



Supporting bioscience innovation in Eastern Africa

An assessment of key processes in four bio-innovate technology systems



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Cover photo: Farmer Field Day, Makueni, Kenya © S.Kilungu / CCAFS / Flickr

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STOCKHOLM ENVIRONMENT INSTITUTE

Working Paper No. 2016-06

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This study was carried out under the, the *Bio-resources Network for Eastern Africa Development (Bio-Innovate) Programme* and the SEI-driven project *Biosciences in Eastern Africa (BEA)*. Both the Bio-Innovate Program and the BEA project were supported by the Swedish International Development Cooperation Agency (Sida).

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EXECUTIVE SUMMARY

Bioscience innovations have significant potential to contribute to sustainable development and economic growth in Eastern Africa. The study is focused on bioscience innovation in Ethiopia, Kenya, Rwanda, Tanzania and Uganda. We examine a selection of bioscience technology clusters and the emerging innovation systems that correspond to each, from the perspective of technological innovation systems. We then identify barriers and enabling conditions for moving bio-innovations from the laboratory to the market in Eastern Africa.

The study focuses on the Bio-Innovate programme, which is currently one of the largest efforts to strengthen bioscience innovation in Eastern Africa. The four Bio-Innovate technological innovation systems analyzed are:

- technologies to improve cassava, sweet potato and potato crops
- conversion of agro-industrial waste to bioenergy and value added products
- value-added products from sorghum and millet, and
- industrial enzymes for a sustainable bioeconomy.

In these four innovations systems, there have been advances in collaborative research and in developing products and technology, but the potential innovations have not yet been brought to market. However, each has, to different degrees, moved forward in the innovation process, demonstrating the viability of potential products and technologies. Ultimately, nurturing and strengthening innovation processes requires stable mechanisms and timeframes beyond those of the projects studied here.

The study shows that it is a great challenge for the four innovation systems to upscale and introduce bioscience innovations to market. Much of the research and development (R&D) carried out in these systems, and also more broadly in many areas of R&D and innovation in the region, is demand-driven, but not business-driven. Another common feature of the systems is that most have weakly functioning innovation processes. While there is strengthened knowledge generation in all four systems, including the capacity for R&D, entrepreneurial activity, market creation, guiding policies and financing are weaker.

Strengthening public R&D

In the field of biosciences, public R&D plays a strategic role in moving knowledge and technology to the market and to various other sectors. This is important given that in Eastern Africa there are generally low rates of private sector investment in R&D and low rates of adoption of promising bioscience technologies. In addition, private sector and market actors are seldom effectively engaged with the public R&D sector, limiting technology dissemination and bioscience innovation.

To convert the promise of the bioscience revolution into market opportunities, there is a need for strong public R&D institutions that can catalyze innovation. In Eastern Africa, this would include supporting the public R&D sector in the following areas:

- *Linking with the private sector:* technology transfer is a resource-intensive and time-consuming activity and to be effective, public organizations need minimal capacity in this area. Options include having a technology transfer office or designated staff supporting scientists on technology dissemination issues, such as advising on intellectual property (IP), patent searches and identifying appropriate market actors.
- *Ability to assess the economic potential of R&D activities:* the ability to assess the economic and commercial potential of technologies and products is often lacking at public R&D institutions. Researchers in public R&D institutions need access to expertise that

can help develop their knowledge of market and private sector needs and the economic potential of public R&D.

- *Rewarding and supporting entrepreneurship*: for public organizations to play a key role in adopting bioscience applications and transferring them to market actors, there is a need for a system of rewarding staff engaged in innovation, knowledge dissemination and entrepreneurship.

Building businesses – incubating public R&D and linking it to the market

The private sector has an important role in moving R&D to the market. Private sector actors that exploit and continuously look for market opportunities are key for entrepreneurship and market creation. Consequently, it is critical to support activities that link public sector and market actors. The study shows that there are few developed public-private partnerships in bioscience innovation in the region. Our study indicates that mechanisms and policies that enable public R&D staff to start spin-out companies can be an equally important way to develop business opportunities from public R&D. However, it is often not enough to link the public sector with the market; there is also a need for mechanisms to incubate businesses to ensure that all actors in the innovation system are effectively linked and supported to play complementary roles. As a result, professional services may be needed to help innovation actors develop and incubate businesses. This would include providing services such as:

- business case development, viability analysis and technology assessment (including intellectual property assessment)
- market assessment and business plan development in areas such as feasibility, strategies and market testing, and
- help with finding financing for development and commercialization.

Creating market demand

Market demand for bioscience innovation is much needed, and it can be created through appropriate long-term policies, and effective and efficient regulation and incentive systems at the national level. Both Tanzania and Uganda have put significant effort into developing national science, technology and innovation (STI) policy frameworks. However, to a large extent these STI policies are too general and have little positive effect on innovation. There are also examples of policies that are counterproductive and prohibitive to bioscience innovation.

To help bioscience flow from R&D to the market there is a need for policies that provide incentives and guiding frameworks that clearly benefit innovation on the supply side and create demand. These would include certification regimes and standards, financial and tax incentives and targeted public procurement specifically to promote and assist innovation. It is also important that interventions are based on a comprehensive social, technological and economic diagnosis of the problems, barriers and opportunities for the innovation systems that are a priority for a particular country.

Financing for innovation and the importance of continuous support

Access to capital and credit facilities under reasonable terms is critical for innovation and long-term impact, but the lack of it is currently a key barrier in both countries. R&D in the public sector and academia often relies on public funding, but to successfully bring the products to market, new funding partnerships are necessary, in which innovation costs are borne by several parties. For example, matched funding programmes may be developed where R&D institutions co-invest with industry partners, thereby ensuring commitment from the industry partner and reducing the risks for all parties.

Today, investments in and support for bioscience innovation remains concentrated in the R&D phase of the innovation cycle, and there is inadequate provision for large-scale pilot tests and large-scale application, or for commercialization of technologies or products. Limited access to capital and credit facilities at reasonable terms also blocks the innovation systems in the cases we studied. In Tanzania and Uganda, innovation efforts are severely restricted by a lack of mechanisms to share financial risk and access bridging funds, venture capital and credit facilities at reasonable terms.

Of importance here is the longevity and follow-through of donor and government support. Innovation is a long-term non-linear and complex process, which is difficult to predict and manage. All innovations come up against unexpected barriers, unforeseen events and have to move through the so-called Valley of Death. Access to long-term support and capital, which enables iterative improvements to products and the innovation processes, is often crucial for success. This pattern is well established in richer countries in areas such as electric vehicles, solar and wind power. We saw similar patterns across all cases examined in this study.

Policy considerations

There is no single, one size-fits-all solution for promoting successful bioscience innovation systems. Indeed, there may be a number of possible pathways for each individual innovation system in each country. The question to be answered is how public policy can strengthen the conditions for bioscience innovation. Below is a shortlist of action points for the policy-making community in Eastern Africa:

- *Establish national bioeconomy strategies* that support the country's medium- and long-term development goals.
- *Build and sustain capacity in the public R&D sector* with highly trained scientific and technical staff who have capacity to link to market actors, and create opportunities and incentives for them to be engaged in innovation activities.
- *Develop incentive mechanisms and enabling rules in R&D institutes* to reward and support entrepreneurship and interactions with the private sector.
- *Develop business incubation and "technopark" infrastructures and services* to assist emerging innovation actors with product and enterprise development.
- *Implement enabling policies and regulatory frameworks that create demand* for the commercialization of bioscience technologies, including certification and standards, public procurements, tax incentives and presidential initiatives.
- *Establish a comprehensive financing mechanism framework* for bringing bioscience technologies to market along the growth path, including small incubation grants, matching grants, soft loans, angel investment, public and private equity/venture capital and commercial loans from specialized banks.

In summary, to improve the effectiveness of bioscience innovation in the region, finding ways of linking R&D with market actors, building business and up-scaling financing and marketing of technologies would be more effective than purely strengthening R&D efforts. Overall, the study shows that focused efforts and investments in areas such as business incubation, financing mechanisms, and enabling policies supporting market demand are needed to convert the promises of the bioscience revolution into market opportunities.

1. INTRODUCTION

1.1 Fostering a bioeconomy in Eastern Africa

The revolutionary advances in biosciences provide an increasingly powerful engine for innovations in sustainable agricultural production, waste management, renewable energy production and the development of a diverse range of novel bioproducts. This has led to the concept of a “bioeconomy”. The central feature of a bioeconomy is that scientific research and knowledge can be applied to biological resources and agricultural systems not only to produce food and feed, but also to an increasingly-wide range of agro-industrial and value-added products with potential applications in sectors such as pharmaceuticals, chemicals, materials and energy (Eaglesham 2006; Schmid et al. 2012).

