Biotechnolgy in Sub-Saharan Africa: An Introduction

The role of modern biotechnology in the economic transformation of developing countries has become the subject of intense academic inquiry and public policy discourse. There is increasing debate about the potential contributions that the technology can make to these countries. Today this debate has stayed at two extremes: one that perceives biotechnology as the source of solutions to many of the economic, social and environmental problems that developing countries are confronted with, and the other extreme that treats the technology with considerable suspicion—as a technology that will bring more ills to the countries. While those in the former position espouse the development and application of biotechnology, the latter group calls for its demise. It is in the context of these two extremes that Africa has to find its own place in the biotechnology revolution.

It is not our task here to argue for or against either of the two positions—which we find simplistic and misinformed of the nature of biotechnology. We shall be concerned with strategic policies and institutional arrangements that would enlarge Africa's prospects of maximizing benefits from biotechnology while at the same time minimizing its risks. Biotechnology has no inbuilt logic to cause harm to or to generate benefits for humanity. It is a social construct whose development and application largely rely on human beings. Indeed, what is crucial is to establish systemic and long-term measures that will enable society to reap benefits from the technology and to address any negative impacts it may cause.

The overall objective of the paper is twofold: to identify and analyse public policy issues that confront African countries in their aspirations or efforts to effectively enter the biotechnology revolution, and to propose a regional programme that would generate new knowledge and information for the formulation and implementation of policies to promote the safe development and application of modern biotechnology. The paper also discusses ways and means of building and/or strengthening capacities of African countries to engage in the international policy debate on biotechnology and its impacts.

The first section of the paper focuses on international trends in biotechnology. It maps out the technology landscape and describes the different actors in the evolution and rapid development of modern techniques. This section also analyses the different strategies and policies that countries of the industrialized world have instituted to engage in biotechnology competitively. Lessons for developing countries, particularly those of Africa, are drawn.

The second section is an overview of the status of biotechnology in Africa. This section describes current research and development (R&D) efforts of some African countries and identifies their strengths, constraints and national policies to promote the technology's development and application.

The third section focuses on public policy issues for safe development and application of biotechnology in Africa. It identifies the range or clusters of policy questions researchers and policymakers need to explore in their research programmes and in the making of policies.

The last section proposes a regional policy research programme on biotechnology. It identifies specific issues or questions, activities, and benchmarks that should form the core of the programme. In addition, the paper erects a conceptual framework and methodology for the proposed activities. Emphasis is placed on those activities that would enlarge the knowledge and information base for public policy making in Africa.

1. Global Trends in Modern Biotechnology

1.1 Evolution and Growth of Modern Biotechnology

Modern biotechnology[1] has its antecedents in scientific endeavours of the late 1960s and early 1970s, with discoveries in such areas as molecular biology, biochemistry and microbiology forming the foundation for the technology's rapid growth into a global industry. Genetic engineering revitalized the application of the scientific knowledge generated in university departments in the USA, Japan and Europe in the 1970s. It has revolutionized the way humanity perceives of and uses living matter. Research and development in the area of genetic engineering are now a source of new products that are improving agricultural production, human and animal health, the environment, and industry in general. In sum, according to the U.S. Office of Technology Assessment (OTA, 1992:3):

> Biotechnology provides potential to produce new, improved, safer, and less expensive products and processes. Pharmaceuticals and diagnostics for humans and animals, seeds, entire plants, animals, fertilizers, food additives, industrial enzymes, and oil-eating and other pollution degrading microbes are just a few of the things than can be created or enhanced through the use of biotechnology.

The development and application of modern biotechnology, and particularly the cluster of techniques associated with genetic engineering, are also posing new challenges to humanity. The challenges are around ethical concerns emerging from the use of the technology to manipulate and transform nature. There are also growing concerns about possible human health, environmental and socioeconomic risks that modern biotechnology may cause. For example, concern has been raised about the potential ecological impacts of releasing genetically modified organisms into the environment. There is fear that such organisms would erode genetic diversity and thus undermine socio-economic and cultural security of many households in the developing world.

The technology and its development are characterized by *uncertainty*. There is uncertainty about the potential of biotechnology—its promises and risks. There is also uncertainty surrounding industrial investment in genetic engineering. This is largely a result of the build up of activist campaigns against the development and commercialization of genetically modified products.

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[1]Modern biotechnology is a cluster of techniques that are used to modify and/or use living organism to produce goods and services. It encompasses such scince - intensive techniques as recombinant DNA and gene splicing and sequencing.

Another important feature of modern biotechnology is its *pervasiveness*—in terms of the wide application of its techniques as well as the potential effects it has on national and global economic systems. Indeed, the impacts of biotechnology on socioeconomic systems are widespread. Given this pervasiveness a large number of diverse actors—policy makers, environmental activists, financial institutions, industry and religious groups—are involved in deciding on the future technological change and developments in biotechnology. What is clear is that it is public perception of the benefits and dangers associated with the technology that will greatly influenced the choices policymakers and industry will make.

Three mainstream technological trajectories or aggregate technological pathways have emerged in biotechnology (Sharp, 1989). These are pharmaceuticals, agriculture and diagnostics. There are, of course, other trajectories such as mineral leaching and pollution control, but these constitute fairly small or limited areas of technological and industrial activity.

The pharmaceutical sector is the leading and most economically prominent trajectory, though agricultural biotechnology has also witnessed rapid industrial growth in the past five years or so. Pharmaceutical sector growth was pronounced in the mid 1980s and was stimulated by the new technological opportunities to reduce the costs that are associated with traditional chemical drug production. The use of chemical entities to produce drugs was yielding few new drugs and was proving too costly. With biotechnology the pharmaceutical industry has acquired capacity to relocate from the use of chemical entities to natural products—particularly plants and microorganisms.

There are other factors that account for the growth of biotechnology-based innovations in the pharmaceutical sector. First is the enormous scientific information and knowledge base created by universities and public research bodies in the USA. A considerable portion of USA government funding to biotechnology has targeted biomedical research in universities and such public bodies as the National Institutes of Health. By 1991 more than US$2.5 billion was available to public biomedical research (Avramovic, 1996). Second, in contrast to agriculture there has been less controversy on the application of biotechnology to develop drugs. There is enormous and growing demand for high value drugs to treat such fatal diseases as acquired immune deficiency syndrome (AIDS) and cancer. Third, the pharmaceutical sector has also benefited from the existence of companies with enormous financial and industrial capability to exploit the scientific information generated by universities.

