 percent of all SOE R&D. However, recent data show a decline in SOE expenditure on R&D (from the peak in 2008/9). To turn around this trend, the following strategies will be adopted:

- The implementation of the new White Paper and the next iterations of the Industrial Policy Action Plan will require explicit plans on how R&D programmes of SOEs will advance South Africa's R&D capability, technological innovation performance and industrialisation. A mechanism will be adopted across all departments responsible for SOEs for improving coordination of long-term planning and funding for R&D programmes in SOEs. Shareholder compact agreements should incorporate performance requirements on R&D so that they serve as a strategic tool for engagements between SOEs and their shareholder departments on these matters.

- A national flagship programme directed at closing the engineering and design gap should be established, in line with national imperatives for human capital development and transformation. This will require existing programmes to be revised to strengthen the links between interventions for high-end skills and those meant to expand technical/vocational competencies required by SOEs relating to design, engineering and small enterprise development.

- Conditions will be created to encourage SOEs to continue R&D partnerships among themselves and with universities, science councils and the local business sector. The aim is to leverage broader knowledge and innovation networks for the benefit of the country. SOEs need a much larger base from which to draw research, engineering and other technical expertise. Already, the collaboration between SOEs and the Centres of Excellence and Research Chairs initiatives, as well as various forms of R&D partnerships, are proving to be crucial.

- Domestic technological knowledge gaps provide a space for sourcing knowledge and R&D services from abroad. For such international sourcing arrangements to be beneficial, they must be linked to a particular strategy for technology transfer and/or localisation in cases where domestic capability is inadequate. Along with the smart buyer principles, strategic sourcing from abroad should be linked to national imperatives for technology accumulation so that in the medium to long term SOEs in specific technology spaces can buy from local service providers and institutions rather than foreign consultants. This will support SME growth, skills development and job creation.

4.5 Policy intent: Support commercialisation of publicly funded intellectual property

Offices of Technology Transfer in higher education and Schedule 1 institutions play a critical role in identifying and protecting new technologies, sourcing licensing partners, and establishing companies to market new technologies.

Support for South African Offices of Technology Transfer will therefore be increased through existing instruments, initially to develop capacity, and, over time, on the basis of the quantity and magnitude of outputs. To support the transformation of higher education, the type of government support to these offices will be differentiated according to the research intensity and technology transfer maturity of the institution in question.

Substantial funding is often required for commercialisation, and to this end, a Sovereign Innovation Fund will be established (as discussed in more detail in Chapter 6 in the context of increasing STI funding in South Africa).

Government will leverage the commercialisation of publicly funded intellectual property to accelerate ownership of new technology-based firms by black people and women.

4.6 Policy intent: Increase the spatial footprint of innovation in South Africa

STI policy has historically focused on R&D and big business, perpetuating an exclusive system that has not optimally contributed to improving local economies. Furthermore, the spatial development patterns of innovation-support mechanisms, including institutional arrangements, remain concentrated in the major metropolitan areas.

Improved spatial inclusivity will receive focus through a stronger role for innovation in rural development, and recommendations to develop subnational systems of innovation. These approaches will bring actors such as local government officials, regional development agencies, local chambers of commerce and community-based entrepreneurs more decisively into the NSI.

Local and inclusive innovation ecosystems will be fostered, harnessing, among others, the current fruits of township economies. These innovation ecosystems will involve government, industry, higher education institutions and civil society.

Local and provincial growth and development strategies will include well-articulated innovation plans. "Innovation hubs" will be expanded to enhance provincial growth and development strategies, and promote provincial technology competencies. As part of these, subnational cooperative research centres (involving industry, science councils and higher education institutions) will be established, where appropriate.

Local innovation ecosystems

The ecosystems will consist of:

- Walk-in innovation centres (preferably established at accessible facilities such as post offices).
- Reconstructed living labs (core activities of the living lab are skills training, community development, social and disruptive innovation, mobile and Internet solutions, social enterprise incubation, impact investing and social franchising).
- Local incubators (preferably attached to an institution with a technology station, and mobile application laboratories).
- Science centres.
- Where necessary, product certification facilities.

Furthermore, a "no wrong door" policy will be adopted across government, particularly at local and provincial government level, which sees innovation-related enquiries routed efficiently to provide the required information or support. This intervention could initially be implemented through an appropriately located hotline or information kiosks.

4.7 Policy intent: Support grassroots innovation

Innovation policy should enable all sectors of society to equitably access knowledge infrastructure, participate in creating and actualising innovation opportunities, and ensure all individuals share in the benefits of innovation. Over the past decade, grassroots innovation has gained prominence in STI initiatives, both globally and in South Africa.

Inclusivity is essential to development and innovation has significant transformative potential. Therefore, grassroots innovation will form a planning priority in all relevant initiatives. It will be funded accordingly, and monitored in all relevant M&E frameworks. All local economic development plans, and provincial growth and development strategies will include a focus on grassroots innovation.

A multi-tiered package will provide support appropriate to the level of development of grassroots innovators. Mentorship will be incentivised through a government-funded voucher system and awards, and corporate social responsibility programmes. Grassroots innovators will be capacitated and supported by, for example, supplier development programmes.

Government will further leverage the potential of publicly funded intellectual property to support grassroots innovation. South Africa will develop a country-specific, second-tier patent system, offering a cheap, no-examination protection regime for technical inventions that would not usually fulfil the strict patentability criteria. With the introduction of a substantive patent search and examination system at the Companies and Intellectual Property Commission, a preferential accelerated patent examination system will be introduced for SMEs, broad-based black economic empowerment companies, previously disadvantaged individuals, and young innovators, depending on criteria such as involvement of start-up companies.

Civil society will also be assisted in its many roles, including as a source of innovation, information, mentorship and networks. Efforts will be made to strategically link this sector to NSI actors such as technology stations and science councils. Its function as innovation intermediary between government and grassroots innovators will be strengthened. Training packages will be developed, using social media and digital technologies, to equip civil society with innovation development skills. Collaboration within the civil society sector will be strengthened and incentivised, including partnerships with publicly funded R&D institutions and science councils in piloting and distributing technology for public benefit.

4.8 Policy intent: Exploit new sources of growth

4.8.1 Support for emerging industries

To facilitate sustained and improved competitiveness, particularly in the context of the Next Industrial Revolution, the ability to incubate and support emerging industries is crucial.

Therefore, to maximise the growth of R&D-intensive and non-R&D-intensive emerging industries, joint planning and co-investment will be facilitated through improved partnering between firms,

universities, science councils and government. Associated support initiatives with large business enterprises, SOEs and SMEs will be prioritised for government support.

4.8.2 The circular economy

The current economic crisis and climate change negotiations present opportunities to move towards a green economy by accelerating eco-innovation. In particular, the circular economy represents a source of new growth. Leading firms and entrepreneurs are exploring green opportunities, aiming to create and capture value from new business models. Policy makers are also increasingly paying attention to the need for radical and systemic eco-innovations as a powerful lever in enabling a long-term transition towards a greener economy.

To achieve this transition, private-sector investment will be needed. The framework conditions and policies for firms and entrepreneurs will therefore incentivise private investment in green innovation. In particular, the uptake of greener technologies will be supported. Policy tools to encourage demand for green technologies will include regulations, subsidies and tariffs, public procurement, standard-setting and consumer policy. Examples include green public procurement legislation and prizes for green technological innovations.

Further, a better understanding of emerging practices and business models related to eco-innovation is needed to enable government to elaborate appropriate policies and encourage industry to take up new opportunities. Government will therefore encourage experimentation and showcase radical and systemic eco-innovations, enhance the understanding of the role that new business models can play, and draw lessons for industry and policy makers to accelerate the deployment and diffusion of promising environmental technologies and solutions.

Public support for green innovation will be expanded, bearing in mind that greening the economy requires scientific discovery and inventions in areas other than energy or the environment, and that public R&D should be supported in a broad range of scientific fields as well as targeted research programmes for climate change and biodiversity. Other mechanisms to drive green innovation will include direct R&D grants to SMEs, providing risk capital for green technology through equity and debt finance, and supporting pilot plants for green technologies generally and for energy technologies in particular. The development of skills will require on-the-job training as well as adaptation of tertiary and vocational training to meet new occupational needs. Networking and knowledge diffusion will also be supported through, for example a programme to foster international exchanges among researchers in the field of environmental and sustainability research.

As numerous green economy initiatives are spread across government, a policy nexus and institutional arrangements will be put in place to promote coherence. The DST, the Department of Environmental Affairs and the dti, among others, will collaborate in establishing institutions to coordinate the diverse array of green growth strategies, programmes and initiatives.