The global bioeconomy is increasingly the subject of attention from policy-makers, corporate decision-makers, and researchers in the social and biological sciences, and the general public. With both short- and long-term shifts in the world’s demand and supply of agricultural and industrial products, there is growing attention to the actual and potential role of bio-based innovations as a means of developing a resource-efficient and productive economy (European Commission 2012). A key question for the countries in Eastern Africa is how to best use science, technology and innovation to foster growth of a bioeconomy that is able to meet the region’s development challenges.

Science, technology and innovation (STI) are at the heart of development pathways under discussion in Eastern Africa. Nearly all Eastern African countries, notably Burundi, Ethiopia, Kenya, Rwanda, Tanzania and Uganda, have developed STI policies, with the overall goal of providing a coordinated framework within which STI can be integrated into the productive sectors, especially agriculture, manufacturing, and services (NEPAD 2006; Juma and Seregeldin 2007).

Biosciences will inevitably play a crucial part in the STI development agenda for the region. The application of modern biosciences is emerging as a powerful tool to: a) assist breeding systems in sub-Saharan Africa to be more efficient in producing improved cultivars for small farming systems, and b) help countries build agricultural production systems that are adapted to climate change. Farmers are beginning to realize that modern biosciences, such as applications of tissue culture, can improve production and lead to new opportunities and value chains and diversified smallholder production (World Bank 2013). Continued investment in biosciences and value chains is likely to increase demand for local crops, thereby improving rural livelihoods. Also, agro-processing industries are likely to be more productive and sustainable, and community-based bio-refineries are likely to emerge that convert crops and agricultural waste into valuable by-products such as feed and bioenergy.

1.2 Objective of the study

Bioscience innovations have significant potential to contribute to sustainable development and economic growth in Eastern Africa. The purpose of this paper is to study a selection of bioscience technology clusters and their corresponding emerging innovation systems. On the basis of these studies, the paper will identify barriers and enabling conditions for moving bio-innovations from the laboratory to the market in Eastern Africa.

The study has three main objectives:

- analyze selected emerging innovation systems within the Bio-Innovate Program to identify strengths and gaps
- use a gap analysis to provide recommendations on addressing and potentially bridging gaps, and

- provide recommendations and advice on how to strengthen the innovations systems and on ways in which countries in Eastern Africa could create a more enabling environment for bioscience innovation in general.

The study compares four innovation systems to highlight similarities and dissimilarities between them. Based on the results, the report also recommends actions and policy measures to improve the conditions for bioscience innovation in the region.

Section 2 presents the background of the study and the conceptual framework. Section 3 introduces the four innovation systems examined in the study. Section 4 presents the results in terms of how well innovation processes are operating, comparing and contrasting the cases. Section 5 discusses the results looking at potential structural explanations for the observed process patterns and other important drivers. Section 6 presents a summary of gaps and barriers, through distilling key drivers and underlying reasons for weaknesses in innovation processes, and elaborates on potential policy and private sector responses and actions to strengthen the system.

2. BACKGROUND

2.1 The Bio-Innovate support for bioscience innovation

The Bio-Innovate Program¹ is one of the largest African efforts aimed at strengthening bioscience innovation in the region. It funds eight bioscience innovation consortia clusters, all of which represent a novel approach to strengthening innovation systems in Eastern Africa. These consortia include both public R&D institutions and private sector partners and have a focus on adapting key bioscience technologies and bringing them to markets in the region.

Bio-Innovate actively supports bioscience innovation in Eastern Africa focusing on crops such as cassava, sorghum, millet, beans and sweet potatoes. The Bio-Innovate program is also assisting African agro-processing industries to become more productive and sustainable in converting agro-waste into valuable products such as bioenergy, food and feed products and other valuable by-products while also reducing environmental impacts.

The Bio-Innovate projects in this study can be gathered into four distinct, but interlinked, bioscience innovation systems. These include:

- crop improvement technologies for cassava, sweet potato and potato
- value-added products of millet and sorghum
- biogas and mushroom production from agro-waste, and
- industrial enzymes.

These technological systems entail the adaption, sharing and use of new knowledge to generate new products. Each of these systems has a network of organizations, enterprises and individuals focused on bringing new products and processes into economic use. Within the Bio-Innovate program, the Biosciences Innovation Policy Consortium (BIPCEA) project has conducted case studies on the four Bio-Innovate technological consortia with the aim of understanding, from a technological innovation systems perspective, the enabling conditions for and barriers to moving bio-innovations from the laboratory to the market in Eastern Africa.

2.2 Conceptual framework

In order to arrive at useful recommendations on strengthening the foundation for bioscience innovation² in the region, it is important to understand the strengths and weaknesses of specific innovation systems³ (Lundvall 1992). Technology development is one driver. However, decades of innovation research has demonstrated that there are many interactions, including positive and negative feedback loops, between the technology and the societal context in which it is nested. Innovation systems can be analyzed using a range of different tools and models – the analysis in this study was guided by a technological innovation systems (TIS) framework. The framework starts with a conceptualization of the innovation system as “...a network or networks of agents interacting in a specific technology area under a particular institutional infrastructure [e.g. norms and regulation] to generate, diffuse, and utilise technology...” (Bergek et al. 2008, Heckert et al. 2011).

At its heart, the TIS has a structure which consists of a) actors and their networks, b) institutions, and c) the technologies themselves and supporting physical infrastructures. The structure enables

1 The Bio-Innovate program is hosted by ILRI, Nairobi and supported by the Swedish International Development Agency (Sida). The program started in 2010 and will end in 2015. URL: <http://bioinnovate-africa.org/>

2 Innovation has been defined as the introduction of a new idea, product or process to a user or user-group (OECD 2009)

3 The concept of the innovation system stresses that the flow of technology and information among people, enterprises and institutions is key to an innovative process. It contains the interaction between the actors who are needed in order to turn an idea into a process, product or service on the market.

a number of crucial system processes that are necessary for the innovation system to function. Through extensive empirical research and a literature review, a number of such processes have been identified and modified over the past years (Hekkert et al., 2007)

In this study, we have chosen to examine six processes to broadly map the strengths and weaknesses of the innovation system for each of the four consortia and also for the overall bioscience innovation framework in the region. These processes are:

1. **Knowledge development and diffusion** addresses the generation, and linking, of knowledge and know-how connected to the technology in question. This includes research and knowledge about markets and business development. The knowledge base on how to apply modern biosciences to improve agricultural crops, utilize agricultural by-products, and to improve waste management, is expanding rapidly worldwide and also in Eastern Africa.
2. **Entrepreneurial activity** concerns the development and testing of market niches and commercialization of the technology and its applications. This would, for example, include entrepreneurship in the private and public sectors to find and establish markets for new products derived from improved sorghum and millet value chains.
3. **Policy guidance** concerns the way in which the system is directed in its development, either through strong overarching industry, or political visions and strategies with coherent policy frameworks. This could include development of new standards to stimulate the use of micro-propagation for producing disease-free cassava or sweet potato.
4. **Market creation** concerns the development of a market, and demand, for the new bioscience-related technologies and products in the region. This would, for example, include markets for improved crop cultivars, waste treatment processes producing bioenergy and other value-added products.
5. **Getting legitimacy** addresses the development of public and industry acceptance for the new technology. This can be a major challenge within the industrial sector, among R&D organizations, within the groups using the technology (such as farmers) and with consumers. Misunderstanding and misinformation around what technologies can and cannot achieve is common, not least when it comes to agricultural biotechnology.
6. **Resource mobilization** addresses the way that system actors can access financial, human and other resources. This would, for example, entail R&D funding, venture capital and equity capital and affordable loans from the financial services sector.

An important part of the TIS analysis is the characterization of the structural components of the innovation system (i.e. actors and their networks, institutions and infrastructure) and how these components interact with the processes listed above (Bergek et al. 2008, Heckert et al. 2011). In terms of actors, the private sector, which exploits and continuously seeks market opportunities, is often crucial for market creation and for deploying knowledge. The existence of a strong public sector research base is often a condition for the knowledge development to take place, while networking that links university research to the commercial sector is often a condition for knowledge diffusion. A lack of entrepreneurial activity is a common structural constraint in low-income countries, and this is in part due to the nature of policies and rules at public institutions, which often limit entrepreneurial activities by their staff.