Agriculture—one of the world's largest economic sectors—is being rapidly transformed by biotechnology. The discovery of gene splicing in the early 1980s opened up enormous scientific and industrial opportunities. In 1995 genes that control the ripening process in tomatoes were identified and the genetic basis for enlarging plants' resistance to weedkillers was discovered. Cloning of plant genes has become another area of major interest of big agro-chemical companies, all of which have bought up seed companies with a view of developing varieties with immunity to their own brands of herbicides. Between 1996 and 1998 Monsanto, a leading science-based biotechnology company, generated several genetically improved crops: Newleaf insect-protected potatoes, Roundup Ready soybeans, Roundup Ready cotton, insect protected corn, Roundup Ready corn, Roundup Ready sugar beets and delayed ripening tomatoes. Monsanto's annual net sales of agro-products are at least US$4 billion.

On the whole, the commercial potential of agricultural biotechnology is growing rapidly. In 1995 about US$312 million was generated by agro-biotechnology companies from the development and sale of products and processes. By early 1999 the companies were making net sales of at least US$2.5 billion. This considerable growth in market sales of agricultural biotechnology products and processes is accounted for by the following factors among others. First, the scientific information base for the development and application of agricultural products and services has been enlarged enormously in the past five years. Science in such areas as recombinant DNA has grown. Knowledge about genetic structures and functions of plants and livestock is growing rapidly, making it possible to exploit a wide range of undiscovered and underutilized traits in plants and animals.

The growth of agricultural biotechnology has been affected by a variety of factors however. There is greater *environmental concern and regulatory uncertainty*. The introduction of genetically engineered agro-products has met growing public opposition. In the absence of sufficient knowledge base to predict adequately the environmental and human health impacts of these products, regulatory uncertainty and public opposition have intensified.

> There are uncertainties surrounding each of the risk factors, rendering it impossible to state precisely how small the risk is. Furthermore, the uncertainties will become larger as the kind and number of introduced genes grow, and as more organisms are altered and released into a wider range of environments. The reasons for these uncertainties are, first, that there is very little in the way of a historical or scientific database of the behavioral characteristics of genetically engineered organisms introduced into the environment; and second, that there is no standard ecological methodology for predicting the outcome of such introductions (Avramovic, 1996:21).

Another factor determining growth of agricultural biotechnology is *public attitude* toward genetically engineered foods. There exists reluctance on the part of consumers—mainly in Europe and the developing world—to eat genetically engineered foods. Led by such environmental lobbies as Greenpeace, consumers are concerned about possible health risks. This is affecting net sales of agro-biotechnology products generally and is a disincentive to corporate investment in agricultural biotechnology R&D.

The third area of intense and growing biotechnology activity is diagnostics. The development of monoclonal antibodies constitutes a separate technological trajectory. Monoclonal antibodies are derived by fusing an antibody with a myeloma (or cancer) cell to combine the growth characteristics of the cell with the specificity of the antibody. The production of diagnostic kits based on monoclonal antibodies is a fast growing industry because of the substantially lower capital costs involved. It also demands less science-intensive skills than the development of a therapeutic drug through genetic engineering. Thus barriers to entry are lower. Many advanced developing countries (including such African countries as Egypt, Nigeria, Kenya, South Africa, Zimbabwe and Ghana) have the capacity to enter and exploit the technological trajectory.

1.2 Innovation Activities Across Countries: An Overview

National competitiveness in biotechnology is largely defined as the ability of a country (its private firms and public agencies) to research, develop and trade in new biotechnology goods and services. It is gauged by assessing such factors as geographical distribution of biotechnology firms and their investment, availability and quality of personnel deployed, nature and volume of biotechnology products exported and net income, and patent intensity. However, there is no authoritative comparative analysis of different countries' competitiveness in the technology. This notwithstanding, the USA is the leader in biotechnology R&D and its commercialization. Indeed, nowhere in the world are there major deliberate efforts to commercialize biotechnology stronger than in the USA. The USA has the largest number of companies engaged in the development and commercialization of biotechnology, ranging from pharmaceuticals to petrochemicals. It has more than 50 public universities actively engaged in the generation of scientific information and knowledge in biotechnology and more than 200 big and small biotechnology companies.

The USA has organized its biotechnology R&D system in such a way as to mobilize and enlarge its commercial capabilities and to shape the character of its competitiveness at the international level. On the public R&D front deliberate policy measures were introduced in the late 1980s and early 1990s to stimulate and/or enrich the active involvement of universities in biotechnology. Significant federal funding was allocated to basic research (mainly biomedical) in the universities. Such public research bodies as the National Institutes of Health (NIH), the National Science Foundation (NSF) and the US Department of Agriculture (USDA) have also allocated considerable funding to basic research. In 1987 the US government spent US$2700 billion supporting biotechnology research, whereas combined Western Europe and Japan official support for such research was not more than US$1.5 billion. By the mid 1990s US government support averaged US$3 billion per year (Avramovic, 1996). The UK and Germany have tended to provide more support to applied research.

The US Federal Technology Transfer Act of 1986 (Public Law 99-502) was established to promote the transfer of public-developed technology in general and biotechnology in particular into the private sector. The law forms the basis for the Cooperative Research Development Agreement (CRADA) under which university and federal laboratories and private sector companies conduct joint research and the collaborating company acquires patent rights at the outset of the collaboration while the university and/or government inventors share royalties from the licensing of inventions (OTA, 1992).

In the USA, Europe and Japan private companies play a major role in the development and application of modern biotechnology. In general, three categories of private companies have been responsible for the rapid growth of the technology. First are those companies that had already accumulated substantial capabilities in second-generation biotechnology, e.g., in fermentation and products like antibiotics, vaccines and enzymes. The second category is those companies that were specifically created to engage in modern biotechnology and had to build capabilities in such areas as genetic engineering. The last category comprises companies that had no prior engagement in biotechnology but perceived the potential of the technology and were willing to invest in its development, sometimes with the aim of diversifying their products. What is common to all of them is that each had direct association with university R&D. The companies that were established to deliberately engage in the technology were in fact born out of university departments by university professors. The other categories relied on universities as sources of scientific knowledge and information. For example, the traditional non-biotechnology companies contracted universities to develop and provide to them basic scientific information and principles in genetic engineering.