4.8.3 A focus on ICT

In collaboration with its NSI partners, government will shape the future of the digital economy and society by cultivating a shared, trusted digital environment that drives inclusion, economic

development and social progress. (The high-level policy actions below need to be read with the text on the role of ICTs in future digital jobs, in Chapter 5, as well as the references to the importance of ICTs for the future elsewhere in the White Paper.)

Cabinet approved the ICT Research Development and Innovation Roadmap, entitled "*Our digital future*", in 2013. The Roadmap identifies several strategic domains, including broadband services and infrastructure, ICT for development, sustainability and the environment, grand science, industry applications and the services economy. It is underpinned by up-to-date research on South Africa's capabilities and development potential in the ICT sector to enable South Africa to exploit market opportunities in areas such as future wireless technologies, e-inclusion, green ICT, geospatial applications, biomedical sciences, smart infrastructure, mining, manufacturing, asset management, m-health, e-services, education, outsourcing and payment solutions.

The development of the domestic high-technology ICT sector will be prioritised within these domains. The overarching objectives are collaborative planning (involving government, business and civil society) on ICT, a focus on universal access to ICT (with broadband as an urgent priority), the development of e-government and pro-poor ICT policies, and the positioning of South Africa to benefit from the Next Industrial Revolution.

To enable collaborative planning, a new policy nexus encompassing the DST and relevant departments such as the Department of Telecommunications and Postal Services will, among other things:

- Drive the digital society in South Africa
- Use big data at local government level to create jobs
- Use open data to transform local government services
- Create localised ICT hubs as Centres of Excellence
- Modernise local government services
- Use e-government services to transform local government services
- Prioritise cybersecurity resilience
- Support emerging start-up digital enterprises
- Use the South African Post Office footprint to deploy e-commerce to revitalise local economies.

4.8.4 The Next Industrial Revolution

As discussed in Chapter 2, the Next Industrial Revolution involves a convergence of different technologies. This global trend has profound implications for South Africa and Africa. For instance, there are opportunities for increased economic growth through the modernisation of existing industries, but also a need to re-skill the workforce for new technological job opportunities as the world of work will see significant changes brought about by technological changes. Various initiatives are under way at policy, industry and technology level, and there has been engagement with international stakeholders such as the World Economic Forum. However, a coordinated national policy response is required, including considerable support and actions from policy makers.

Significant effort and funding are being expended in developing enabling technologies for the Next Industrial Revolution, for example, robotics and artificial intelligence. However, these are not yet coherently packaged in a way that South Africa can fully benefit from them.

If the full potential of the Next Industrial Revolution is to be realised, new institutional arrangements will be needed to manage convergence, as will expanded R&D aimed at the enabling technologies. These arrangements must support research at universities in disciplines relating to current base technologies while developing knowledge in new areas.

A national research, development and innovation platform will be formed to drive priority R&D in areas related to the Next Industrial Revolution. This platform will be managed by a steering committee including the DST, the dti, the Department of Telecommunications and Postal Services and the National Treasury. Other government members will be co-opted as necessary (for example, from the Economic Development Department). Business and labour will also be included in the steering committee.

4.9 Policy intent: Strengthen government's role as an enabler for innovation

In an entrepreneurial state, government typically takes the lead by making high-risk investments in sectors such as information technology, biotechnology, nanotechnology and green technology. The private sector invests only after the state has made the initial high-risk investments. This means that the state often acts to correct market failures and shape new markets.[26] However, for the state to play this role, it will need to develop a more innovation-enabling mindset and culture.

Government will therefore digitise all major administrative processes, especially programmes providing benefits and incentives to individuals and firms. The digitisation strategy will identify measures required to assist the greater personalisation of government support to individuals and enterprises, while ensuring sensitive data is protected and safeguarded.

Effective service delivery and the implementation of e-government initiatives depend on affordable and widely accessible broadband Internet access. The DST and the Department of Telecommunications and Postal Services will collaborate to provide broadband for efficient service delivery.

The DST will further work with the Centre for Public Service Innovation to help entrench a culture of innovation – challenging the mindset of public servants, using awards to motivate them and celebrating role models. Experimentation will be embedded in the centre's initiatives as far as possible. The centre will be tasked with rolling out e-government activities to enhance service delivery, for example, digitising the application process for driving licences and passports.

4.10 Policy intent: Foster an innovation culture across society and government

No ambitious STI policy agenda, such as that set out in this White Paper, can be sustained without an enabling culture. STI is influenced by social and cultural values, norms, attitudes and behaviours, which may be described as an "innovation culture". An innovation culture thrives on inspiration, creativity,

collaboration, problem-solving and risk-taking. It enables us to pursue ideas and learn from taking risks and making mistakes. Adopting this culture will require a shift to encourage South Africans in business, government and civil society to take risks on smart ideas. Establishing such a culture will take time. It will need to be nurtured and reinforced by a range of initiatives.

4.10.1 Lay a solid foundation for innovation and entrepreneurship in society

An innovation mindset needs to be fostered from the early stages of childhood. Curiosity, creativity, critical thinking, the ability to learn from failure, and entrepreneurial skills will feature strongly in the curriculum at its various stages: in early childhood development, at school and during post-school education and training.

The DST will work with relevant government departments, such as the DHET, the Department of Basic Education, and the Department of Social Development, to develop standards and programmes to build an innovation mindset from early childhood.

4.10.2 Celebrate successful entrepreneurs and innovators as role models

Successful innovators, mentors and entrepreneurs will be celebrated as role models. Initiatives to achieve this will include advocacy and awareness, awards across society at all levels of government, and exchange and incubation programmes. These initiatives will be implemented as a partnership between government, the business sector and civil society.

Particular attention will be paid to equity considerations, ensuring that people who often do not have the opportunities to become innovators, such as the youth, women and people with disabilities, are given these prospects though incentives for role models to coach, mentor and fund them.

4.10.3 Encourage experimentation in the NSI

Experimentation has significant potential to support transformation through innovation-led improvements to service delivery. The state will provide support for experimentation through, for example, risk procurement and including investment in more varied demonstration projects in the policies of relevant government departments. The DST and the dti will work with sister departments and local and provincial governments to encourage experimentation, and officials will be trained to act as innovation facilitators (modelled on the concept of agricultural extension officers).

A critical dimension of experimentation is to stimulate co-learning and co-creation among researchers, officials and users/buyers of technology. Civil society will need to play a stronger role in planning and implementing projects that lend themselves to experimentation. A requirement of funding will be to capture the learning from the experiment (for example, by way of policy briefs, social media or workshops).

CHAPTER 5: EXPANDED CAPABILITIES FOR INNOVATION

STI accelerates the transformation of societies. Scientific research has expanded knowledge and led to discoveries of new medical treatments, increasing human life expectancy. It has resulted in breakthroughs in agriculture, such as the introduction of high-yield and drought-resistant crop varieties. Climate science has enabled societies to implement measures to mitigate the effects of climate change. Research in the social sciences has increased understanding and tolerance between communities and racial groups. It has contributed to building cohesive and inclusive societies and developing evidence-based government policies. Disseminating research helps to nurture a thinking citizenry that functions effectively, creatively and ethically as part of a democratic society.

As discussed in Chapter 1, the research system in South Africa is strong, with researchers developing new knowledge on issues across the public policy agenda, as well as those relevant to business and civil society. These outputs have been varied and significant, providing new business models, means of improving the delivery of public services, new approaches to protecting and supporting families, and new solutions to public health issues.

This chapter outlines how to increase these outputs through expanding and transforming the research system. The research system here is considered not only from the perspective of institutional and demographic transformation, but in terms of the nature of research being conducted to ensure that South Africans can thrive in a rapidly changing and increasingly technologically advanced world. The chapter further discusses how to strengthen the supply of high-level skills, increase the openness of the system and improve the diffusion of knowledge. It focuses on scientific infrastructure, the supply of science and technology skills to the economy, and the links between science, innovation and society, including the need for public engagement. The chapter concludes by addressing the important issue of science diplomacy and internationalisation.