The TIS approach allows us to unpack and assess the key components of the innovation system to clearly identify its strong and weak parts. Summarizing the results for each function of the TIS makes it possible to identify the major gaps. We developed our own quantitative scale to describe the strength of the processes of the innovation system. The quantitative scale has four levels, as follows:

1. *Very poor. The function is not fulfilled, or there are serious weaknesses.*
2. *Poor. While the function is partly fulfilled, there are major weaknesses.*
3. *Fair. While the function is broadly fulfilled, there are still important weaknesses.*
4. *Good. The function is adequately fulfilled.*

A more detailed description of this scale and how the criteria are applied in the cases is included in Appendix 1

By assessing the strengths and weaknesses of each of the processes, and seeking explanations and drivers for this pattern in the structural components of the innovation system, it is possible to identify areas where interventions are needed (either by public or private actors) (Hillman et al. 2011; Bergek et al. 2008). Following this, we elaborate on recommendations designed to strengthen the weaker parts of the system while maintaining and building on components and processes that are already strong. Through public policy or governance interventions, the TIS can be influenced and strengthened, either via the structural components (strengthening or creating new actors, such as organizations, or funding network building), or via the processes directly (including funding an R&D programme, strengthening markets through public procurement, and developing enabling policies).

2.3 Method and data sources

The study focused on all six countries where the Bio-Innovate program is operating: Burundi, Ethiopia, Kenya, Rwanda, Tanzania and Uganda.

Data was collected through a review of national and regional policy documents and institutional reports, focus group discussions and in-depth interviews with key actors, including industry representatives, in each technological system. Data was also collected during visits to the various Bio-Innovate partners participating in the four Bio-Innovate projects analyzed in this study, and from Bio-Innovate projects and programme reports.

We invited key actors in the various innovation systems to participate in one-day focus group discussions. These focus group discussions were held in all six countries apart from Burundi, but participants from Burundi joined focus group discussion in Rwanda. Each discussion involved 10–15 participants and used common guidance material, framed around the key TIS processes listed above. The scoring was completed using the quantitative scale (outlined above) of the strengths and weaknesses of the various functions according to an agreed guidance format (included as Appendix 1).

3. THE FOUR TECHNOLOGY INNOVATION SYSTEMS

The four Bio-Innovate TIS are described below.

3.1 Technologies for improving cassava, sweet potato, and potato crops

Cassava, sweet potato, and potato are important crops in Eastern Africa. They are sources of food, processed products and animal feed, and generate income for millions of resource-poor farmers in the region. Although they have great potential to alleviate malnutrition and poverty, and are priority crops in Eastern African agricultural research programmes, the productivity of these crops is still severely limited by various viral diseases. This includes the emerging cassava brown streak virus disease (CBSVD) and sweet potato virus disease (SPVD), which can cause losses of more than 90% in crop yields.

This TIS encompasses a Bio-Innovate project using micro-propagation techniques to screen and develop disease-free and improved cassava, potato and sweet potato planting materials that are better adapted to climate change in diverse agro-ecologies. The TIS also incorporates the development of efficient seed multiplication and delivery systems for tuber crops in Eastern Africa. The use of micro-propagated plants offers many added benefits. For example: 1) they are more vigorous, allowing for faster and superior yields, 2) more uniform, allowing for better marketing and 3) can be produced in large quantities in short periods of time, allowing for faster and better distribution of existing and improved cultivars, including genetically modified banana.

Micro-propagation of banana and coffee is well established in Uganda and Kenya and commercial production of micro-propagated banana is growing in the region (Blomme et al. 2013). Micro-propagated tuber crops are not yet commercially produced, partly because of the difficulty of developing functional and commercially viable systems for seed multiplication and delivery. The Bio-Innovate crop improvement project is an attempt to develop a model for efficient seed multiplication and delivery systems for tuber crops in Eastern Africa. A functional innovation system for micro-propagated tuber crops would ultimately make a major contribution to sweet potato and cassava varieties through improved yields of better quality produce and improved food security and livelihoods in the region. Sweet potatoes and cassava are also drought-resistant crops. Consequently, providing better planting material to encourage stronger adoption of these crops could also contribute to a more climate change-resilient farming system in Eastern Africa.

3.2 Converting agro-industrial waste to bioenergy and value-added products

The agro-processing industry is vital for Africa (World Bank 2013) but produces large amounts of waste, which contributes to environmental pollution in the region. The discharge of untreated industrial effluents and agro-waste into rivers and lakes is a serious problem that threatens local livelihoods, negatively affects ecosystems and limits access to clean drinking water. In many cases, this waste could be used to generate bioenergy and other value-added products, such as edible mushrooms or biofertilizers (Fisher et al. 2010)

Biogas has traditionally been used to a limited extent in Eastern Africa in small installations that provide household energy and gas as fuel for cooking, heating and lighting in social institutions. Although household-scale biogas can improve energy access, industrial scale biogas can offer significant economic and environmental benefits across entire agro-industrial sectors. Thus donor and commercial interest has so far been focused on medium- to larger-scale projects involving the development of biogas production from industrial agro-waste. This has included using municipal wastewater and sisal, vegetable, and slaughterhouse waste to produce bioenergy and bio-fertilizers and lessen the discharge of untreated waste. Most of these have been pilot projects, demonstrating feasibility and testing processing models. (Fisher et al. 2010). However, due to technical problems, high investment costs, and an unfavourable policy environment, the commercial po-

tential for industrial biogas and electricity generation in Eastern Africa remains largely untapped. A study on agro-industrial biogas potential in Kenya by DBFZ (Deutsches Biomasse Forschungs Zentrum)⁴ concludes that there is strong potential for agro-industrial biogas to produce energy and other valuable by-products in Kenya (Fisher et al. 2010). According to this study, biogas from all examined subsectors could cover up to 16% of total Kenyan electricity production. As energy prices increase, and environmental regulations become more strict,⁵ there is renewed interest in biogas production from agro-waste, which may pave the way for commercial production of bio-energy and other value-added products from agro-industrial waste.

This TIS encompasses two Bio-Innovate projects, which aim to demonstrate innovative production technologies to produce biogas and value-added products such as mushroom and bio-fertilizers from agro-industrial wastes while also reducing environmental pollution. In the two projects, there is a focus on waste from processing coffee, meat, banana and sisal (see bioinnovate-africa.org for more information).⁶ A functional innovation system in this area would demonstrate the potential for novel biogas production technologies in Eastern Africa to convert agro-waste to a number of valuable by-products while at the same time efficiently reducing environmental pollution.

3.3 Value-added products from sorghum and millet

Traditional African crops such as sorghum and millet are well adapted to local growing conditions, particularly in the semi-arid tropics, and they consume less water than, for example, maize. These traditional crops also have interesting, but unexploited, nutritional characteristics. Increasing productivity and use of these crops would not only improve food security and rural livelihoods and alleviate poverty, but also strengthen a crop production better adapted to climate change (AGRA 2014).

However, sorghum, cassava and millet, are seriously under-utilized, under-researched and under-developed. In terms of innovation and agro/food processing, these crops have been grossly neglected in most African countries and little science-based technology has been used to add value to them. To realize the full potential of these crops, there is a need to add value and to process them into a wider range of products, making them more marketable and more profitable. An increasing number of private actors, including breweries and food companies, are processing food and beverages from sorghum and millet. An example of adding value to sorghum is the production of a sweet sorghum variety (*Epuripur*) for brewing beer in Uganda. Rapid urbanization and a rising middle class are increasing demand for a greater variety of processed food products. Overall, therefore, there is an emerging market for value-added crop products in Africa.

This TIS encompasses a Bio-Innovate project that looks at improving use of sorghum and finger millet by adding value to the product, and diversifying, commercializing and industrializing it. Optimized malting and extrusion technologies will lead to products such as quality malt, clear-malt drinks and malted-extruded snacks.

A functional innovation system for adding value to millet and sorghum would, therefore, secure and strengthen demand for and profitability of these crops, and potentially benefit small-scale and subsistence farmers and help to stimulate pro-poor growth. Such an innovation system would also provide an improved basis for agro-processing, large-scale but also community-based value addition and development of new agro-enterprises in the region.

4 Examining the theoretical potential of 13 types of biomass waste from various agroindustrial businesses in Kenya, including municipal waste in Nairobi.

5 Some agro-processing plants in the region have been closed due to unacceptable environmental impacts.

6 See: <http://bioinnovate-africa.org>

3.4 Industrial enzymes for a sustainable bioeconomy

The agro-processing sector in Eastern Africa has a vital role to play in generating economic growth and adding value to local African crops. Industries processing products such as leather, textile, pulp, paper, detergents and starch, are a backbone of the region's industrial sector. However, most of these industries are associated with environmental pollution and inefficient processing. Industrial enzymes have significant potential to replace imported chemicals and make processing more competitive, resource effective and sustainable, as well as contributing to new areas of by-product utilization.