US competitiveness has been based on the emergence and rapid growth of the second category of companies—the new small companies dedicated to commercial exploitation of modern biotechnology. Indeed, "[t]he proliferation of small firms exclusively dedicated to commercializing biotechnology is basically and overwhelmingly a USA phenomenon" (Avramovic, 1996:50) Fairly recent assessment and analysis by Ernst & Young demonstrate the USA's intensifying hegemony in modern biotechnology. In 1997 Europe had 1,036 biotechnology companies investing US$2.2 billion in R&D, employing more than 39,000 people and generating $3.1 billion in revenue while US companies invested US$9.4 billion in R&D, employed 140,000 people and posted total revenues of US$18 billion.

In Western Europe the mid 1980s saw the emergence of biotechnology programmes to foster national competitiveness in the development and application of the technology. These programmes were established and managed in national public agencies responsible for research in agriculture, environment, mining and human health. Cross-sectoral committees were formed to ensure that there was coherence and synergy in national biotechnology activities. Austria, Denmark and Italy were among the first countries to form national biotechnology coordinating committees (OECD, 1998). Germany developed the first organized government strategy for biotechnology R&D. Its institutional arrangement consisted of a variety of leading science bodies such as the Max Planck institutes and Frauenhofer institutes. The institutions have dedicated biotechnology research programmes, and some have accumulated considerable technological capabilities in the area. They are major sources of scientific knowledge in various aspects of biotechnology.

Switzerland has an impressive record of national engagement in the development and commercialization of biotechnology. It has a strong private sector biotechnology R&D with concentration in pharmaceuticals. Most of the funding for biotechnology comes from private companies. By 1998 private financing of biotechnology R&D constituted at least 65% of the total with a large portion of this going to such areas as recombinant Deoxyribonucleic Acid (rDNA) and exploitation of monoclonal antibody technology to develop diagnostic kits.

Unlike in the USA where small dedicated companies have been at the forefront of biotechnology research and commercialization, in Japan it is such big and established companies such as Mitsubishi Chemical and Takeda Pharmaceutical. Japanese private investment has largely focused on pharmaceuticals with increasing rDNA related R&D. One of the key features of Japan's policy regime is the fairly restrictive guidelines for rDNA research. The process of obtaining approvals for the research is strictly regulated.

In most other countries of Asia biotechnology R&D is largely conducted by public sector bodies though there is increasing involvement of local and foreign private companies. In countries such as Taiwan and Korea overall government spending on R&D forms a relatively high percentage of gross national product. These countries have targeted pharmaceuticals and agriculture (Acharya and Mugabe, 1996). China has focused its biotechnology efforts on the development of two-line hybrid rice, transgenic cotton and recombinant drugs for a number of critical diseases. A target-directed non-viral vector system, which can transfer exogenous genes into tumor cells in vivo to efficiently and significantly inhibit the growth of the tumor has been developed, achieving a major breakthrough in the area of gene therapy. Most of this R&D is in the public sector with heavy government involvement.

The State Science and Technology Commission (SSTC) of China is responsible for the country's planning and policy for biotechnology R&D in the country. There are four programmes under the SSTC: the 863 Programme, Key Technologies Research and Development Programme, and the Torch and Spark programmes. The 863 Programme was launched in March 1986 with the objective of enhancing China's international competitiveness and capabilities in science and technology general and biotechnology in particular. The 863 Programme has focused on genetic engineering for animals and plants for high yields/improving quality, development of vaccines, gene therapies, protein engineering for food industries, and agriculture.

In addition to the national activities by private and public sector agencies, international public research bodies are playing a major and growing role in biotechnology R&D. Some are conduits for the transfer of scientific knowledge and information about biotechnology. The United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP), and the United Nations Industrial Development Organization (UNIDO) made significant contributions in facilitating the transfer of knowledge and information on biotechnology. They facilitated international cooperation and development in biotechnology. For example, UNESCO and UNEP established the international network of microbiological resources centres (MICRENS) that were instrumental in training Third World scientists in microbial aspects associated with biotechnology.

In the 1980s UNIDO spearheaded the creation of the International Center for Genetic Engineering and Biotechnology (ICGEB) with headquarters in Trieste, Italy. The ICGEB is engaged in building national capacity in industrial, agricultural, pharmaceutical, animal and human health biotechnology. The ICGEB has now more than 30 affiliated centres around the world some of which have emerged into centres of excellence[2].

The Consultative Group on International Agricultural Research (CGIAR) has a number of centers that are engaged in agricultural biotechnology R&D. The International Centre for Tropical Agriculture (CIAT) in Colombia, the International Maize and Wheat Improvement Centre (CIMMYT) based in Mexico, the International Potato Center (CIP) in Peru, and the International Livestock Research Institute (ILRI) based in Kenya are among the leading international public biotechnology R&D institutes.

[2] See below description of centres of excellence affiliated to ICGEB.

2. Biotechnology in Sub-Saharan Africa: A Status Overview

2.1 Research and development (R&D) Initiatives

The past two decades have witnessed increased investment in biotechnology research and development (R&D) by a number of African countries. Public research institutions and a few private companies in the region have established projects or programmes on biotechnology R&D. The nature of activities and levels of investment in the technology vary from one country to another and from one sector to another. These initiatives are also managed by a variety of institutional forms—from laboratories in established national agricultural research bodies and national biotechnology centres, to national biotechnology programmes managed in sectoral research agencies and international research bodies such as those of the Consultative Group on International Agricultural Research (CGIAR).

African countries' entry into biotechnology has been stimulated by many interrelated factors. First is the cumulative nature of the technological change in biotechnology. While there have been radical innovations in the technology based on prior scientific knowledge and the associated research, institutional arrangements have removed knowledge related barriers to entry. In agriculture, for example, some African countries (Kenya, South Africa, Nigeria, Egypt and Zimbabwe are some examples) have a long tradition of scientific research conducted in mature institutions. Their knowledge base and accumulated expertise have made it possible for them to leap into the second generation of biotechnology.

There are generally three categories of countries in biotechnology: (a) those that are generating and commercializing biotechnology products and services using third-generation techniques of genetic engineering; (b) those that are engaged in third-generation biotechnology R&D but have not developed products and/or processes yet; and (c) those that are engaged in second-generation biotechnology (mainly tissue culture). In the first category are Egypt, Zimbabwe and South Africa, while Kenya, Uganda and Ghana are examples of the second. Tanzania and Zambia are in the third category. Most of the biotechnology activities have focused on enhancing agricultural productivity.