5.1 Progress, gaps and approaches to expanding capabilities for innovation

5.1.1 Research and the next generation of researchers

South Africa has a strong and growing science and technology system, including world-class universities.[3] Research publications produced by these universities tripled from 5,540 in 1994 to 15,542 in 2014, with the per-capita research output doubling from 0.39 in 2001 to 0.84 in 2014. South Africa has active global knowledge partnerships and long-standing collaborations with leading science nations, resulting in the increasing international mobility of researchers (inward and outward). South African researchers, through the work of the DST, have formalised access to global research infrastructures (for example, the European Organisation for Nuclear Research). A recent bibliometric assessment of South African papers shows that more than 50 percent are co-authored with international partners.[4, 5]

Several flagship programmes to address the shortage of skilled researchers have been introduced, including the South African Research Chairs Initiative and the Centres of Excellence. However, more programmes are needed to achieve the required critical mass for research towards social and economic transformation, while driving equity and transformation. The trends are encouraging, with,

for instance, the undergraduate percentage of SET enrolment increasing between 2005 (29.4 percent) and 2015 (29.7 percent), albeit marginally. Furthermore, in 2014, total university enrolments approached 1 million, with postgraduate students (honours, master's and PhDs) constituting about 16 percent of total enrolments (the NDP target is 25 percent). The DST has been working to increase this level through bursaries, with the main objective being to provide comprehensive bursary funding that compares favourably with entry-level salaries at each qualification level. The introduction of the Comprehensive Bursary Programme that targeted honours students improved the retention of postgraduate students.

Data on doctoral students graduating each year shows that the numbers have more than doubled in the period 2002–2014. While the number of PhDs has increased to 41.8 PhDs per million of the population in 2015, it is still lower than the NDP target of 100 per million of the population by 2030. An important driver in the production of doctoral graduates is the number of PhD-qualified staff at universities. Between 1996 and 2014, this number increased by 65 percent. By 2014, 43 percent of the research and instructional staff were PhD-qualified, which, although representing a substantial increase, is still far off the 75 percent target set in the NDP. For the NDP target to be reached, the percentage of matric learners passing science and mathematics with at least 50 percent needs to be raised and the decline in the number of female learners passing these subjects has to be reversed (there has been a 50 percent decrease between 2008 and 2016).[9]

Furthermore, while the number of PhD-qualified staff increased by 65 percent, the number of enrolled PhD students increased by 350 percent (from 1996 to 2014). This situation has led to a well-documented supervisory bottleneck, where increases in doctoral enrolments have not been accompanied by increases in PhD-qualified research and academic staff, which constrains the development of high-level human resources.

In 2013, the Minister of Science and Technology approved a set of equity-based guidelines for bursaries and scholarships. These guidelines have contributed to transforming the postgraduate cohort. Although there is significant room for improvement, especially at the higher levels in the research system (discussed below), South Africa's gender-equity performance is better than many more advanced countries: recent survey data reveals that the percentage of women researchers was 44.3 percent in 2014/15, which is higher than participation rates in many developed countries.[6] Research outputs by historically disadvantaged groups are also growing; the share of scientific papers published by black authors has increased from 10 percent to 32 percent, while that of women authors increased from 20 percent to 32 percent in the period 1998 to 2014. However, racial and gender inequalities persist. Furthermore, the number of full-time equivalent researchers in the system has not increased significantly from the date of the earliest available data in 2005/6.[6]

There are international concerns about the diminishing role of the humanities and social sciences in academia and the wider knowledge sphere. However, in South Africa evidence does not support concerns about the prioritisation of natural, physical and engineering sciences over the humanities and social sciences. This notwithstanding, the humanities and social sciences must play a stronger role in the science system – not in a narrow utilitarian sense or as mere supporting disciplines. The challenge is to incorporate humanities and social sciences knowledge and insight into STI work. The

humanities and social sciences are most relevant when they can contribute on their own terms, according to their strengths.

Inherited structural inequities are limiting our research system. This is reflected in the differential capacities of our institutions. Research performance is highly variable across different sectors (universities, industry and science councils), and within different institutions in the same sector. The higher education sector is responsible for nearly 90 percent of all research publications, compared to about 8 percent for all the science councils and national research facilities. Within the university sector, five universities produce more than 60 percent of research outputs from the sector.

The National Plan for Higher Education sought to transform the higher education system, bringing about institutional mergers to eliminate historical disparities, and the differentiation of universities according to mission.[7] Despite the plan, performance gaps abound between universities and universities of technology, on the one hand, and historically disadvantaged and advantaged institutions, on the other. For example, three-quarters of PhD graduates are produced by six universities.

5.1.2 Infrastructure

Through focused attention, mainly by the DST and its entities, there has been notable progress across all categories of research and innovation infrastructure. For instance, South Africa has developed the South African Research Infrastructure Roadmap. Five national facilities and one major project – the MeerKAT/Square Kilometre Array – have been established, as well as national preclinical facilities at higher education institutions. In terms of high-end infrastructure, the Fluorochemical Expansion Initiative, a titanium pilot plant and several technology demonstrators have been established.

Cyber infrastructure, which is important for a digital society, has also shown progress. Examples include the Centre for High Performance Computing, the South African National Research Network, the Data Intensive Research Initiative of South Africa, and the National Integrated Cyberinfrastructure System. The ICT Research, Development and Infrastructure Roadmap was developed and is being implemented. Finally, progress with global infrastructure is encouraging. South Africa considers its international collaborations with the European Organisation for Nuclear Research, and national facilities such as MeerKAT/Square Kilometre Array, the Southern African Large Telescope, and the iThemba Laboratory for Accelerator-Based Sciences among its achievements in this category.

Despite this progress discussed in Sections 5.1.1 and 5.1.2, the full potential of South Africa's research system and its human resources is yet to be fulfilled. The following policy interventions aim to:

- Improve research outputs
- Expand and transform the research system and facilitating knowledge diffusion
- Ensure an open, responsive and diverse knowledge system
- Upgrade knowledge and innovation infrastructure
- Develop skills for the economy
- Improve internationalisation and science diplomacy
- Diffuse a culture of innovation and science literacy.

Policy intents and actions

5.2 Policy intent: Expand and transform the research institutional landscape

To expand the research system, the institutional landscape will be grown and diversified by establishing new research institutions and consolidating existing programmes, after conducting the relevant studies. Lessons will be drawn from the Ministerial Review on the Science, Technology and Innovation Institutional Landscape.[28]

The university funding formula introduced in 2003 had a positive effect on research outputs. The system will maintain a strategic focus on increased incentives for research outputs – particularly for researchers doing inter-, multi- and transdisciplinary work. The DST will continue its support for the DHET's Staffing South Africa University Framework, which aims to change the size and composition of university staff.

The DST and the DHET, in collaboration with international partners and industry, will continue to strategically develop research-intensive universities, while strengthening the research capacity of universities underperforming in terms of research, with a focus on historically disadvantaged institutions and universities of technology. However, it is important to recognise existing areas of excellence in universities of technology and historically disadvantaged institutions – as the type of institution is not the only factor constraining research performance. Programmes to improve research capacity will be established. The twinning of research-intensive universities with historically disadvantaged institutions will be encouraged.

The DST, the DHET and other relevant government departments will intensify focus and collaboration around the incentive programme for science councils to improve their research performance. Research partnerships between universities and science councils will be facilitated and supported. Moreover, the DST will deepen partnerships with R&D and STI-intensive government departments like the departments of Energy, Environmental Affairs, and Higher Education and Training to strengthen support for the research enterprise.

5.3 Policy intent: Transform the profile of the researcher base

The DST and the DHET will emphasise the development of black and women researchers at emerging researcher level (with a specific focus on black women), and mentor them beyond qualification to take up senior management positions in research management and science institutions.

Over the short term, an increase in the number of researchers will be achieved through focused, fast-tracking interventions that will tap into the PhD-qualified research-inactive "silent majority" of existing permanent academic staff, especially black staff and women. Interventions include the Thuthuka initiative, which seeks to advance the equity and redress agenda within the research sphere. South Africa's research system has not leveraged or optimised the talents and skills of its majority population

groups (black people and women), and there is therefore a need to accelerate the research enterprise by supporting emerging researchers and next-generation researchers (see the Glossary for an explanation of these terms).

The DST will intensify its support for various initiatives that develop historically disadvantaged institutions, aligned with the DHET's differentiation framework for the higher education sector.

5.4 Policy intent: Improve the research system's output of human resources

The White Paper adopts a broad view of human resource development in higher education, recognising the urgent need to:

- Take cognisance of the multidimensional nature of black students' lived realities (such as university fees, accommodation, nutrition and transport).
- Change the demographics of the professoriate.
- Transform the curriculum and research agendas.
- Cultivate greater awareness of Africa.
- Eliminate racism, sexism and all other forms of unjust discrimination.
- Improve academic success rates and expand student support for black students in particular.

5.4.1 Supervisory capacity

Given the country's supervisory capacity constraints and the global research projects that it hosts, the need to attract world-class research talent by easing immigration rules cannot be overemphasised. Government will continue to focus on this issue.