There are a growing number of applications for enzymes in industrial processes and the global industrial market is growing fast, with a current estimated value of US\$ 7 billion. Worldwide, over 120 companies are known to produce industrial enzymes and more than 80% of the companies controlling up to 90% of the market are located in Europe and North America. None are in Africa. Africa has however a significant potential for the discovery of novel enzymes that may prove highly useful in industrial processes.⁷ Development of a local enzyme production sector may also assist in a much-needed expansion and revitalization of the African agro-processing sector, including leather tanning, textile, pulp, paper, starch, detergent, biofuel and chemical industries.

Production of industrial enzymes at commercial scale in the region has many challenges⁸, but also has several advantages. Local availability of such enzymes in sufficient quantity and at an affordable price could encourage industries to adopt modern, resource-efficient and environmentally friendly processing. It could also play an important role in establishing a foundation for the development of industrial biotechnology in the region, giving countries in Africa the chance to have a share in the growing global industrial enzyme market. This would be important for the region, which is in the process of finding new pathways to expand its agro-industrial manufacturing sector.

This TIS encompasses a Bio-Innovate project that focuses on increasing production of three target enzymes, such as proteases, amylases and xylanases, for use in regional industries such as leather processing, textiles, pulp and paper, animal feed processing, and starch and detergents. Enzymes produced locally at competitive prices and with expert support on their use could become an important field of innovation in Eastern Africa. A functional Eastern African innovation system for the production of industrial enzymes has potential to lead to a more competitive agro-processing and bio-refinery sector that adds value to local bioresources, generates jobs and improves livelihoods.

7 Because of the availability of a large amount of diverse raw materials, Eastern Africa has significant potential for growth in this area. Considering the huge microbial biodiversity that exists in the region, enzymes potentially valuable for various industrial applications are still awaiting discovery.

8 Such as raising necessary capital, reaching economies of scale, finding staff with appropriate skills, etc.

4. RESULTS: STRENGTHS AND WEAKNESSES IN THE INNOVATION SYSTEMS

4.1 Crop improvement technologies for cassava, sweet potato, and potato

There is an adequate knowledge base for crop improvement at universities and public research organizations and, to a large extent, in the emerging private sector. This is particularly true for R&D, where the public sector knowledge base for developing micro-propagation protocols for various crops has been steadily growing. Many public institutions are now able to develop and adapt tissue culture for a large number of crops relevant to the region, including banana, pineapple, coffee, potatoes and sweet potato. However, dissemination is limited by a lack of certification of tissue culture cultivars ensuring a high quality of planting material and disease-indexing skills. The production cost for micro-propagated material is also high.⁹ Therefore, more work is needed to develop more cost-effective large-scale micro-propagation methods to reduce the cost of improved planting material and facilitate commercialization and wide adoption.

Entrepreneurial activity in this field of innovation is increasing in Uganda and Kenya, is more limited in Tanzania and Ethiopia, and weak in Burundi and Rwanda. In Uganda and Kenya, there are now several private companies selling micro-propagated banana and coffee planting materials. This includes AgroGenetic Technologies (AGT) Limited in Uganda and Genetics Technologies International Ltd (GTIL) and Mimea International Limited in Kenya. These companies produce millions of micro-propagated banana, coffee and pineapple plantlets on a commercial basis. There is not yet any private sector involvement in the dissemination of micro-propagated tuber cultivars at a commercial level. However, there are public-private partnerships in this area, including some that have developed through the Bio-Innovate program and its consortia, focused on developing and disseminating improved varieties of cassava, potato and sweet potatoes. In this project, model seed distribution systems for micro-propagated cassava and sweet potato seedlings have been designed, developed and pilot tested by the R&D partners and their private sector counterparts—GTIL in Kenya and Biocrops in Uganda.

All countries have broad policies and strategies on crop improvement and food security, but there are no specific policies stimulating the production of micro-propagated material, such as mechanisms for certification of micro-propagated disease-free cultivars

Farmers well connected to value chains, agro-processing opportunities and markets can afford to regularly buy micro-propagated crops. There is a commercial market for improved and disease-free cultivars of banana and pineapple in the region. The demand for micro-propagated banana cultivars in Kenya and Uganda is increasing and awareness is rising of the benefits delivered by micro-propagated material. Micro-propagated banana cultivars are sold at around US\$1 per plant, which, although a high cost for most farmers, can be justified through higher production rates and stable markets. In the case of tuber crops, a large part of the farming community in the region is not familiar with, and cannot afford to buy, tuber seeds and improved cultivars. As a result of weak value chains, agro-processing opportunities and markets, the demand for improved micro-propagated tuber cultivars is weak. This makes it challenging to up-scale and commercialize micro-propagated tubers.

A lack of certification and common management standards for ensuring the quality of planting material adds to the marketing challenges. Market conditions also differ depending on proximity to large markets, such as big cities. The prospects for establishing viable nurseries to mass-propagate and sell disease-free tuber cultivars to farmers are likely to be better close to urban areas, rather than more remote rural areas with weak markets. The lack of options for adding value is also negatively affecting the markets for micro-propagated plant material.

⁹ This includes high costs for infrastructure, such as laminar hoods and autoclaves, but also high running costs for ethanol and electricity for climate chambers.

Cassava, sweet potato and potato are important for food security in Eastern Africa, but increased disease rates threaten production. Therefore, legitimacy is high for technologies that ensure crop stability and improve yields. A negative influence on legitimacy is that many farmers are unaware of the potential of micro-propagated cultivars. In addition, there is a perception that micro-propagated crops are associated with genetically engineered organisms (GMOs) and concerns that improved crop varieties lose their natural taste.

The major resource limitation is capital, such as bank loans, venture capital or government support, to develop and maintain nurseries that mass propagate disease-free cultivars. There is also inadequate funding for business incubation, establishing markets and improving business models.

In summary, crop improvement technologies are characterized by fairly strong processes in knowledge development, entrepreneurial activity and legitimation. However, weak market creation, weak policy guidance and weak resource mobilization seriously limit the potential of this innovation system.

4.2 Converting agro-industrial waste to bioenergy and value-added products

There is an adequate knowledge base at universities and public research organizations for producing biogas. There is significant technical capacity within the R&D public sector to develop and adopt modern biogas production technologies using a wide variety of agro-waste substrate. However, in the case of the one of the biogas projects under Bio-Innovate, more knowledge and data is needed to ensure that mushrooms growing on different agro-waste substrates, in particular coffee waste, are safe to eat. The knowledge base for biogas production within the industrial sector is also growing, even though many industrial and semi-industrial biogas plants run at sub-optimal level. Limited knowledge on installation and maintenance is a problem in the region. The skills to carry out a techno-economic analysis of the potential to produce biogas are also lacking.

Entrepreneurial activity in this field of innovation is increasing in all countries in the region. A growing number of private sector actors are involved in, or planning the development of, facilities that produce biogas for their own energy demands and to produce electricity for the national grid. No private actors are yet involved in producing and selling value-added bio-fertilizers or edible mushrooms from agro-waste. There are some vibrant public private partnerships in this area, including two of the Bio-Innovate projects in Tanzania, Uganda and Ethiopia, which are developing technologies for using sisal, coffee and banana agro-waste to produce biogas and value-added products. There is close collaboration in both these projects between public sector¹⁰ and private actors,¹¹ aimed at demonstrating the technical and commercial feasibility of converting agro-waste to bioenergy and to products such as edible mushroom and bio-fertilizers, while also reducing environmental pollution (see bioinnovate-africa.org for more information). Of interest here is that two of the private sector partners in these projects, Banana Investments Ltd in Tanzania and Modjo Tannery Share Company in Ethiopia, have made significant financial contributions to these projects and report significant returns on their investments. Overall, however, the entrepreneurial activity in this field has not reached the level where private sector actors are selling and installing these technologies at agro-processing facilities on a commercial basis.

All countries in this study have broad regulations, policies and strategies for energy production and waste treatment, including the discharge of waste. But, attempts to enforce this legislation, by directing the agro-processing industry to treat its waste and invest in new technology, are often ineffective. However, in both Uganda and Tanzania, there are examples of industries being

10 College of Natural and Applied Sciences, University of Dar es Salaam; Chemical Engineering Department, Institute of Technology, Addis Ababa University; and Department of Biochemistry, Makerere University

11 In Ethiopia: Coffee Plantations Development Enterprise and Modjo Tannery Share Company. In Tanzania: Banana Investments Ltd and Mohammed Enterprises Sisal Plantation Ltd. In Uganda: Kampala Abattoir.

shut down by authorities due to non-compliance with environmental regulations.¹² In addition, no specific policies are in place to stimulate the production of biogas or utilization of agro-waste and there are policy barriers, such as high taxation on imported equipment. Burundi and Rwanda, however, have tax-free imports for agricultural machinery to encourage agricultural production.