South Africa and Egypt are biotechnology leaders in the region. With considerable scientific infrastructure and clear programmes on biotechnology, the two countries have focused on cutting-edge biotechnology areas and have commercialized some of their products. South Africa's biotechnology R&D focus is on genetic engineering of cereals (maize, wheat, barley, sorghum, millet, soybean) lupins, sunflowers, sugarcane, vegetables and ornamentals, as well as on molecular marker applications. These include diagnostics for pathogen detection; cultivar identification for potatoes, sweet potato, ornamentals, cereals, cassava; purity testing of cereals seedlots; marker assisted selection in maize and tomato; and markers for disease resistance in wheat. Egypt has invested considerably in genetic engineering of potatoes, maize and tomatoes. Field tests and commercialisation of genetically modified potatoes are under way in the country.

Biotechnology R&D are largely undertaken by departments at universities and national agricultural research bodies. Some of the universities have established units or programmes that are now dedicated to biotechnology R&D. The University of Cape Town, South Africa, has a number of internationally cutting-edge research activities in biotechnology conducted within its Department of Biochemistry, which qualifies as a centre of excellence in biotechnology R&D. Having started biotechnology R&D activities in the early 1980s, the Department has extensive experience in such areas as thermodynamic and spectroscopic investigation of protein folding, and protein Deoxyribonucleic acid (DNA)/(Ribonucleic acid) RNA interactions, regulation of gene expression during the sea urchin embryogenesis, cloning of vertebrate gonadotropin-releasing hormone receptors, and isolation of genes responsible for certain nutritional characteristics of crop plants with a view of producing transgenic plants. Its teaching and training activities are at doctoral and MSc levels. By 1995 the Department had generated two specialized doctoral degrees in biotechnology and at least eight MSc degrees. The 27-member scientific staff had by 1999 published its biotechnology research in several international and local journals. It has links with private sector (e.g., Monsanto) and other public research bodies in the country and engaged in several contract research activities for local crop companies.

In collaboration with the Agricultural Research Council (ARC), the University of Cape Town Department of Microbiology in 1997 developed and released for field-testing the first transgenic potato in the country. The potato has been engineered with CP genes that confirm resistance to potato virus Y and leafroll virus. In addition, the Department's research efforts have generated tobacco that is resistant to cucumber mosaic and tobacco necrosis viruses, via expression of both CP and CP gene antisense Ribonucleic acid (RNA). It also developed maize streak virus (MSV) as a high yield vector for maize cell culture systems and is now engaged in research to develop MSV-resistant maize.

Zimbabwe has made significant efforts to define target areas of biotechnology. The Department of Crop Sciences at the University of Zimbabwe has been applying tissue culture to develop disease-free varieties of coffee, potatoes and tomatoes. Elite coffee bushes have been cloned using the leaf disc technique of Staritsky. The Tobacco Research Institute in Zimbabwe has over the last decade used pollen culture to incorporate resistance to two troublesome diseases in a new variety of tobacco. Research is under way to introduce resistance to other diseases in tobacco using somaclonal variation. It is notable that tobacco has been a model plant for biotechnology research and Zimbabwean scientists have had access to the latest techniques. This is also the most important export crop for the country and therefore it has received special research attention.

The Biotechnology Research Institute (BRI) of the Scientific and Industrial Research and Development Centre (SIRDC) was established by the Government of Zimbabwe in 1992 with funding from the Government of Zimbabwe and the Royal Government of the Netherlands. Its mandate is to consolidate and coordinate as well as provide scientific leadership to Zimbabwe's biotechnology R&D activities. It had built a considerable scientific infrastructure and expertise in tissue culture and genetic engineering.

In Kenya, most of the agricultural biotechnology R&D activities focus on improving the yield potential of cereals and some export crops such as coffee and pyrethrum. Institutions engaged in agricultural biotechnology R&D in Kenya include the Kenya Agricultural Research Institute (KARI), the Department of Biochemistry of the University of Nairobi, the National Potato Research Centre (NPRC), and the Jomo Kenyatta University of Agriculture and Technology (JKUAT). Research at the Biochemistry Department of the University of Nairobi focuses on genetically modified organisms (GMOs) such as capripox virus and rinderpest recombinant vaccine production, and production of transgenic sweet-potato which are at the moment in field testing.

Africa hosts several international research bodies active in biotechnology. A good example is the International Livestock Research Institute (ILRI) based in Nairobi, Kenya. ILRI is one of the centres of the Consultative Group for International Agricultural Research (CGIAR). Its remit is to conduct research on tropical diseases of livestock and to develop techniques for the management of such diseases. ILRI has exploited biotechnology techniques to obtain antigens that can be used in specific and sensitive diagnostic tests for tick-borne diseases of livestock. Compared with conventional techniques, these new generation tests are cheaper, easier to use and better suited to national programmes of tropical countries.

With more than 65 scientists, ILRI is the world's leading institute in tropical livestock diseases research. Its Biosciences Research Programme has accumulated a critical mass of scientific expertise in animal genetics, and its activities are at the cutting-edge of science. The programme's research in quantitative and molecular genetics has focused on the identification of markers to help identify and exploit desirable genetic traits. In 1996 ILRI released a recombinant vaccine (designated p67) against East Coast fever (theileriosis) for field trials. The vaccine is based on a protein found on the surface of the organism that causes East Coast fever (ECF) and stimulates an antibody-based immune response to the parasite as it invades the host. Research is now going on to develop the second-generation vaccines that target a later stage of the parasite, once it has invaded the host's white blood cells and stimulates a response from cytotoxic T cells.

In the area of diagnostics, ILRI is applying molecular biology technology to identify unique proteins for four parasites: *Babesia bigemina, Theilleria parva, Theileria mutans* and *Anaplasma marginale*. These proteins have been used to develop improved ELISA (enzyme-linked immunosorbent assay) tests specific to each parasite and thus improve the sensitivity and specificity of diagnosis of diseases caused by these parasites.