Government will expand instruments that have proven successful in research and postgraduate outputs such as the South African Research Chairs Initiative. Research chairs are required to spend 80 percent of their time on research and student supervision. Government will put in place programmes to establish full-time equivalent research positions at universities.

The experience and expertise of the current ageing cohort of researchers will be used, while putting in place research and supervision transfer skills programmes to benefit younger and emerging researchers.

In order to increase the proportion of university staff with PhDs, direct support for attaining a PhD will be prioritised, particularly for staff at universities where the proportion of PhD-qualified staff is below the norm. Twinning programmes with research-intensive universities and international institutions will focus on helping staff at historically disadvantaged institutions and universities of technology attain PhD qualifications.

5.4.2 Postdoctoral fellows

Postdoctoral fellows make an invaluable contribution to the research system by mentoring postgraduate students. The number of postdoctoral fellows hosted at universities and science councils has generally increased, but their contribution has not been optimised because their status has not been defined. The DST and DHET will formalise a set of guidelines on how to optimise the contribution of postdoctoral fellows.

Given the sustained increases in the number of PhD graduates, government aims to support and retain an appropriate percentage of each annual graduating PhD cohort in the postdoctoral programme for eventual absorption into the academic and research system.

To improve demographic representation among established researchers, the DST and the DHET will target and retain a significant number of black and women doctoral graduates in the postdoctoral fellowship programme, particularly South Africans. Foreign postdoctoral fellows will be targeted in strategic priority areas to alleviate supervisory bottlenecks. At the same time, the DST and the DHET will establish a programme for South African postdoctoral fellowships abroad that targets black people and women.

5.4.3 Human resource development pipeline

The DST and the DHET are the key government departments responsible for strengthening the postgraduate human resource development pipeline, supported by other relevant government departments such as the Department of Labour

Currently, too few students are supported at too low a financial level. Therefore, significant increases in public support for postgraduate studies are required, especially given that the gradual implementation of free higher education might result in increased postgraduate enrolments. Increased public support for postgraduate studies will also require government, industry and international funders to coordinate their efforts. A framework will be developed for cooperation across government, particularly with departments that have SET postgraduate bursary programmes.

In addition to research master's and PhDs, the NSI and the economy require technical and other skills that support innovation. Government will therefore expand its student support programmes to include the development of technical, engineering, entrepreneurship and innovation-related skills, such as in intellectual property management.

The DST, in collaboration with the Department of Basic Education, needs to scale up existing initiatives to increase grades achieved in science and mathematics at school.[29] Developing a scientist or engineer begins early in life with the nurturing of children's health, curiosity and creativity. Therefore, early childhood development programmes will be expanded by the departments of Basic Education, Social Development and Health. The government aims to use the potential of STI to increase the reach and impact of such programmes.

Within the context of a digital society (and workplace), government will put in place specific interventions to enable all children (and, where appropriate, adults) to become digitally literate. Examples could include making greater use of mobile phone technology and existing public

infrastructure in rural areas such as post offices, schools or libraries to introduce children to gaming and coding, and to teach adults digital skills. The private sector will be encouraged to partner with the government in these endeavours.

Government will assist researchers and scientists to work with teachers to introduce modern scientific concepts as early as pre-primary and primary school level (in particular in ICT-related skills training linked to the Next Industrial Revolution). The adoption of schools by universities and science councils can reinforce such an approach. Furthermore, SET-based industries will be incentivised to adopt schools for support – although government will not abdicate its responsibility in this regard to the private sector. Another more long-term option is to explore the possibility of linking postgraduate funding to a quota of community service to assist with the teaching of SET in schools. Such a programme should, however, not compromise completion times and rates.

5.5 Policy intent: Strengthen skills in the economy

The following sections discuss how to address the issues of developing human capability within firms and elsewhere in the economy.

5.5.1 Firm-level research capability

While firms do sometimes contribute to basic science, more often they carry out applied research that has a particular application to a specific market and a more certain return. This generates fewer externalities and is likely to be easier to finance.

As investments in R&D by the private sector may decrease during times of economic distress, government will continue to support research in the private sector, thereby increasing employment in relatively well-paid high-technology industries in South Africa. Government will, for instance, continue to use the R&D Tax Incentive to encourage private-sector investment in scientific research, but will increase the efficiency of this incentive, and explore other incentives.

Open platforms could also have an amplifying effect by dramatically increasing the pool of individuals available to address a given question and decreasing the time to develop solutions, ultimately decreasing the time to market. The DST will therefore continue to explore opportunities and barriers (for example, intellectual property and mission conflicts) for universities, science councils, government and the private sector to participate in open collaboration platforms.

5.5.2 Absorption of doctoral graduates into the economy

Increased absorption of doctoral graduates is possible only if the acquired PhD-level skills and training are appropriate to the needs of industry, government and science councils, among others. Government and industry must be co-creators of human resources and nurture an increased appetite for PhD-level skills. Government will put in place incentives, for example, tax breaks for industries investing in funding PhDs from their own workforce.

Increased cooperation between universities, industry and government will increase the relevance of PhD training. Therefore, the diversification of knowledge workers through doctoral programmes

facilitated jointly with industries, such as industrial doctorates, will be pursued. Government will also invest in tracer studies to understand the career paths and mobility of people with PhDs across different sectors (such as universities, science councils and industry).

5.5.3 Diversity of post-secondary education

In South Africa, there is a need to improve the responsiveness of the post-school education and training system to skills for the 21st century workforce, in particular to innovation and technology-driven change that affects organisations and individuals alike. A key characteristic of the South African labour market is that the education level and skill base is lower than that of many other productive economies. The pool of students who can potentially access university and science-based Technical and Vocational Education and Training programmes is very small in comparison to the skill demands in the country.

The main constraint for South Africa's education and training system and labour market is the inadequate quality of basic education (particularly in languages, mathematics and science). This impedes progression to and success in post-school education and training and the workplace. There needs to be a coordinated system-wide effort involving the Department of Basic Education, the DST, the Economic Development Department, the dti, the Department of Labour, and the DHET to improve the quality of teaching and learning from the foundation phase of schooling, and to ensure stronger integration of government departments' strategies targeting skills development and education.

Through initiatives by the DHET, the post-school education and training sector must increase the supply of science, technology, engineering and mathematics graduates and teachers, especially secondary school mathematics and science teachers and early childhood development practitioners.

At technician level, there is an undersupply of engineering technicians and associate professionals, as well as building and construction, metal, machinery, electronic, electrical and related trades. The sector must develop enrolment targets in line with skills needed for the labour market.

5.5.4 Education and training for a future of digital jobs

The government will plan the future human resource needs of the country (according to the NDP and beyond) in a coordinated manner to ensure that scarce educational resources are optimised. More specifically, the DST will work with the DHET (and the Department of Basic Education) to integrate the need for STI skills into the South African National Skills Plan.

The talent and skills of our people are the engine behind South Africa's innovative capacity. Furthermore, the 21st century demands a highly skilled, well-educated workforce that welcomes change, is prepared to take measured risk, and creates new ideas to drive innovation. It is therefore important that South Africa invests in the development of human talent to meet the demands of a global, knowledge-based economy. Government needs to equip South Africa's youth with skills for the future, expose more students to coding and computational thinking, and train students in problem-solving and critical reasoning skills. South Africa, already facing skills backlogs, needs to capacitate its citizens to thrive in this new world and ensure inclusive economic progress for the country. Our

education system must equip students to be successful entrepreneurs, hold a diverse number of jobs, or work across a number of industries.

To thrive in the digital economy, ICT skills will not be enough. Several types of skills are needed: technical and professional skills, including ICT specialist skills for workers who drive innovation and to support digital infrastructures and the functioning of the digital ecosystem; ICT generic skills for workers and citizens to be able to use digital technologies; and ICT complementary "soft" skills, such as leadership, communication and teamwork skills, required for the expanding number of opportunities for ICT-enabled collaborative work.

Education and training systems will be modernised to ensure a better workforce for the influx of new kinds of jobs arising from trends in ICT and the Internet of Things.

South Africa's educators will design future-ready curricula that encourage critical thinking, creativity and emotional intelligence as well as accelerate acquisition of digital, science, technology, engineering and mathematics skills to match the way people will work and collaborate in the future, particularly in the context of the Next Industrial Revolution. The DST, the Department of Basic Education and the Department of Telecommunications and Postal Services, among others, will collaborate in reshaping the country's skills development agenda in line with the jobs landscape of the future.

5.6 Policy intent: Ensure an open, responsive and diverse knowledge system

As discussed in Chapter 2, the world is facing challenges that require not only intensified knowledge development and research, but also new forms of knowledge production, through Open Science and by combining inputs from different disciplines.