The market conditions for biogas are steadily improving in the region, due to rapidly increasing energy demand. The market for edible mushrooms and bio-fertilizer in Eastern Africa is also promising and production is growing as a result of an increased supply of agro-waste. The slowly expanding market for biogas is hampered, however, by the substantial cost of up-scaling biogas production.

There is high legitimacy for producing biogas and reducing agro-waste in the region (UNEP 2013). The potential to trade carbon credits to mitigate greenhouse gas emissions from agro-waste is adding to the interest. There are additional drivers, such as deforestation and health problems¹³ connected to the current use of wood for fuel, which are stimulating the development and utilization of biogas for cooking and heating. On the negative side, there is a lack of strong advocates for using renewable energy such as biogas.

The major resource limitation is capital, such as bank loans, venture capital or government support, for developing and maintaining biogas and mushroom production. There is also inadequate funding for business incubation, establishing markets and improving business models.

In summary, converting agro-industrial waste to bioenergy and value-added products is characterized by fairly strong processes in knowledge development, entrepreneurial activity and legitimization. However, weaknesses in market creation, policy guidance, and resource mobilization are limiting the potential of this innovation system.

4.3 Value-added products from sorghum and millet

While the knowledge base at universities and public research organizations is increasing, there is limited ability to develop a wide range of products. There has been extensive innovation in the private sector in using sorghum for beer production, and some efforts to develop other sorghum and millet products. Despite an expanding base, there remains insufficient knowledge on optimizing processing conditions and Good Manufacturing Practices (GMP). In addition, there has been limited testing and development of business models. The wide variation in the quality of sorghum and millet, due to harvesting and mixing of a multitude of varieties, also makes agro-processing a challenge.

Entrepreneurial activity in this field of innovation is increasing in all countries in the region. A growing number of businesses, including breweries and food processors, are processing food and beverages from sorghum and millet. There are also public-private partnerships in this area, including through one of the Bio-Innovate projects, which is adding value to millet and sorghum through the production of non-alcoholic clear malt drinks, instant sorghum flour, and sorghum/millet-based snack bars. In this Bio-Innovate project, there is close collaboration between public sector¹⁴ and private actors¹⁵ aimed at developing product formulations, testing markets and demonstrating the technical and commercial feasibility of using millet and sorghum for a variety of value-added products. Entrepreneurial activity can be characterized as fair, given the increasing number of products and commercial actors on the market.

12 In Uganda this has been done by the National Environment Management Authority.

13 Due to indoor poor air quality from using wood for cooking.

14 Makerere University, Uganda, Sokoine University of Agricultural Sciences, Tanzania, Hawassa University, Ethiopia

15 Morogoro Ben's winery Ltd in Tanzania, Lisha Products Ltd in Uganda, Addilo Complementary Foods Process Unit, in Ethiopia, Simple Foods in Kenya.

All countries in East Africa have broad policies covering standards and regulation of food production, but there are few examples of policies to stimulate the production of valued-added food or other products from sorghum or millet. There are also policy-related barriers, such as high taxation on imported processing equipment, in most of the countries. Burundi and Rwanda have, however, tax-free imports for agricultural machinery to encourage agricultural production.

The market for new value-added products from sorghum and millet is promising and improving. But market promotion of the benefits of consuming sorghum and millet value-added products is so far limited. Rapid urbanization and an emerging middle class is driving interest in processed local food, which contributes to growing demand for value-added products from these crops. There are no government initiatives that would create market demand, such as procurement programmes of nutritious food products from sorghum or millet for schools.

The growing interest and legitimacy for adding value to sorghum and millet value is driven by the need to reduce poverty and increase utilization of important food security crops that are well adapted to drought and climate change. There is also a drive towards improved security of food and feed nutrition in all countries in the region. Sorghum and millet products are, to some degree, associated with poverty, which may impact the acceptability and legitimacy of sorghum and millet products. There is no known advocacy platform to use local materials and value-added products from sorghum and millet in the region.

The major resource limitation is similar to the two cases above, and includes lack of venture capital, lack of government support for developing pilot production facilities, and inadequate funding for business incubation, establishing markets and improving business models.

In summary, developing value-added products from sorghum and millet is characterized by fairly strong processes in knowledge development, entrepreneurial activity and legitimation. However, weak market creation, policy guidance, and resource mobilization are limiting the potential of this innovation system

4.4 Industrial enzymes for a sustainable bioeconomy

The knowledge base at universities and public research organizations for developing industrial enzymes is emerging but remains limited to a few institutions. There is also a lack of skills to analyze the techno-economic and market potential of industrial enzymes and an absence of business models for producing and using industrial enzymes. Skills in large-scale enzyme production and developing proof of concept are also weak.

Entrepreneurial activity in this field of innovation is in its infancy in all countries in the region. Few, if any, small-and-medium-sized enterprises (SMEs) are engaged in exploring opportunities. There are no public private partnerships in this area, apart from those initiated through the Bio-Innovate program.¹⁶ The production of enzymes is highly proprietary and there is a need for clear national and institutional Intellectual Property (IP) regimes. IP management is a challenge, however, and institutional skills and policies for managing IP in the area of industrial enzymes remain weak in the region.

All countries in East Africa have broad policies and regulations covering agro-processing but there are no specific incentives to develop and use industrial enzymes. There are also policy barriers, such as high taxes on imported agro-processing equipment in many of the countries in the region, with the exception of Rwanda and Burundi.¹⁷

¹⁶ Discussions on partnership with Leather Products Institute and Bekas Chemicals PLC and Modjo Tannery Plc, Addis Ababa, Ethiopia were initiated, but so far not developed into any functional partnerships

¹⁷ The governments in both Burundi and Rwanda have decided on tax-free imports for agricultural machinery to encourage agricultural production.

Market conditions for industrial enzymes are in their infancy but hold promise for the region, and, to date, awareness raising and promotion of industrial enzymes has been limited. Up scaling of technologies, pilot projects, proof of concept and business models are also lacking.

The growing interest in, and legitimacy for, industrial enzymes and technology is expected to improve competitiveness and sustainability of the agro-processing sector. However, advocacy forums for increasing the use of industrial enzymes are absent.

The major resource limitation is similar to the cases above, such as lack of venture capital, government support for developing pilot production facilities and inadequate funding for business incubation, establishing markets and improving business models World Bank (2013).

In summary, developing industrial enzymes is characterized by fairly strong processes in legitimation, but weak knowledge development, entrepreneurial activity, market creation, policy guidance and resource mobilization, which seriously limit the potential of this innovation system.

4.5 A Summary of the strengths and weaknesses

In the sections above, we have looked at six different processes of the four innovation systems and identified the strong and weak parts of the systems. The results for each function are summarized in Table 1. A quantitative scale of 1–4 has been used to rate the strength of the innovations systems and their functions and is described below. The criteria for the scale and the various levels are listed in Appendix 1.

Table 1: Strengths and weaknesses of the various functions in the innovation processes

Innovation case	Knowledge development	Entrepreneurial activities	Policy guidance	Market creation	Getting legitimacy	Resource mobilization
Crop improvement technologies	3	3	2	2	3	2
Value-added products from sorghum and millet	3	3	2	2	3	2
Converting agro-industrial waste to bioenergy and value-added products	3	2	2	2	3	2
Industrial enzymes for a sustainable bioeconomy	2	1	1	1	3	2

Legend:

1. Very poor. The function is not fulfilled, or there are serious weaknesses.	
2. Poor. While the function is partly fulfilled, there are major weaknesses	
3. Fair. While the function is broadly fulfilled, there are still important weaknesses.	
4. Good. The function is adequately fulfilled	

The following can be seen from Table 1:

- Legitimacy is fair in all four innovation systems. In general, legitimacy for all four innovation systems is strong among policy-makers, scientists and the broader development community. Legitimacy is however weaker among consumers and market actors pointing to the need for broader awareness raising and marketing.
- Knowledge development is not a limiting factor in using biosciences for improving seed systems, crop value addition or converting agro-waste to useful products, but is a limiting factor for industrial enzyme production
- Entrepreneurial activity is not a limiting factor in using biosciences for improving seed systems or crop value addition, but is a limiting factor for converting agro-industrial waste to bioenergy and a major problem in developing industrial enzymes for a sustainable bioeconomy.
- Policy guidance, market creation and resource mobilization are limiting factors in all four innovation systems.

In conclusion, R&D knowledge, technical and entrepreneurial capacities are no longer major limiting factors in the innovation systems studied, with the exception of industrial enzymes. The major problem and the key barriers are instead, a lack of policy guidance, market creation and resource mobilization.