On the whole, African countries are at different stages in the development of biotechnology. Some have moved up the technology ladder and are applying more sophisticated techniques such as molecular markers, but others are still in the tissue culture level of application. For example, Egypt and South Africa have moved rapidly into such areas as gene sequencing, characterization of pathogens and gene promoters, while Tanzania and others are still at rudimentary levels of biotechnology development and application. Table 1 summarises selected biotechnology research in Africa

Table 1: Agricultural biotechnology in Africa: Some selected cases

Country	Area of research
Egypt	Genetic engineering of potatoes, maize and tomatoes
Morocco	Micropropagation of forest trees, date palms
	Development of disease-free and stress tolerant plants
	Molecular biology of date palms and cereals
	Molecular markers
	Field-tests for transgenic tomato
Cameroon	Plant tissue culture of *Theobroma cacao* (cocoa tree), *Hevea brasiliensis* (rubber tree), *Coffea arabica* (coffee tree), *Dioscorea* spp (yam) and *Xanthosoma mafaffa* (cocoyam)
	In vitro culture for propagation of banana, oil palm, pineapple, cotton and tea
Cote d'Ivoire	In vitro production of coconut palm (*Cocos nucifera*) and yam
	Virus-free micropropagation of eggplant (*Solanum* spp)
	Production of rhizobial-based biofertilizers
Ghana	Micropropagation of cassava, banana/plantain, yam, pineapple and cocoa
	Polymerase chain reaction (PCR) facility for virus diagnostics
Nigeria	Micropropagation of cassava, yam and banana, ginger
	Embryo rescue for yam
	Transformation and regeneration of cowpea, yam, cassava and banana
	Genetic engineering of cowpea for virus and insect resistance
	Marker assisted selection of maize and cassava
	DNA fingerprinting of cassava, yams, banana, pests and microbial pathogens
	Genome linkage maps for cowpeas, cassava, yams and banana

Senegal Well established MIRCEN programme
Production of rhizobial and mycorhizal-based biofertilizers for rural markets
Well established in vitro propagation of tree species in cooperation with several international agencies

Ethiopia Tissue culture research applied to tef
Micropropagation of forest trees

Kenya Production of disease free plants and micropropagation of pyrethrum, bananas, potatoes, strawberries, sweet potato, citrus, sugar cane
Micropropagation of ornamentals (carnation, alstromeria, gerbera, anthurium, leopard orchids) and forest trees
In vitro selection for salt tolerance in finger millet
Transformation of tobacco, tomato and beans
Transformation of sweet potato with proteinase inhibitor gene
Transformation of sweet potato with feathery mottle virus coat protein gene
Tissue culture regeneration of papaya
In vitro long-term storage of potato and sweet potato
Marker assisted selection in maize for drought tolerance and insect resistance
Well-established MIRCEN providing microbial biofertilizers in the East African region

Uganda Micropropagation of banana, coffee, cassava, citrus, granadella, pineapple, sweet potato
In vitro screening for disease resistance in banana
Production of disease free plants of potato, sweet potato and banana

South Africa Genetic engineering of cereals: maize, wheat, barley, sorghum, millet, soybean, lupins, sunflowers, sugarcane; vegetables and ornamentals: potato, tomato, cucurbits, ornamental bulbs, cassava and sweet potato; fruits: apricot, strawberry, peach, apple, table grapes, banana
Molecular marker applications of: diagnostic for pathogen detection; cultivar identification—potatoes, sweet potato, ornamentals, cereals, cassava; seed-lot purity testing—cereals; marker assisted selection in maize, tomato; markers for disease resistance in wheat, forestry crops
Tissue culture for: production of disease free plants—potato, sweet potato, cassava, dry beans, banana, ornamental bulbs; micropropagation of potato, ornamental bulbs, rose rootstocks, chrysanthemum, strawberry, apple rootstocks, endangered species, coffee, banana, avocado, blueberry, date palm; embryo rescue of table grapes, sunflower and dry beans; in vitro selection for disease resistance—tomato nematodes, guava wilting disease; long term storage—potato, sweet potato, cassava, ornamental bulbs; in vitro gene bank collections—potato, sweet potato, cassava, ornamentals; forest trees, medicinal plants, indigenous ornamental plants

Zimbawe	Genetic engineering of maize, sorghum and tobacco Micropropagation of potato, cassava, tobacco, sweet potato, ornamental plants, coffee Marker assisted selection
Zambia	Micropropagation of cassava, potato, trees (*Uapaca*), banana Hosts SADC Nordic-funded gene bank of plant genetic resources

Source: Brink, Woodward and DaSiva, 1998 in Juma, 1999b.

2.2 Constraints to Biotechnology R&D in Africa

Governments have a fundamental role to play in the promotion of biotechnology, its safe development and its application. The role of government is crucial, particularly in Africa where national economies are weak and the private sector's abilities to promote technological innovation are constrained by the fragmented nature of markets. As we have already observed many African countries face problems of scarce resources for allocation to technological activities in general and biotechnology R&D in particular. This makes it crucial to institute strategic policies for mobilizing financial resources and enlarging private engagement in biotechnology R&D.

Some African countries (e.g., Egypt, South Africa and Zimbabwe) have set national goals and priorities in the area of biotechnology. In many other countries of the region, however, there are no explicit biotechnology policies and defined priorities. In addition, little effort has been made to integrate biotechnology considerations into overall national development policy and planning. Implicit policy regimes such as science and technology policies make only general reference to the role of biotechnology and national aspirations to engage in the development and application of the technology. Nevertheless, some countries (e.g., Kenya and South Africa) have industrial property laws that make reference to the protection of biotechnology innovations through patents.

The role of biotechnology and its management are also being referred to in biosafety regulations being developed by some African countries. In Zambia and Cameroon the establishment of such regimes has preceded national engagement in modern biotechnology, while in South Africa, Zimbabwe, Egypt and Kenya the regimes are largely associated with efforts to develop and apply the technology. Kenya's biosafety guidelines are founded on its desire "to benefit from the development and use of modern biotechnology given that none of the existing regulations and acts are geared towards addressing specifically biosafety in the development and use of biotechnology products"(NCST, 1998). The proposed framework describes national biotechnology R&D efforts and states that risk assessment and management regimes should promote these efforts in ways that ensure they generate products and processes that are safe for the environment and human health.

Mauritius's biosafety framework focuses on measures for the safe development and introduction of genetically modified organisms. The country has already applied modern biotechnology to generate a herbicide resistant traits in sugarcane. The framework articulates the country's aspiration to extend the application of the technology to other sectors like aquaculture and recommends practices and procedures for the safe use of modern biotechnology.