5.6.1 Open Science and Open Innovation

South Africa is exploring the transition to Open Science and this work will be intensified. It will require the country to not only strengthen regulatory frameworks and data skills, but also to adopt a more open approach to innovation and to instil an enabling innovation culture across society (as discussed in Chapter 4).

Incentives for Open Science will be fostered and created in education programmes and the careers of researchers. A focus on citizen science will also be introduced. Barriers to Open Science will be removed, ensuring that legislation and practice support, rather than thwart, the principles of open and collaborative science. Government will therefore review these, taking into account certain aspects of intellectual property rights from publicly funded research, as well as the policies and institutions governing access to research data and research publications.

As a general principle, all of South Africa's publicly funded research and research data should be available to the public for free (with the exception of data that can compromise sovereign security). As a result, Open Science will make research more transparent, rigorous and efficient; stimulate innovation; and promote public engagement.

The DST will work with the higher education sector and the relevant government departments to ensure data-related skills development for making efficient use of new scientific datasets, tools and methods.

Digital technologies are making the conduct of science and innovation more collaborative, international and open to citizens. In the next decade, as connectivity becomes ubiquitous, the shift to more distributed, networked and open organisational models will become commonplace. Those unable to make the change will be left behind.[23, 24] Therefore, government will prioritise funding for providing digital resources to communities and institutions that need them the most.

As part of its commitment to African STI cooperation, South Africa will also work to advance the Open Science agenda elsewhere on the continent and within regional frameworks. The strategic role of the African Open Science Platform, hosted by the Academy of Science of South Africa, which promotes African-wide development and coordination of data policies, data training and data infrastructure, will be leveraged with the support of the DST and the National Research Foundation (NRF). In addition, South Africa is one of the founding members of the global Open Government Partnership, and took over the chair in 2015. As one of the signatories of this partnership, South Africa is committed to developing an open data policy framework and action plan.

5.6.2 Diversity of knowledge fields

Public investment in science and research (both fundamental and applied) is an investment in the nation's future, ensuring that South Africa has a productive economy and a healthy society – and contributes to a sustainable world. To this end, a general shift in focus towards innovation is required in the South African STI landscape. However, this does not imply an NSI overly focused on investment in experimental and/or applied research. Instead, a dynamic balance is needed, determined on the basis of, among other considerations, the status of the field of knowledge in question, perceived innovation opportunities, and the research intensity and structure of the industries involved.

Studies on the state of health of the different knowledge fields in South Africa will be intensified to allow the DST and other funding institutions to strategically and sustainably deploy research funding. This notwithstanding, support to all academic disciplines, that is, the arts (performing arts and visual arts), humanities (such as languages and literature, and philosophy), social sciences (including economics, law, psychology and sociology), natural sciences (physics, chemistry, biology and so on), and applied sciences (engineering and technology, medicine, health sciences, agricultural sciences and computer science) must continue. In doing so, government policies must recognise the importance of language as the carrier of scientific meaning and information, particularly in the home language of children.

Many of the challenges facing humans in the near future, particularly in developing countries, will be solved by the engineering sciences (for example, infrastructure for rapidly growing cities and improved transport and logistics, water and energy infrastructure, and satellites to ensure information security for the state). Given the present shortage of skilled engineers in the country,[9] government will develop instruments to increase support for engineering science and research.

Regardless of the type of research being conducted, two requirements will remain important, namely, whether the research is aligned to the country's needs and delivering the required impact, and whether the research is of a consistently high standard (which to an extent overlaps with the first requirement). Government will therefore implement a framework for research evaluation and impact assessment, supported by a Responsible Research and Innovation framework for the South African context.

5.6.3 Role of the humanities and social sciences

The DST recognises the growing interconnections and complementarity between the natural sciences and the humanities and social sciences, the potential for creativity and innovation that these connections can generate, and the limits of using scientific approaches in isolation to tackle societal challenges.

Purposeful inclusion of the humanities and social sciences will be prioritised, not only in the role of observer and commentator, but also in conceptualising, planning and executing innovation initiatives.

The DST and DHET will further ensure that the equipment and infrastructure required for the humanities and social sciences, for example, survey equipment and ICT infrastructure, is given prominence in the various equipment and infrastructure funding instruments in the NSI.

Relevant government departments will commit stable funding for a programme of social surveys and institutionalise several critical longitudinal socioeconomic surveys, for example, on education outcomes (international comparison), health behaviours of South Africans, and aspects related to social cohesion and entrepreneurship.

5.6.4 Complex societal problems and inter- and transdisciplinarity

"Interdisciplinarity" is usually characterised by collaboration and the integration of concepts and methods (and in turn may lead to the creation of new concepts and knowledge). "Transdisciplinarity" takes this a stage further and may represent a different kind of knowledge production, embracing both scientific and other types of knowledge and the involvement of a broader range of expertise, including potentially the end users of such research.

A transdisciplinary research process links societal problem-solving with scientific knowledge production in a process of co-producing knowledge. Therefore, close interaction with societal actors that can take decisions, can act, or are affected in the respective field is key. To overcome the knowledge-action gap, the approach includes stakeholders from the beginning (co-design), deliberates on normative target questions (for example, "What are more desirable futures?"), and co-produces knowledge on how to reach these targets.

Support for transdisciplinary research faces many obstacles. These include institutional and administrative rigidities, established specialisations among journals and professional societies, funder preferences and policies, and the incentives and constraints embedded in academic and research career tracks. It is important to address these, but there should, however, not be a top-down forcing

of inter- or transdisciplinary approaches. The idea is to build a more balanced research ecosystem that will stimulate creativity and advance our understanding of the world.

Universities and science councils will find creative ways, including incentives (for example, publications funding) for experienced and established cross-disciplinary researchers to mentor and guide cross-disciplinary research projects, as well as to play a role in strategic advice at the institutional level in promoting such activity.

The DST and DHET will encourage universities and science councils to intentionally promote transdisciplinary research by reducing institutional barriers to transdisciplinary research and interdisciplinary research teams. It will also develop structures to encourage input and participation from outside ongoing projects in such a way as to bring together, in a transdisciplinary research environment, researchers from several institutions, representing multiple approaches. Funding agencies such as the NRF will support transdisciplinary research and create stepping stones for transdisciplinary careers.

Transdisciplinary research brings insights and ideas to people. But we do need to work on the skills involved. It is necessary to embed a transdisciplinary approach in academic institutions. The institutional culture is still predicated on publications rather than other outputs. Incentives such as increased funding for large multidisciplinary projects (that include the humanities and social sciences) and awards to increase awareness will be put in place to stimulate this behaviour, at both national and institutional level. This dimension of knowledge generation will be included in the research evaluation and impact assessment framework to ensure that it is implemented.

5.6.5 Selection of key research areas, sectors and technologies

According to the OECD, it is important for countries such as South Africa (middle income, with small innovation systems) to focus their STI efforts.[14] However, NACI points out that an incorrect choice of focus area or focus strategy can be more damaging than a strategy of diversification.[25] Furthermore, analysts have noted that the resources of the South African NSI are too thinly spread to make a significant impact in priority areas. Some of the areas in which there has been good knowledge production may not necessarily be aligned to the areas in which innovation for socioeconomic impact is most needed. The issue of selection is therefore both important and complex.

The DST will develop the process for the selection of focus areas as shown in the box below.

Process for selecting focus areas

- Identify the national STI priorities using South Africa's commitment to the Sustainable Development Goals and NDP objectives. Examples of such priorities include the need for greater inclusion and transformation; areas of massive social need, for example, social security, housing, health and education; opportunities for firm growth, exports and job creation; broadening the concept of geographic advantage to determine research focus areas; environmental sustainability and reaping the benefits of the green economy; preparing for a changing world, focusing on, for example, emerging research areas and the demands of a digital society, the potential disruption of the Next Industrial Revolution, using smart cities as centres of growth, and improving network infrastructure; and potential risks to the country, for example, environmental, sociopolitical and geopolitical.

- Within these STI priorities, determine the possible focus areas using an agreed set of selection criteria, based on the criteria of national priorities and the country's capacity to succeed in the chosen areas, for example, where a competitive or comparative advantage exists, and where the required critical mass of investment is feasible.

- Institutionalise the selection process by selecting focus areas for the whole of government and supporting these at the level of the Presidency to ensure that government action on these focus areas is coordinated. In support of the selection procedure, government will institutionalise independent foresight and environmental scanning capacity at NACI.

- Concentrate resources on priority focus areas at critical mass through the new budget coordination process; direct DST funding of research to areas directly linked to national priorities; and involve both research-intensive institutions and historically disadvantaged institutions in tapping the potential of the entire research system.