4.6 Summary of major gaps

In Table 2 below, the major gaps identified in the four innovation systems are briefly summarized. Not all of the gaps are relevant to all of the innovation systems. Some of these gaps are general in nature for all cases and also for many industrial sectors, such as, high taxation rates on imported machinery and processing equipment. Other gaps are more specific to sectors or cases, such as lack of feed-in tariffs to sell electricity generated from biogas to national electricity grids, which is a negative factor for biogas production from agro-waste.

Table 2: The major identified gaps in the four innovation systems

Process	The major gaps
Knowledge development	<ul style="list-style-type: none"> • Weak skills in analysis of technological, economic, and market potential of innovations, especially in the public sector • Viable models and skills for up-scaling and large-scale production are lacking. As a consequence, production costs at commercial scale are too high • Business and marketing skills are a limiting factor • Market responses to innovations are lacking in most systems
Entrepreneurial activity	<ul style="list-style-type: none"> • Inadequate entrepreneurship skills in the public sector • Few SME engaged in bioscience innovation • Limited public private partnerships • Business incubation facilities are weak or lacking • Institutional skills and policies for protecting intellectual property are lacking both in the public and private sector
Guidance policies	<ul style="list-style-type: none"> • Specific policies are lacking such as tax incentives to lower barriers or create market incentives • Ineffective enforcement of environment legislation • High taxation on imported machinery and equipment • A lack of standards and certification processes for innovation products (e.g. micro-propagated crops, bio enhanced seeds, malted crop products)
Market creation	<ul style="list-style-type: none"> • Weak marketing skills and activities in establishing an interest in, and demand for, new innovations • Actors (e.g. farmers, SMEs, consumers) are unaware of the benefits new innovations can bring • Business models for up-scaling of technologies and pilot projects/essentially lacking • Government not active in creating a market for innovations (e.g. attractive feed-in tariffs for electricity produced from biogas)
Getting legitimacy	<ul style="list-style-type: none"> • Could be strengthened through marketing and improved awareness of new technologies/products • External drivers, such as interests and advocacy groups lobbying for a technology or innovation are weak
Resources	<ul style="list-style-type: none"> • Human resources and R&D structures are adequate for most innovation systems, with the exception of industrial enzymes production • Credit facilities are poor and interest rates unfavourable • Capital both for pilots and for more scaled venture capital is severely limited • Funding opportunities for the development of proof of concept and successful pilot projects are few • Business incubating services are unavailable

5. FACTORS SHAPING THE FOUR INNOVATION SYSTEMS

5.1 General observations on the innovation system structure

5.1.1 Actors and their networks

A large number of actors, both private sector and academic institutions, are involved in micro-propagation for crop improvement in Uganda and Kenya, and to a lesser degree in Tanzania and Ethiopia. There are few actors involved in Burundi and Rwanda. Despite the large number of private sector actors active in micro-propagation, so far few of them have engaged in micro-propagation of disease-free tuber cultivars.¹⁸ In all countries, there are advocacy groups for crop micro-propagation, such as the Tissue Culture Business Network of the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA).

Many private sector and academic institutions are involved in biogas production in the region, with the largest number in Kenya. Bio-Innovate projects are new entrants in this innovation system, in that they produce edible mushrooms from the agro-waste as well as biogas. No private sector actors are installing these technologies at agro-processing facilities on a commercial basis.

With respect to sorghum and millet, a growing number of private sector actors and academic institutions are developing new products from the crops.

Only a few academic institutions are involved in the development of industrial enzymes, and these are only in Kenya and Ethiopia. No private sector actor in the region is active in this field.

The actors and organizations needed to move bio innovations to the market do exist in the form of universities and research organizations, firms and enterprises, government agencies and civil society organizations, which are ready to interact and form a functional innovation system. The exception is in the production of industrial enzymes, which is a new area of R&D in the region, pioneered by a few research institutions and scientists. However, in all of the innovation systems, the actors are not interlinked to function well in networks or as consortia. This is particularly true with industrial enzymes. With all four systems, there is also a lack of specialized actors, supporting specific parts of the innovation systems. One example is the lack of agro-dealers for crop micro-propagation nursery inputs, which makes it difficult to establish local nurseries that can scale-up the dissemination of clean micro-propagated material.

As often seen in innovation systems, growth in the number of actors, and especially new entrants, can change the dynamics of a system relatively fast. One example is micro-propagation of bananas in Uganda and Kenya, where the number of private sector actors willing to explore market opportunities has increased rapidly during the last five years. This has had a positive influence on the dynamics of the innovation system. The strength of structural components and the number of actors is also clearly linked to the function of the system. Expanding knowledge formation, vibrant experimentation and entrepreneurship and a functional market stimulate new actors to enter the innovation system, catalyzing its development.

5.1.2 Technology infrastructure

R&D institutional infrastructure is a necessity for countries wanting to take part in the bioscience revolution. This includes the availability of laboratories and the management expertise to maintain them. The region now has many public R&D laboratories with modern research equipment, in both larger universities and agricultural research organizations.¹⁹ Many of these institutions

¹⁸ The focus has instead been on more commercial crops such as coffee, banana.

¹⁹ Including Kenya Agriculture Research Institute (KARI) and National Agricultural Research Organisation (NARO), Uganda.

also have functional greenhouses and facilities for field trials. However, equipment for large-scale and pilot-scale testing of agro-processing, waste treatment and biogas production is a limitation in all countries.

Physical infrastructure enabling the private sector to work closely with the public sector, such as innovation incubators or science parks, is largely absent in the region. Generally, weak infrastructure, lack of modern **roads**, power failures and water shortages also negatively affect innovation in the region.

5.2 Knowledge development

Knowledge development in all the studied innovations systems is at an acceptable level, although significant weaknesses remain in some areas. A challenge all countries face is maintaining and continuously upgrading the knowledge base in the R&D sector. This requires long-term government commitment and competitive funding opportunities that reward the formation of new knowledge that can feed into the innovation systems.

The Bio-Innovate Program has greatly strengthened the R&D knowledge base in all four innovation systems. Overall, Eastern Africa is at a point where the R&D knowledge base is no longer a major limiting factor in any of the four Bio-Innovate innovation systems studied, with the possible exception of the production of industrial enzymes. Gaps remain, however, including weak marketing skills and limited ability to assess the economic potential of commercializing technologies and products. Also, skills are weak in developing cost-effective production and commercial distribution regimes. These weaknesses are probably due to limited participation and engagement from the private sector in the consortia supported by Bio-Innovate. This makes it important for the partners in these innovation consortia to build new links with additional private sector partners with the necessary know-how, in the region and internationally. The ability to up-scale and commercialize bioscience innovation is also weak among SMEs in the region. In the private sector there is also a need for institutional learning, sharing experiences from successful technology dissemination and commercialization, and the ability to manage risk and find innovative financing solutions.

While public R&D institutions need to be effective in generating and adapting new knowledge and technologies, they are often ill equipped to move innovation beyond the research stage. This applies in particular to universities that are only structured and organized to train and educate. Universities in Eastern Africa are under increasing pressure to deliver tangible products from research. However, most Eastern African public institutions lack structures and policies for technology transfer and innovation, such as IP policies, IP management expertise, capacity to develop effective contractual agreements, marketing skills and the ability to establish links with market actors.

5.3 Entrepreneurship

The Bio-Innovate program, including the BIPCEA project has made a significant contribution to strengthening entrepreneurial activities in the four innovation systems, linking public R&D with private sector and market actors. Generally, there is a lack of entrepreneurial activity that moves R&D knowledge to the market. In the case of the micro-propagation of tubers and value addition to millet and sorghum, there is promising entrepreneurial activity. Breweries and food processors are increasingly interested in agro-processing of local crops such as banana, millet and sorghum. The number of actors engaged in value addition and agro-processing is slowly increasing in the region, which will have a positive influence on all four innovation systems. With the conversion of agro-industrial waste to bioenergy and industrial enzyme production, entrepreneurial activity is still limited.

Weak entrepreneurship skills at public R&D institutions is problematic. Given that very little R&D is done in the private sector in the region, it is crucial that there are entrepreneurial scientists in the public R&D sector able to see the potential for innovation and technology dissemination of ongoing and adapted R&D. Unfortunately, very few public institutions in the region have a rewarding environment for entrepreneurial activities.