There are a number of policy challenges that hinder the development and application of biotechnology in many countries of Africa. First is the *lack of clear priorities* and investment strategies. As we have stated above, most African countries have not identified specific areas or technological trajectories in which to invest to meet specific goals. Biotechnology policies need to be based on or informed by clearly articulated national priorities and goals. In the absence of identified priorities it is difficult for these countries to make informed and long-term policies. Perhaps it is because of this lack of identified priorities that in some countries (e.g., Tanzania) biotechnology R&D is now spreading across the institutional terrain with increasing duplication and strain on resources (Kasonta, 1999). Indeed, many African countries tend to spread thinly their limited financial and human resources across biotechnology sectors and research agencies. While many countries have recognized the importance of setting biotechnology priorities and consolidating resources in a few research institutions that have the potential to grow quickly into centres of excellence in biotechnology, the countries have not established and applied strategies for identifying such institutions and ways of setting priorities. They continue to operate with isolated, competing and often scientifically weak research agencies. As we have observed elsewhere, the countries have stand-alone institutions "established in anticipation of funding rather than out of genuine interest in promoting the use and conservation of biodiversity—[and] are unlikely to yield long-term benefits unless they are part of a broader institutional and policy framework" (Juma et al., 1994)

The second set of policy issues pertains to the *short-term and low level financing of biotechnology R&D* in many African countries. While authoritative or reliable estimates are unavailable, in most countries of Africa government funding to biotechnology is less than US$250,000 per year, the exceptions being Egypt, Mauritius and South Africa. Nor have most countries instituted specific policies to ensure adequate and consistent funding of biotechnology R&D. The main challenge for public biotechnology R&D in Africa is increasingly how to find investment capital to sustain basic research and to bring laboratory findings to commercial use. Government policies to stimulate venture capital, contract research, partnerships with the corporate sector and other forms of financing are much needed. Research is also needed to identify specific policies on financial mechanisms for biotechnology R&D.

The third category of policy issues relates to the *role of intellectual property protection* and its impact on the acquisition, development and diffusion of biotechnology. In most African countries institutions for administering industrial property rights (particularly patents) are still in their infancy. While a good number of the countries have established patent offices, the utility of these as sources of scientific and technological information has not been adequately exploited. In many countries of the region intellectual property laws are in a state of flux with increasing demand from the international community, particularly the World Trade Organization (WTO) to revise them to meet requirements of the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS). There are increasing concerns, particularly from environmental and health groups, that harmonization of national laws with the TRIPS agreement will undermine prospects of achieving environmental sustainability and human health security in Africa. There is also a growing debate on the impact of intellectual property protection on the transfer of modern biotechnology to African countries. Concern on this issue is largely based on the view that intellectual property protection is a barrier to transfer of technology. There is, however, no empirical evidence of this.

In addition to the foregoing policy considerations, the development and growth of biotechnology in Africa face a number of structural constraints. First, current institutional arrangements are inimical to effective biotechnology R&D. In many countries (with the exception of South Africa, Egypt and Zimbabwe) biotechnology R&D is merely an add-on to other broad national research agendas. There are no specific and institutionally organized biotechnology programmes and many of the R&D initiatives are efforts of a few isolated scientists. There are no dedicated biotechnology research departments or institutions in most of Africa. In addition, most of the current biotechnology R&D is donor funded and coordinated and managed in the public sector with very few, and weak, links with the private sector. Second, in many of the countries scientific and technological infrastructure for sustained biotechnology R&D may be lacking and where it exists it is locked in isolated agricultural research bodies working on a few crops. Much of the current research in agricultural biotechnology, for example, is being undertaken in older established agricultural research institutions. The obvious advantage of this is that institutional memory and history can provide major benefits to the research infrastructure in the country as a whole. This places even greater pressure on these institutions, however and their ability to provide adequate attention to the new technology becomes crucial. It is not clear from this evidence that sufficient skills and funding are available for these older institutions in African countries.

Although there has been significant growth in the level of funding to agricultural biotechnology R&D in most countries, the available financial resources are still comparatively low to allow the countries to engage effectively in cutting-edge activities. An assessment by Falconi (1999) showed that Indonesia's total expenditure for 1985–1996 was just US$18.7 million. Mexico's expenditure was $20.4 million and Kenya spent just about $3.0 million. Overall, Falconi's 1999 assessment showed that private expenditures in agricultural biotechnology in developing countries constitute a mere 8% of the total. It is likely to be lower than 5% of the total investment in Africa.

In addition to the institutional financing constraints that many countries face, there is a shortage of scientists in new areas of biotechnology in general and agricultural biotechnology in particular. However, the pool of scientists in such areas as molecular biology is growing. For example, Falconi's survey showed that the number of researchers in agricultural biotechnology doubled in Indonesia and Kenya between 1985 and 1996. It quadrupled in Mexico and Zimbabwe, with at least a fivehold increase in PhD holders. However, the level of expenditure per researcher or scientist declined in most countries.

In addition to the institutional constraints that many countries face, there is a shortage of scientists in new areas of biotechnology in general and agricultural biotechnology in particular. However, the pool of scientists in such areas as molecular biology is growing. For example, Falconi's survey showed that in the number of researchers in agricultural biotechnology doubled in Kenya between 1985 and 1996. It quadrupled in Zimbabwe, with at least 5-time increase in PhD holders. However, the level of expenditure per researcher or scientist declined in most countries.

3. Public Policy Issues for Africa

Increasing public interest in and attention to biotechnology have generated a variety of complex, interrelated policy issues that governments are now expected to address. These issues fall in three broad categories. The first category comprises those policy issues associated with how to enlarge national competitiveness in biotechnology. In this category are such key policy concerns as the nature of national public institutions and how they are configured to achieve a system of innovation, the role of private firms in biotechnology research and development, and the different mechanisms of establishing and sustaining articulation within the firms and between the firms and public research bodies. Other concerns include the role of intellectual property protection in stimulating innovation in biotechnology, innovative financing of biotechnology R&D, and ways and means of facilitating the acquisition and/or transfer of biotechnology.

Private–public sector cooperation or partnership in R&D has over the past two decades become a prominent form of organizing and managing technological innovation mainly in developed countries. It is starting to take root in the newly industrialized countries (NICs) as well as in the economies in transition. The pressure of international competition, increased diffusion of information and communication, declining public financing of R&D, and the opening up of national economies—including liberal foreign direct investment and trade regimes—have facilitated the enlarging of private industry engagement in R&D. In the area of biotechnology, industry is perhaps the holder of the largest volume of technological information and knowledge. It is thus crucial that African countries tap into this pool in order to build their technological competence in biotechnology.