5.6.6 Knowledge diffusion

Government will enhance knowledge diffusion by adopting an Open Science paradigm (as discussed in Section 5.6.1) to encourage the sharing of ideas and research results. Knowledge diffusion will also be improved through enhanced coordination of STI activities across the NSI that will allow the smooth flow of researchers and knowledge between enterprises, universities, science councils and government. Similarly, the increased absorption of people with PhDs and other highly skilled people into research-performing institutions will enhance knowledge diffusion. Some of the mechanisms that could be used to achieve this are joint appointments and public-private partnerships.

Research cooperation will be improved. Investment in research programmes at the interface of various public research institutions (for example, universities and science councils), SOEs and industry will help build bridges for sustainable research cooperation, and ensure that skills produced by universities match those required by industry and science councils. Programmes at the interface will demand easy movement of researchers between universities, science councils and industry. This will be achieved through, for instance, joint appointments, and staff and student mobility programmes.

The contribution of public research institutions and their outputs in supporting government policy and national priorities needs to be enhanced. This will include a programme similar to the Technology and Human Resources for Industry Programme. In this regard, research grant schemes to incentivise collaboration between universities and other public research institutions in inter- and transdisciplinary research will be developed.

Government will support increased networking and the diffusion of knowledge by leveraging existing global partnerships and knowledge networks better, introducing specific programmes for the secondment of South African researchers to institutions in other countries, providing increased support for training abroad, and providing enhanced support for conferences and workshops. An appropriate quota of international research cooperation engagements and resources will be channelled to historically disadvantaged institutions and universities of technology. Similarly, the role of Office of Technology Transfers needs to be enhanced, creating demand for in-bound technology transfers.

5.6.7 African research cooperation

South Africa's profile as a destination of choice for researchers and students from other African countries wishing to gain international experience and expertise needs to be promoted. Already, other African nationals are making significant contributions to strengthening the human resources available to the NSI. At the same time, programmes designed to afford international mobility, exchange and training opportunities for South African researchers and students should include a concerted pan-African focus, promoting the outward mobility of South Africans to Centres of Excellence and institutions elsewhere in Africa, amongst others

5.7 Policy intent: Support a science-literate and science-aware society

One of the prerequisites for an effectively functioning NSI is a society that is aware of the value and the potential dangers of science, is able to evaluate the products of science, uses the processes of science in their daily lives (for example, asking questions, collecting and analysing evidence, and evaluating possible results), and engages in debate on science-related matters of public interest. Greater public awareness of scientific issues will also stimulate the interest of young South Africans in pursuing careers in science – thereby increasing the number of secondary students choosing subjects to prepare them for university studies in science, technology, engineering and mathematics fields.

In the current global "post-factual" society, raising science awareness is of increasing importance in efforts to provide credible alternatives to dubious sources of information. However, with growing access to the Internet and the proliferation of unverified information across digital media, these efforts are all the more difficult. In South Africa, the problem is compounded by issues in the education system and the fact that the spatial development patterns of apartheid have to a large degree persisted, particularly in rural areas, which means that many people live beyond the reach of science awareness campaigns.

Since 1996, the South African government, led by the DST, has made good progress in stimulating public awareness of science. Some gaps remain to be addressed, as detailed below.

5.7.1 The institutional environment

The role of the South African Agency for Science and Technology Advancement, as the national coordinator of science engagement in South Africa, will be entrenched through legislation. A system-wide science engagement coordination model will be instituted, going beyond the DST and its entities, enabling the higher education sector, industry, research councils, science centres and other r elevant stakeholders to collaborate in science engagement.

Government will introduce an approach for dedicating a fixed percentage of the transfers by STI-intensive departments to their entities for the purposes of raising science awareness.

Support for existing science centres will be sustained, and support packages will be developed to establish more strategically positioned science centres, including world-class national flagship science centres or museums. This will involve private-sector co-funding.

5.7.2 Incentives for researchers

Scientists who participate in science engagement activities will be awarded continuing professional development points by the South African Council for Natural Scientific Professions.

Conditions for research training grants and research development programmes to science councils and public universities (for example, Research Chairs and Centres of Excellence) will make it mandatory for recipient individuals and institutions to communicate their research to the public.

Initiatives such as early childhood development and digital literacy programmes can only produce the required results if society is science literate. It is therefore necessary to train scientists and researchers in science communication and science engagement skills. These trained researchers and scientists would then help to introduce developmentally appropriate engagement activities and projects for both adults and school learners. Government will aim to have these skills taken up in the curricula of SET students in the higher education sector.

5.7.3 The reach and effectiveness of science engagement activities

To increase the reach of awareness initiatives and promote access to information, science engagement activities will increasingly target the local government level, using appropriate communication technologies and techniques, including mainstream media and social media.

The development of science engagement and communication skills will be prioritised. Such skills development initiatives will target journalists, scientists, students, learners, educators and science interpreters.

Indicators to measure the success of system-wide science engagement performance will be adopted to inform an institutionalised survey on public perceptions of science and co untry comparison studies.

5.8 Policy intent: Upgrade and expand research infrastructure

Research infrastructure is recognised as a key element for boosting scientific knowledge generation, accelerating technology development, enhancing both technological and social innovation, and providing advanced scientific training for new generations of scientists and science managers. Furthermore, research infrastructure provides an enabling environment for established researchers to improve their performance and knowledge and innovation outputs.

The factors that underlie current challenges in the provision of research infrastructure include:

- A lack of long-term planning by institutions to meet the high demand for research and laboratory equipment.
- Inadequate funding to upgrade and replace old research infrastructure, lack of national accredited health (preclinical) research facilities, and the need to improve the overarching governance for distributed research infrastructure.
- Inadequate specialised skills related to research infrastructure, for example, for maintenance.
- Inadequate coordination across institutions in providing data-intensive research infrastructures, and lack of digitisation facilities.
- The challenges and gaps arising from the emerging imperatives for a competitive NSI, including a lack of capability to fully exploit the convergence of ICT to drive the digital society and transformation.
- Insufficient access to research infrastructure for grassroots innovators.
- Inadequate provision of research infrastructure to support social research.

To adequately renew and maintain the current infrastructure base, a long-term coordinated planning approach for research infrastructure investment (across different departments, as well as the relevant SET) will be developed. The investment planning will make provision for renewal and replacement, as well as maintenance and technical support.

To help address the challenge of insufficient funding for research infrastructure across the entire innovation value chain, a national research infrastructure fund at the National Treasury will be established with long-term planning horizons. It is estimated that the required investment in research infrastructure will be R1.5 billion per year in real terms (investment is currently around R1 billion per year) for the country to remain competitive in terms of knowledge and innovation outputs, as well as to train the next generation of researchers.

There is a specific need for increased investment in high-end infrastructure to support innovation, produce new products and develop new industries, among other things. Examples of this type of facility are those focused on resource beneficiation, such as pilot plants for the platinum powder industry and hydrogen fuel cells. The exact level of funding required would depend on the type of high-end infrastructure, but an agreed percentage of total funding will be used to support such infrastructure.

Lack of coordination and integration among departments in providing and accessing research infrastructure leads to bottlenecks and duplication of effort. Government will establish an intergovernmental coordination and steering platform with a clear mandate and scope, strategy and policy guidelines, co-funding, shared procurement agreements, and joint planning principles to address the lack of coordination.

Government will retain the six national research facilities currently managed by the NRF as research infrastructure platforms. However, the implementation of the South African Research Infrastructure Roadmap would require South Africa to have many more. The management model will therefore be changed to facilitate scale-up, sustainability and improvements in the performance and delivery of these facilities.

Training and developing key human resources is critical to ensure the optimal and sustainable use of research infrastructure. Government will therefore introduce a mandatory requirement that infrastructure provision policies include human resource development support (scientific and technical) for infrastructure development and maintenance through internships, curriculum changes in higher education institutions, and absorption into the workplace.

Not sharing or integrating research infrastructure leads to isolated and duplicated approaches to research infrastructure deployment and use. To address this challenge, government will develop programmes and interventions that build a continuum of research infrastructure capabilities at institutional, regional and national level (vertical integration). It will also establish distributed national research infrastructure to optimise and share resources, including for the humanities and social sciences.

Grassroots innovators that are not part of formal systems of innovation need access to research infrastructure. Government will therefore establish open access (and mobility) research infrastructure support (excellence/evidence-based) platforms for grassroots innovators, as well as to support innovation for inclusive development.