The business potential for innovations is often either ignored or neglected in the design of research project proposals, as is the consequent need to decide whether market or non-market avenues will be appropriate for technology development and diffusion. This means products seldom reach the market and promising research remaining in the laboratory where it cannot contribute to economic development. A key problem for all of the studied innovation projects is a lack of business models and plans. It is striking to note that in all the case studies, R&D was not carried out in direct response to a clear and articulated commercial demand on the part of a private company or market actor, which often is the case in other parts of the world, including Europe and the United states. This is typically referred to as “market-pull” based R&D in contrast to “technology push” (Nemet, 2009). Potential commercial demand is a critical factor in assessing whether a particular innovation has commercial prospects and can therefore be distributed through commercial channels, or has no immediate market prospects. It would have been useful in all of the projects, if development and dissemination costs had been assessed early on, even if it was a rough estimation, to ensure market competitiveness and sustainability of these innovation systems.

The private sector in the region plays an increasingly important role in moving R&D to the market through innovation partnerships. However, in the Eastern Africa countries, as in many emerging and developing countries, few private sector actors are investing in R&D and collaboration between academia and the private sector is not common. One reason is that the private sector often does not know what the public sector is doing and what potential exists for collaboration. At the same time, the public sector is often largely unaware of private sector activities and market demands. Few mechanisms exist in the region for collaboration between academia and market actors, so there is little experience of how to collaborate. To add to the difficulties, there is distrust between the private and public sectors, which negatively impacts contact between them. There is also a need to raise awareness through success stories that show the potential for academic and publicly driven R&D to be used by the private sector.

Another problem is that actors in innovation consortia are seldom properly interlinked or supported to play complementary roles. The Bio-Innovate program has developed a number of novel innovation consortia. These consortia, including projects in the four technological clusters, would have been greatly helped by professional incubation services assisting with matters such as IP management, marketing, business plan development and accessing funding. These incubation services are largely lacking in the region.

5.4 Guiding policies and an enabling environment

An enabling environment and guiding policies are needed for an innovation system to be functional. All four innovation systems are also, to a large extent, influenced by, and dependent on, policies and regulations in a large number of policymaking areas, including science, technology and innovation (STI), agriculture²⁰, environment²¹, climate, energy²² industrial development and trade.

Uncoordinated, incoherent and conflicting policies are a significant problem for innovation in the region and a key reason for many of the policy gaps and constraints in the four studied innovation system. There is an absence of functional mechanisms for a broader integrated policymaking process, harmonizing and strengthening policies across sectors and moving towards agreed goals and

20 Seed policies, food and feed standards, certification procedures of biocontrol agents, etc.

21 Regulating discharge and waste treatment.

22 Policies, incentives for production of bioenergy

targets. All four countries also lack focused national goals, targets and specific government programs supporting innovation in the agricultural and agro-processing sectors. Having an effective priority-setting regime, action plans and a clear roadmap for supporting bioscience innovation and developing a bioeconomy, would assist with the move towards a broader and more integrated policymaking process.

All countries in the region have put significant effort into developing national STI policy frameworks. This includes new innovation agencies and innovation funding opportunities. This is a new development but in the case studies analyzed, the relationship between the national innovation policy environment (STI policies) and innovation outcomes is not obvious. It is often easier to see negative impacts from other policies that are not consistent with STI policies, or from an absence of policies or regulatory frameworks, than positive impacts from specific innovation policies. A major gap in the four innovation systems and in STI policy frameworks across the region is a lack of policies supporting entrepreneurship in the public sector, public private partnerships and mechanisms to support linkages among innovation actors. Policies designed to create demand for bioscience innovations are also absent (see below).

Policy gaps and barriers in several areas have affected the function of innovation structures in all the four studied innovation systems. In all cases, high taxation rates on imported machinery and processing equipment is a negative factor. With the conversion of agro-industrial waste to bioenergy, unfavorable, unclear and poorly defined feed-in tariffs to sell electricity generated from biogas to national electricity grids is also a negative factor. This could be addressed by policies such as financial incentives for using renewable energy, which would stimulate biogas production and efforts to improve agro-processing efficiency, utilization of agro-waste and drive the use of industrial enzymes. Conversion of agro-industrial waste to bioenergy and the production of industrial enzymes are also negatively affected by a lack of progressive environmental regulations. This allows agro-processing industries to continue 'business as usual', discharging untreated waste into the environment.

The lack of progressive seed regulations²³, which would stimulate the development of new, improved seeds and cultivars, is negatively affecting the innovation system around the development of micro-propagated tubers. Improved quality standards would have provided a positive incentive and accelerated innovation in this area.

Policies affecting SMEs are stifling innovation across all four systems. Much remains to be done in introducing regulatory frameworks and providing government support to simplify entrepreneurial activities, the development of start-up companies and improving skills in the private sector.

Another way governments could support innovation is by demanding certain products or innovation with particular attributes, through the government procurement process. An example is the constructed wetland system to treat waste, which has been rolled out on a small scale in institutions such as schools and prisons with some government support²⁴. This could also entail government offices, schools, and hospitals procuring value-added products from millet and sorghum. To date, government procurement has not been a major factor in any of the studied innovation systems. There are, however, government procurement schemes in the region that have made a difference. One is the procurement of micro-propagated banana tissue culture by the Government of Rwanda, which has created demand and supported an emerging private sector in this field.

Policies and institution's administrative routines are also important to support the flow of bioscience R&D from the public sector to the market. Generally, there is a lack of institutional structures and policies, including among Bio-Innovate R&D institutions, for technology transfer and innovation. This includes institutional IP policies, IP management expertise, the capacity to

23 E.g., India's guidelines and quality system for micro-propagated crops

24 Within the BIO-EARN Programme (1998-2010) in Tanzania and Uganda

develop effective contractual agreements, marketing skills, and the ability to establish links with market actors. There is also a lack of effective administrative routines for collaboration with partners from the private sector and from other countries. Slow procurement procedures, which have delayed the implementation of projects, have been a problem for all four Bio-Innovate technological clusters. Clearly, more effective procurement regimes are a key for improving all R&D institutions in the region.

In conclusion, for bioscience R&D to flow from the public sector to the market, governments in the region need to develop more effective and coordinated policies, incentives and guiding frameworks, which can steer and support innovation in key areas.

5.5 Market creation

Weak market demand for products generated in the four innovation systems has had a negative effect. Each system has the potential for a functional market to be established, but doing so is hindered by a lack of techniques, skills and resources to market technologies and products.

In all of the cases, market awareness and collaboration with the private sector have been key aspects of project development. Nevertheless, it is striking to note that none of the projects developed their R&D program and innovation agenda in direct response to a clear and articulated demand from a specific market, private company or market actor. While this is often the case with R&D projects developed in academia around the world, understanding demand is crucial in assessing the potential of an innovation, either for commercial distribution or for non-commercial public good.

In the case of micro-propagated tubers, this would require farmers being made aware of the economic benefits of micro-propagated and improved cultivars through farm extension activities, establishing farmer-driven nurseries, grassroots advocacy groups and active support from the public or private sector partners. The ability to sell farm produce on the market for attractive prices is also crucial. This has been demonstrated in Uganda and Kenya, where the development of improved and clean banana cultivars through micro-propagation technologies is clearly linked to market opportunities. Near cities, and where markets are lucrative, there is a high demand for micro-propagated banana plants, which is in contrast to rural areas that tend to be less well connected to attractive markets and, as a result, experience lower demand for micro-propagated cultivars. The same demand pattern is likely to apply to improved cassava, sweet potato and potatoes. Therefore, in many rural areas where markets for these cultivars are weak, it will be challenging to develop nurseries, maintain stable long-term dissemination efforts and up-scale activities.

With regard to sorghum and millet, much remains to be done to establish a stable market for value-added products, including investing in marketing and engaging consumers to get feedback on products and product development. These are long-term activities requiring substantial resources.

There is currently low demand for biogas among potential customers, including households, which highlights the need to create markets for biogas. The main marketing constraints for the production of biogas innovations include: i) lack of coherent marketing strategies, ii) little knowledge of potential target group(s) and their needs, and areas with the highest potential and, iii) lack of knowledge, skills and tools to establish business models for biogas production and to generate a stable flow of biogas customers and biogas producers.

It is a more complex matter to market industrial enzymes, and will rely heavily on successful pilot-scale studies and solid proof of concept. Convince potential users and buyers of the value of industrial enzymes will also rely on solid economic evaluation, and data on the use and performance of specific enzymes and related proprietary characteristics. Much remains to be done in this area.

5.6 Getting legitimacy

In all four innovation systems there is strong legitimacy for the impact the new technologies and products could have on food security, climate change resilience, converting agro-waste into beneficial products, and reducing environmental problems.