A significant portion of the body of scientific information on modern biotechnology is in the private domain, within large biotechnology firms and in small but dedicated biotechnology companies in the industrialized world. For public research institutions in Africa to access this information they will need to create strategic links to the private companies in the industrialized countries. Furthermore, commercialization of biotechnology is most effectively achieved through the participation of the private sector. The economic history of public R&D in many parts of the world demonstrates that public agencies have limited capacity to engage in the commercialization of new innovations. They often require private entrepreneurs to take their innovations into the economic domain (Kenney, 1986). As some of the public agencies in Africa start to generate new biotechnology products and processes they will require private entrepreneurs. Private biotechnology companies already have the basic technological and organizational abilities to assist them in commercializing products and/or processes.

Another good reason is that private biotechnology companies are potential new sources of financial resources for biotechnology R&D in Africa. The historical evolution of biotechnology in such countries as the United States, Germany and Japan vividly demonstrates the role of companies as sources of finance for biotechnology R&D. In Japan, biotechnology companies have financed biotechnology R&D through such arrangements as venture capital. In the USA they have provided finances to university departments and scientists to undertake specific research on contract basis. Countries of Africa may wish to explore and exploit financial opportunities associated with partnering with private companies.

The *second* category of policy issues is about the management of risks generated by the development and application of biotechnology. Such issues include technology assessment, liability and redress, regulation of trans-boundary transfer of living modified organisms, and socioeconomic impacts or consequences and how to assess and manage them. Risk assessment and management are now high on the agenda of national policy making with the adoption of the Cartagena Protocol on Biosafety. It is likely that many African countries will ratify the Cartagena Protocol. By doing so they will incur legal obligations to domesticate its provisions into their national policies, administrative measures and laws. The Protocol gives its parties leeway to use some of the existing domestic measures to ensure "an adequate level of protection in the…safe transfer, handling and use of living modified organisms resulting from modern biotechnology that may have adverse effects on the conservation and sustainable use of biological diversity …specifically focusing on transboundary movements"(UNEP, 2000). The Protocol also allows parties to establish new biosafety regimes, and certain parties may, on certain provisions, decide to do nothing so long as doing so does not impinge on the rights of other state parties to the Protocol.

Three key considerations that countries must not ignore in their efforts to implement the Cartagena Protocol on Biosafety are: (a) the need to emphasize the establishment of a long-term programme of work that treats biosafety as an integral part of biotechnology development, with emphasis on Article 19 of the Convention and Article 22 of the Protocol; (b) the use of the Biosafety Clearing-House (BCH) established by Article 20 of the Protocol as an international source of scientific information on biotechnology products, particularly those derived from genetic modification, rather than merely as a facility with information on risks associated with LMOs; and (c) the need to have a common regional approach to implementation of the Protocol in order to maximize information sharing and regional learning.

The *last* category comprises those issues pertaining to the biotechnology–biodiversity nexus. These include regulating or facilitating industry's access to genetic resources for biotechnology R&D, rights of farmers and the potential impacts of the technology on their traditional gene pool, and generally the impact of biodiversity prospecting on the conservation of ecosystems. Key challenges relate to the establishment of policies that will enable the region to regulate access to their genetic resources and share benefits in the form of biotechnology: Essentially, what kind(s) of policies and legislation would enable them to acquire biotechnology in exchange for genetic resources? African countries should carefully explore this issue as they develop regulations on access to genetic resources. They will need to institute policies and measures that will enable them to maximize benefits in the form of biotechnology capacity. But the search for the relevant and necessary policy regimes should be informed by international agreements such as the Convention on Biological Diversity, the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS), and the International Undertaking on Plant Genetic Resources.

As part of the ongoing review of the TRIPS agreement, African countries have raised a number of concerns that are directly related to their technological interests. These concerns include access to technology, regulation of access to genetic resources in accordance with the Convention on Biological Diversity, protection of plant varieties in a way that supports research and the interests of local communities, and the option of developing or unique systems for the protection of local biological resources and the associated traditional knowledge. What is clear is that the countries should adopt policies that explicitly link trade in their genetic resources to the enhancement of their technological competency in biotechnology. Training in biotechnology as well as participation of local scientists in biotechnology R&D conducted by firms that would have access to genetic resources are some of the benefits that the countries may derive from biodiversity prospecting activities.

While governments of Africa are expected to confront these and other sets of complex issues, their capacity to engage in policy analysis and policy making on biotechnology the issues is fairly limited. Thus the enhancement of these should be treated as a priority by national and international programmes. The nature of policies that would stimulate and enlarge biotechnology R&D in Africa is going to be a subject of study for several years to come. Technology policy groups and institutions in Africa have not really established coherent policy analysis programmes on these issues. Demand for policy analysis is growing, however, as many countries show interest in the technology.

4. A Research Agenda: Activities and Methodology

4.1 Programme Objectives

The complexity of issues raised above calls for an understanding of the relevant technical aspects and an adequate empirical foundation for policy-making and implementation. Thus that policy research on the issues should be conducted through interdisciplinary approaches that involve both natural and social scientists. We propose the establishment of a regional programme to conduct comparative research on specific science and technology policy issues that influence or determine the capacity of African countries to effectively engage in biotechnology. Such research would generate the necessary empirical foundation for the formulation of systemic biotechnology policies. Its specific objectives would be to:

* Understand and compare the factors that influence the rate of technological change in the area of biotechnology in Sub-Saharan Africa.
* Conduct technology foresight and monitor international trends in biotechnology to inform regional and national technology procurement efforts.
* Identify and analyse policies that determine the acquisition or procurement of modern biotechnology from the industrialized countries, and the specific opportunities and constraints influencing its adoption in Africa.
* Promote information exchange and use in technology policy formulation and implementation.
* Build capacity of African researchers to engage in comparative analysis of biotechnology policies.

The proposed programme would be implemented through networking, that is aimed at sharing information and experiences, exchanging staff, training in specific areas of research, and providing technical assistance. The programme would be designed in such a way as to ensure continuous interaction and information flow through the ATPS network of institutions and individuals. The results of the programme will go towards helping African countries to formulate and implement policies that would enable them to reap benefits from biotechnology while at the same time managing any risks.

4.2 Programme Activities

To achieve the objectives of the proposed programme, an interrelated set of activities comprising country studies, symposium and dissemination would be undertaken over a period of three years:

4.2.1 Comparative Country Studies

In order to get a detailed understanding of the status of biotechnology in Africa, it is proposed that country studies focusing on selected sectors and firms as well as policy themes be undertaken in ATPS network member countries. The studies would be guided by a coherent conceptual framework Specific key policy issues to be explored include:

Innovative mechanisms for financing biotechnology R&D**:** Country studies on this theme would identify existing national mechanisms (e.g., venture capital, credit facilities, tax relief and contract research) and the nature of policies that either promote or hinder the growth and application of such mechanisms. The studies would also provide a comparative analysis of financing of biotechnology R&D in a non-African country, where possible. Details of the scope of the studies would be elaborated upon in a separate background paper on financial mechanisms for biotechnology: a global overview of approaches and strategies.