South Africa's national policies and strategies that include investment planning for research infrastructures must embrace a pan-African regional and continental focus. African regional e-infrastructures, such as dedicated high-speed research networks, will be essential for enabling intensified intra-African research collaboration, which South Africa needs and seeks to promote. Investment planning for large-scale facilities with expensive construction and operational costs should consider the possibility of jointly developing the facilities with other African partners as regional or continental facilities. Programmes and networks should also be developed to facilitate reciprocal access and collaboration between different African countries' national facilities. South Africa will work within the frameworks of the AU and SADC to support the formulation of African continental and regional research infrastructure policies and strategies.

Through partnerships with international research facilities such as the European Organisation for Nuclear Research, the European Molecular Biology Laboratory, the European Synchrotron Radiation Facility, and the Joint Institute for Nuclear Research, South Africa has gained access to cutting-edge research infrastructure that cannot be duplicated in South Africa because of its complexity and the

massive financial investment needed. These partnerships have provided South African scientists with an opportunity to conduct research at the frontier of knowledge; attracted prominent visiting scientists to South Africa; extended the PhD and master's supervisory capacity of South African higher education institutions; provided opportunities for training, and skills and technology transfer; contributed significantly to the internationalisation of South African world-class research; enhanced South Africa's visibility and footprint in the international scientific community; and leveraged international research funding from new partnerships. These partnerships will be intensified.

There are weak links and partnerships between the private and public sectors on investment in research infrastructure. Government will establish bi-directional open access (and mobility) research infrastructure support (excellence/evidence-based) platforms to encourage private-sector investment in research infrastructure.

To attract multinational corporations to locate their technological infrastructure in South Africa, incentives and the appropriate skills will be required. For South Africa to use public funding to support such facilities, it will be necessary to ensure that the new technological infrastructure is backed by a group of companies or by entire industrial sectors on the basis of their potential competitive gains, as well as scientific organisations.

It has become critical for the country to formulate the risks of adoption or non-adoption of an integrated digital strategy. To mitigate the risks, government will develop a South African integrated digital strategy setting out the key enabling role that the use of ICT will have to play. It will also develop national legislation/policy on digital data to regulate data sharing and access, ethics, privacy, and intellectual property at national level.

5.9 Policy intent: Expand internationalisation and science diplomacy

STI features prominently on the global political, economic and social agendas. The majority of countries are responding to the imperative of investing in STI and, more than ever, the global STI enterprise is characterised by intensive international cooperation and competition. The dynamics of Open Science, Open Innovation and open access to knowledge networks with data as their major currency will see the identity and roles of major international STI actors evolving. The industrialised economies of Asia, Europe and North America may continue to dominate scientific output and innovation performance rankings, but emerging economies, especially China and India, are starting to challenge this dominance. Non-state actors, especially multinational companies with R&D facilities distributed across the globe, also play an important role.

The mobility of researchers and entrepreneurs allows the exchange of experience and expertise, and funding increasingly flows across national borders. Scientific progress is often dependent on the global pooling of talent and resources, as evidenced by international partnerships for the construction and operation of large-scale research infrastructures. Countries also invest in STI to enhance their economic competitiveness by boosting their trade and investment profiles, as well as to attract STI talent or investment in pursuit of their national agendas. Strategic engagement in multilateral partnerships has the potential to position the country as an international STI partner of choice. South

Africa is involved in many such engagements (for example, the Group on Earth Observations), which should be further leveraged to the country's advantage.

One of the strengths of South Africa's NSI, and a critical one given that it is comparatively small, is its extensive and active set of international partnerships. Over the past 20 years, global cooperation and support have contributed significantly to the growth and development of the NSI. However, well-resourced South African institutions find it much easier to take part in these programmes than historically disadvantaged institutions, and a more inclusive approach will therefore be needed in future.

South Africa will continue to prioritise support for the development of STI capacity in Africa and the implementation of the Science, Technology, and Innovation Strategy for Africa. Informed by the pan-African focus of both South Africa's foreign policy and strategy for international STI cooperation, the country has a responsibility to contribute to STI capacity building in Africa. It is important to emphasise the importance of international engagement, not as an objective in its own right, but as an integral part of the overall further evolution of the NSI. The government's initiatives below relate to the strategic policy context, implementation modalities, and planning and coordination of international cooperation.

5.9.1 Enhanced strategic focusing

Rather than following an ad-hoc approach, science diplomacy will be strategically harnessed as an instrument to advance South Africa's foreign policy agenda and optimise the role of international STI cooperation in the implementation of Chapter 7 of the NDP, "Positioning South Africa in the World".

South Africa's engagements with African STI partners will be more strategically coordinated to ensure the implementation of the AU and SADC STI agenda, to better leverage synergies between the two agendas and avoid duplication. The government will facilitate support for a pan-African STI funding agency, including the joint publication of articles with researchers from the rest of the continent.

The Sustainable Development Goals will be the guiding multilateral policy framework for South Africa's international STI cooperation. It is anticipated that developments in the African and regional context will increasingly affect the NSI, as South Africa's political and economic integration deepens in the AU and SADC.

As competition for international cooperation opportunities intensifies, efforts to promote South Africa's profile as a global STI partner of choice will be stepped up. This will include initiatives such as institutionalising the management of Science Forum South Africa.

5.9.2 Efficiencies in international cooperation

To improve the NSI's innovation performance, a systematised framework for South Africa's engagement with international innovation partnerships (as opposed to the traditional academic and basic research-orientated focus of international cooperation) will be developed, with particular attention given to funding instruments.

Interventions will be developed to increase South African researchers' access to training opportunities abroad, responding to capacity needs in the NSI and ensuring that the NSI re-absorbs South Africans studying abroad, while also attracting skills to South Africa and fostering cooperation with the South African diaspora. The interventions will include a focus on attracting postdoctoral researchers to South Africa, with the specific aim of boosting South Africa's PhD productivity through increased supervisory capacity. The overall role of international cooperation in enhancing South Africa's research capacity, for example, through co-authorship, will be strengthened.

There will be an intensified focus on attracting STI-related investment into the country, and these efforts will be better aligned with government's general efforts to attract foreign investment into South Africa. The intent is to secure at least 15 percent of South Africa's GERD from international sources, and to grow this ratio over time.

A strategy will be developed to increase the participation of historically disadvantaged institutions in international collaborations, and to ensure that international collaboration does not perpetuate exclusion.

5.9.3 Planning and coordination for international cooperation

Coordinating mechanisms will be developed to ensure greater strategic focus and efficiency in international STI cooperation, avoiding fragmentation and duplication. These will include intelligence and information sharing, joint priority setting, and encouraging the exploitation of synergies.

Indicators and an M&E framework will be developed to better gauge the impact and outcomes of international STI partnerships. This will include systems for enhanced knowledge management of all South Africa's international STI cooperation initiatives (government and business).

CHAPTER 6: FINANCING SCIENCE, TECHNOLOGY AND INNOVATION

Very few of the ambitions of this White Paper will be realised without adequate funding. Financial resources directly influence the size, shape and strength of the NSI and its ability to support the NDP. The White Paper concludes with this chapter on financing South African STI.

6.1 Progress in financing STI, identifying existing gaps and expanding NSI financial resources

Recent reviews[2, 30] have all pointed to the fact that the South African NSI is underfunded, both at the aggregate level and at the level of STI in critical sectors of the economy, such as agriculture and mining. Furthermore, the reviews have noted that funding is not appropriately spread across the entire innovation value chain, and that foundational STI functions such as human resource development and infrastructure provision are underfunded. To enhance South Africa's innovation performance, increased funding is also needed for leveraging international funding and resources, technology transfer activities, and public incentives to encourage private-sector research, development and innovation.

GERD in constant 2010 rand terms and as a percentage of GDP has increased slowly over the past two decades. However, South Africa's global share of R&D has declined by 25 percent over the period 2007 to 2013, while India and China have grown their shares by 18 percent and 92 percent respectively. GERD as a percentage of GDP was 0.8 percent in 2015/16, a small improvement from the 0.77 and 0.73 percent that had been reported in the previous four R&D surveys. This improvement is significant, however, since it takes place in the context of slowing GDP growth, which was 2.5 percent in 2013 and 1.7 percent in 2014 and 1.3 percent in 2015.

The relatively low level of GERD and the near stagnation of GERD/GDP, particularly in comparison with other emerging economies, is a concern, and it is important to understand the figures in more detail. The business sector, which includes local private enterprises (large businesses, SMEs and start-up firms), SOEs and multinational enterprises, has a significant influence on the overall trend of GERD. Between 2004 and 2015, business funding increased by 6 percent whereas government funding increased significantly by 40 percent.