National systems of innovation in biotechnology: Studies or assessments of the nature and level of interactions among actors involved in national biotechnology R&D would be conducted. Such studies would focus on linkages or intensity of interaction within the overall system of biotechnology innovation in the country. Methodological and conceptual frameworks developed by such agencies, as the United Nations Conference on Trade and Development (UNCTAD) would be explored used if where appropriate. The emphasis would be on promoting policy makers' understanding of their national systems of innovation.

Intellectual property protection and technology transfer: *As* stated above, issues of intellectual property protection and how such protection affects national efforts to procure biotechnology are increasingly moving to the mainstream of public policy discourse in Africa. However, there is a paucity of empirical information and data on whether and how intellectual property protection affects technology transfer. Comparative country studies would be undertaken to establish, on the basis of empirical evidence, the intellectual property protection–technology transfer nexus in African contexts. The countries would be selected on the basis of the nature and strength of their protection regimes and level of biotechnology R&D. A detailed conceptual and methodological framework for such country studies would be developed.

Technology risk assessment and management regimes: *A*s African countries get into new biotechnology trajectories and as they become parties to the Cartagena Protocol on

Biosafety, they will be required to establish or strengthen their existing policies, procedures and institutions for risk assessment and management. This proposed programme would be a vital source of information on specific areas of capacity building. We propose that some detailed assessments of country regimes and capabilities in technology risk assessment be undertaken. A number of African countries would be selected for the assessments, which would be guided by or based on clear and common methodology that would be developed in detail.

For each of these clusters of research issues a specific paper with detailed conceptual and methodological approaches would be commissioned. These papers would lay the epistemological basis for the comparative country studies.

4.2.2 Regional Annual Symposia on Biotechnology in Africa

To promote networking, exchange of information and review of the country studies, annual regional symposia on biotechnology would be organized. These would bring together ATPS network researchers, policy makers and donors to discuss specific issues emerging from the country studies. Each symposium would be organized around a particular theme (i.e., a symposium on each of the themes suggested above). It would be open to foreign researchers who wish to share experiences with African experiences from other parts of the world.

4.2.3 Publishing, Dissemination and Networking

The central form of information exchange would be through the series of published monographs , policy briefs and edited volumes. The publications would be disseminated widely to make the results of the programme available to policy makers, entrepreneurs, scientists, donors and practitioners. They would also be circulated through specialized networks as African Biotechnology Stakeholders Forum (ABSF) and would be made available through ATPS website.

A key feature of the proposed programme is networking. Networking would be through the regular exchange of information, collaborative research, network research, data management, training and exchange of researchers. In addition to the main ATPS network, sub-networks on biotechnology policy may be established to deal with specific areas of research or regions with special needs.

4.3 Conceptual Foundations

Establishing a common conceptual framework for such a set of complex policy issues to be analysed through diverse teams of scholars/researchers in a heterogeneous group of African countries is not an easy task. It is for this reason that we propose to prepare an overview concept and methodology paper for each cluster of policy issues suggested above. Nonetheless, there are some common conceptual strands applicable to the pursuit of all of the above research issues and two conceptual metaphors obtain for their analysis. The first is a concentration on a set of issues/questions pertaining to *technological capability* to procure, diffuse, assess and manage risks, undertake research and development, and generally manage biotechnology. Without taking a linear and reductionist approach, technological capability is best assessed and understood within a conventional input-output model and the extent to which tacit and non-tacit elements of the inputs are interlinked. Emphasis will be placed on linkages—policy and organizational—in the system in which the capability is created, mobilized and articulated.

The second concentration would be the conceptual basis for understanding technological change as a *cumulative evolutionary* process. Here there are well established theoretical and methodological bases for analysing the issues we have suggested above. The emphasis using this theoretical axis would be on examining technological convergence—how the evolution and development of biotechnology in any system depends on the existence and growth of other technological systems such as information technology. This would also provide a basis for looking into the social context of innovation in biotechnology and the socioeconomic as well as environmental externalities generated by the technology.

On the whole, the conceptual foundations that would be developed and/or adopted for the research would need to recognize the dynamics of policy analysis and management. First that in policy analysis we are dealing with a wide range of strategic actors who shape the direction of policy. Such actors operate through an institutional environment that is conducive to the adoption of their ideas. Policy formulation is thus part of the dynamics of social learning and should not be viewed in the conventional sense of a linear relationship between policy formulation and implementation.

4.4 Institutional Arrangements for Programme Implementation

Projects to be implemented under the proposed programme would fall into the four categories of issues suggested under section 4.2.1. This categorization should be seen as basically organizational. Though some of the projects would have distinct theoretical and policy features, many cannot fit into pigeonholes. It should be noted that the programme should be open to new issues and projects, some of which may not necessarily conform to the outlined framework. Thus the management of the programme should be built on the principle of openness to new ideas and approaches. It should aim at promoting synergy with other initiatives of other networks (e.g., African Biotechnology Stakeholders' Forum (ABSF) and institutions in the region. Its key value should be to add new value to current efforts.

The implementation of activities under the programme will be through ATPS members and institutions working on some of these issues. Emphasis should however be placed on ensuring that the network is made of researchers and institutions willing to adjust their current research efforts and approaches for efficient implementation of the programme.

The execution of the programme would be co-coordinated by the ATPS Secretariat and the African Centre for Technology Studies (ACTS). The main activities would include:

* Coordinating project development and fund raising,
* Developing/commissioing background (conceptual and methodology papers),
* Selecting proposals for support,
* Organizing symposia,
* Publishing and disseminating findings,
* Maintaining a documentation unit on international biotechnology R&D worldwide,
* Identifying and facilitating research activities in the network,
* Overseeing the use of funds, and
* Generally, providing intellectual leadership to the programme.

4.5 Expected Outputs

If the proposed programme is carefully developed and its activities efficiently implemented the following results would be generated:

* The understanding of factors that determine the rate of technological change in the area of biotechnology in sub-Saharan Africa would be increased.
* The body of information and knowledge on which to base policy making on biotechnology would be enlarged.
* National capacity to formulate biotechnology policies would be enhanced.
* African researchers' skills in biotechnology policy analysis would be built.

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Preface

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