There are signs that this trend is changing; for instance, the business sector contributed to the bulk of GERD recovery in 2013 and 2014, although such increases were off a low base. In fact, this sector remains the largest performer in the history of the South African R&D survey. Furthermore, foreign funding for R&D decreased from 15.3 percent in 2004/5 to 13.0 percent in 2015/16, which is a relatively small decrease over a period straddling the 2008/9 global financial crisis, pointing to resilience in South Africa's ability to attract foreign funding.

Over the past two decades, public resources for innovation have increased significantly: the budgets of all departments active within the NSI have increased in real terms, led by the DST, whose expenditure has increased nine-fold since 2005/6.[30] Government funding of R&D has continued to grow steadily and sustainably over the past five years, amid slow growth conditions. In addition,

sectoral public investment in R&D is taking place via sector-specific science councils such as Mintek, the Agricultural Research Council and the Medical Research Council.

Despite these signs, increased funding by all sectors, not only for R&D but for STI in general, remains critical. Government funding is necessary to catalyse investments in areas where other actors have limited incentives to fund. For a developing country like South Africa, the rationale for government investing in STI is even greater, given that the country not only needs to catch up on several dimensions of economic growth and development, but also needs to establish new SET capabilities for its long-term competitiveness.

However, government funding on its own is insufficient to meet the demands for growing the NSI to its full potential: increased private-sector involvement for resourcing the NSI is vital, both to advance private-sector objectives and to support the government in research, development and innovation initiatives for the public good. Furthermore, a modern, open economy must attract higher rates of international funding and resources for research, development and innovation. With South Africa now more integrated globally than it was in 1996, it faces a new test, namely, to match its peers in attracting the shifting global research, development and innovation investments that continue to favour emerging economies. It will therefore need to provide equitable co-investment to attract funding from international partnerships.

Finally, in addition to the problem of general underfunding of the NSI, the 2012 Ministerial Review[2] highlighted the need to improve the allocation of public funding to STI priorities as resources are often too thinly spread to achieve impact in priority areas critical to South Africa's development. There is also room to increase the productivity of funding.

To address the reasons for the situation described above, this chapter contains policy proposals to:

- Increase funding to the NSI, with a focus on increasing business and foreign investment in STI, as well as to encourage provincial and local governments to invest more in STI as part of their development strategies.
- Improve the allocation of public funding for STI and the coordination of public investment to ensure that government's STI priorities are appropriately funded.
- Enhance the efficiency of funding in the NSI.

6.2 Policy intent: Increase levels of funding

Government recommits to the target of increasing the intensity of R&D investment in the economy so that GERD reaches 1.5 percent of GDP in the next decade, and an aspirational 2 percent a decade later. A number of interventions will be aimed at realising this objective, as discussed below.

Provincial and local governments will deliberately contribute more to STI funding and, over time, will set appropriate targets for investment in STI as part of their growth and development strategies. Examples of investment opportunities are incubation and testing facilities.

National STI-intensive government departments will set appropriate targets for STI in their budgets. In particular, line departments will commit a percentage of their budget for sectoral research, development and innovation plans and invest in their line science councils accordingly.

The mandates of development finance institutions, the Industrial Development Corporation, and the Development Bank of Southern Africa will be expanded to scale up funding for industrial innovation activities. This approach will help establish a closer interface with the Technology Innovation Agency, and scale up the overall level of government support for research, development and innovation. This will serve to close a critical gap in funding for large-scale projects that require government funding commitment to catalyse large-scale private-sector action. The approach will also accelerate South Africa's investments in other parts of Africa, in the context of the AU's Agenda 2063. In this regard, possible partnerships with the BRICS Development Bank will be explored.

International investments in STI will be included and appropriately positioned in the Trade and Investment South Africa initiative (based at the dti) to attract STI-linked foreign direct investment. The focus will be on promoting foreign direct investment, including targeted engagements with multinational companies. In terms of scope, international investment is considered to include direct investment by multinational corporations that fund and perform R&D, as well as mutually beneficial partnerships in human resource development, scientific infrastructure, knowledge networks and collaborative R&D.

New funding models across the innovation value chain will used. Examples include corporate social investment, crowd funding and partnerships/collaborations between actors across different sectors and borders. The growing sector of corporate social investment funds and non-profit organisations presents opportunities to advance grassroots and social innovation, for example, through venture capital funding. Government will introduce instruments such as matching funding and awareness raising to make greater use of these.

There is a specific need for increased commercialisation funding. A sovereign innovation fund will be formed to leverage co-investment by the public and private sectors to address gaps in technology commercialisation. The fund will be designed to complement and enhance existing funding instruments, and to provide large-scale funding for the development and maturation of radical

innovations and emerging industries. Within the public sector, agencies such as the Technology Innovation Agency, the Industrial Development Corporation, and the Development Bank of Southern Africa, in cooperation with the National Treasury, can contribute to this fund.

6.3 Policy intent: Develop funding priorities

To guide long-range planning and budgeting for the STI sector, decadal plans identifying priorities for STI will be developed by the DST, in collaboration with relevant role players across the public and private sectors. The STI decadal plans will identify funding requirements, per priority sector, across the entire innovation value chain – both supply-side (for example, research and human resource development funding needs) and demand-side (for example, co-funding incentives, public procurement commitments to assist with commercialisation, and sector innovation funds).

In the short term, new industries that add value to South Africa's mineral and agricultural resources, and move the country higher up the value chain, will be prioritised in the decadal plans. Long-term priorities will be determined according to the assessment of market drivers, the strategic use of techno-economic studies (including analysis of competitive advantage), the identification of lead users and industrialisation partners, governance arrangements, and funding requirements (see Chapter 5 for more detail on the selection of focus areas).

The decadal plans will further assist the Department of Planning, Monitoring and Evaluation in the Presidency in drafting its annual Budget Mandate Paper on funding priorities for government.

6.4 Policy intent: Institutionalise framework for guiding public STI investment

A new framework for guiding public STI investment will be established to serve as a mechanism for funding priority setting and allocation.

Framework for guiding public investment in STI

The framework will be aimed at establishing tighter connections between public STI investments and NDP requirements, enabling the prioritisation of STI funding within the overall government budget; bridging immediate social needs and the requirements for long-term economic growth and development through STI; helping government departments to set aside adequate STI funding to develop the priority sectors for which they are responsible; identifying opportunities for increased private-sector investment, including where public-sector investment can leverage private-sector investment; improved allocation of funding to sustain the NSI base, for example, for human resource development, research, infrastructure, technology transfer, incentive and reward initiatives, and to ensure the financial sustainability of STI institutions; and harmonisation of funding from different sources, for example, funding by the DHET for higher education institutions and by the DST for science councils.

The DST, working with NACI, will develop a public STI investment framework. NACI's role will be to undertake foresight studies and provide an independent STI M&E function (including regular analysis of the public STI spending). The framework will be based on analysis of STI funding requirements in line with strategic and sovereign priorities, as well as consultations across government through an interdepartmental STI budget committee at the level of director-general, including relevant national departments (departments with significant STI mandates) and provincial governments.

The STI investment framework will guide funding allocations by the National Treasury. To achieve this, government will institutionalise an appropriate structure as part of its Medium-Term Expenditure Committee processes to enable the interdepartmental STI budget committee to interface with the Ministers' Committee on the Budget. The DST, through the Budget Coordination Process, will assist the National Treasury with advice on funding needs for STI priorities and related programmes identified by the STI investment framework. Each department will, however, remain responsible for overseeing the transfers to their public entities, and monitoring and reporting on key deliverables.

6.5 Policy intent: Improve funding efficiencies

Although the case for increased funding is clear, it will also be necessary to optimise existing funding through improved coordination (across government, as well as between the public and private sectors) and to reduce duplication of effort and improve synergies. Furthermore, to ensure optimum results from investments, the efficiency of the public NSI institutions, to which most of this funding is deployed, needs to be enhanced, where necessary.

The South African funding regime currently consists of many different institutions with varying mandates and levels of funding, creating a landscape that is difficult for any innovator or institution to navigate. To simplify the application processes and reduce duplication, the mandates and funding instruments of the following institutions, among others, will be harmonised: the Technology Innovation Agency, the National Intellectual Property Management Office, relevant sections of the Small Enterprise Development Agency, the Technology and Human Resources for Industry Programme, the Support Programme for Industrial Innovation, elements of the Industrial Development Corporation, and parts of the NRF. The intention is to ensure a seamless transition between functions and instruments.

The administrative capabilities of the relevant institutions will improve efficiency through, for example, simplified application processes, uniform application forms, "one-stop shop" approaches (including an information/application portal) for addressing questions/assisting applicants, standardised approaches to evaluation and more information sharing, especially among SMEs.

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