However, there are factors that are reducing this legitimacy. For example, as micro-propagated material improves, farmers can, to a large degree, use cuttings as planting material, which over time may lower demand, incentives, and the ability to develop a stable seed-delivery system. In the case of sorghum and millet, many potential consumers view them as “poor man’s” crops, which may lead to slow market development. In the case of biogas production, there is low demand for biogas among potential customers, including households. This might in part be due to a lack of awareness of the technology and its benefits among potential biogas producers and users, requiring awareness-raising efforts. In addition, developing and running biogas digesters is often seen as a dirty and unattractive job, which also negatively affects perceptions of the technology.

These factors could all be addressed by marketing, training and education. One option for cost-effectively supporting marketing, training and education efforts would be involving grassroots advocacy groups which could play a critical role in technology promotion.

5.7 Resources

The study shows that there are adequate human resources to drive the innovation process in the systems, except in the production of industrial enzymes where there is a lack of skilled scientists and engineers. However, more human resources and specific skills will be needed to enable all four systems to expand.

The cost of bringing a product to the market can be substantial and often far exceeds the initial R&D costs. Lack of capital and funding to move products to market are major barriers for all of the four innovation systems. Limited funding is especially hampering advanced stages of the process, such as pilot tests, up scaling, marketing and commercialization, product deployment and technology improvements.

Commercial credits from banks are not yet a viable option for funding innovation processes in the region. Given current weaknesses in national financial systems and an unstable business environment, commercial banks prefer to give credits to projects, which have considerable investment from industrial partners. Industrial and private sector actors are often only willing to co-invest in R&D projects after the pilot demonstration stage is complete and market prospects are promising. In addition, commercial interest rates are generally high (e.g. 10–25% per year in Uganda) and often unaffordable for new enterprises.

In general there is a severe shortage of venture and risk capital in the region to assist partners in the innovation consortia to move products towards commercialization. Pilot cases that demonstrate the market potential and performance of public technologies would be attractive to the private sector and could increase their appetite for taking a risk and investing in commercializing public R&D. Funding mechanisms for large-scale pilot testing and proof of concept would therefore be very valuable. It is, however, important to note that even when institutions are able to gather resources to run large-scale pilot tests with the aim of commercializing their R&D results, many of these pilot projects may not in the end be commercially successful.²⁵ This must be factored in when designing opportunities for funding innovation.

25 For example due to new market conditions, competition from alternative technologies etc.

6. SUGGESTED FRAMEWORK FOR ACTION ON BIOSCIENCE INNOVATION IN EASTERN AFRICA

Innovation is often a complex process that is highly dependent on policies, institutions, and financial and human resources. Countries in Eastern Africa are in the process of developing a more enabling environment for bioscience innovation, including the necessary structures and policies. At the same time, private companies and public R&D institutions are increasingly engaging in bioscience innovation. However, coordination is often lacking between different branches of government on developing policies, regulations and funding regimes that affect innovation and product development.

In this study, we have identified a number of gaps and barriers that affect the ability of these innovation systems to further expand and have a significant impact on development. Table 3 summarizes these gaps and barriers and the corresponding government and institutional responses, and also identifies potential actions to create a more enabling environment for these innovation systems. In the following sections, we elaborate on the suggested responses summarized in Table 3 and the key issues in the design of an enabling environment for bioscience innovation.

We have clustered the responses from the table into four broad categories of potential intervention:

1. Creating capacity: developing R&D organizations able to catalyze innovation
2. Building business: linking R&D with market actors
3. Creating market demand: establishing conducive policies and rule frameworks
4. Financing innovation: bridging the gap between R&D and the market.

6.1 Creating capacity: developing R&D organizations able to catalyze innovation

Countries in the Organisation for Economic Co-operation and Development (OECD), including the U.S., Japan, and countries in Europe, the private sector is investing heavily in R&D and applied research. This is particularly true in knowledge-intensive areas such as information technology and biotechnology. In other parts of the world, such as Asia, Africa, and Latin America, the public R&D sector drives the adoption of new knowledge and technologies, playing a strategic role in moving them to the market and to various sectors. However, public organizations need to build capacity in this area to be effective in transferring and disseminating technology, and also need to develop policies and structures that reward and foster entrepreneurship and innovation.

It continues to be a challenge in the region to offer the competitive remuneration and career opportunities needed to recruit and retain highly trained academic staff at public R&D institutions. Creating incentives for scientists to engage in innovation activities is a strategic issue that needs to be high on the science, technology and innovation policy agenda in Eastern Africa.

In summary, Eastern African countries need strong public R&D institutions able to catalyze innovation if they are to convert the promises of the bioscience revolution to economic opportunities. Below, we describe a number of key potential interventions to support R&D.

6.1.1 *Linking with the private sector*

Technology transfer is resource-intensive and time-consuming. For public organizations to engage in innovation and link with the private sector, they need to ensure that they have a certain minimum capacity in areas such as technology transfer and dissemination. This capacity could be in the form of a technology transfer office, or designated staff to support scientists in technology dissemination. This support could involve supplying agreement templates, advising on IP issues, conducting patent searches, and identifying appropriate and potential market actors.

Table 3: Summary of gaps/barriers and potential policy responses and actions from governments, public and private sector actors

Gaps and barriers	Potential responses from government and the public and private sector	
	Government	Public and private sector
Knowledge development Lack of business and marketing skills on how to move innovations from concept to the market	Provide additional funding for innovation. Support incubation services able to foster the innovation process and link actors in the innovation chain	Improve ability to analyze the technological, economic and market potential of innovations Strengthen links with private sector and market actors Establish institutional technology transfer units
Entrepreneurial activities Inadequate entrepreneurship skills in the public sector Few SMEs engaged in bioscience innovation Limited public private partnerships (PPP) Lack of institutional skills and policies in the public and private sector for protecting intellectual property	Support business incubator services Support the development of platforms for public and private sectors to meet and discuss opportunities for collaboration and technology transfer Develop clear national IP regimes	Provide incentives for entrepreneurship at institutional level Improve awareness of, and training on, entrepreneurship, marketing skills and business opportunities arising from public R&D Establish institutional technology transfer units able to facilitate public private partnerships and/or licensing of technology Develop institutional IP policies and IP management skills and provide IP awareness training
Guidance/policies Lack of coordination of policies and regulations affecting innovation Lack of policies and targeted government actions lowering barriers or creating market incentives for bioscience innovation High taxation on imported machinery and equipment, stifling innovation Lack of standards and certification processes for innovation products (e.g. micro-propagated crops, malted crops)	Develop functional mechanisms for a broader policy-making process integrating, harmonizing and strengthening policies across sectors in support of innovation Improve government policies for innovation and targeted government actions to foster specific innovation areas Consider lowering taxation on imported machinery and equipment, or provide preferential treatment for priority areas Improve standards and certification processes for novel products	Lobby for coordinated policies Lobby for specific policies and targeted government actions, e.g. feed-in tariffs to sell electricity generated from biogas to national electricity grids Lobby for improved standards and certification processes for novel products
Market creation Lack of awareness among market actors (e.g. farmers, SMEs, consumers) of the benefits of new innovations Government not active in creating a market for innovations	Promote innovation and support awareness of the potential benefits of innovations for sustainable development and economic growth Government procuring technology for key projects visualizing market potential	Improve marketing skills and activities in establishing an interest in, and demand for, new innovations Popularize successful innovations Lobby for specific government procurement.
Financial Resources Lack of ability to upscale technologies and to establish pilot projects/proof of concept and business models Credit facilities poor and interest rates unfavorable Venture capital severely limited	Government to increase support and funding for innovation, pilot projects, proof of concept visualizing market potential Government to actively mobilize support (e.g. from development banks, donors venture capitalists) for innovation	Public and private sector partners more active in exploring opportunities to share costs for pilot projects and proof of concept visualizing market potential Institutions to actively market examples of successful innovation and opportunities for profitable innovations to various funding agencies

6.1.2 Ability to assess economic and societal potential of R&D activities

The public sector has a key role in adopting new technologies. However, the ability to assess the potential of technologies and products for commercialization is weak among researchers in the region. As a result, they need access to expertise that can carry out a market assessment of the economic potential of their R&D.

If a private company is expected to develop and disseminate an innovation, it is important to be able to demonstrate the relevance and economic viability of the technology. This implies, a need for economic and/or marketing analysis in the design of the R&D projects, in addition to scientific evidence. It is therefore crucial that market actors are closely involved in the design of R&D activities; something R&D institutions or funding agencies need to address when funding innovation in the region.

It is also important to do regular studies on the effects of adopting bioscience-derived products on local and national economies, the environment, and human health, as well as on the resource efficiency of production processes. Such studies would help answer some of the concerns about the safety and socio-economic effects of the use of bioscience technologies, and also support future policies and funding strategies. These studies could be made by interdisciplinary consortia of scientists in the region, and possibly undergo peer review by high-quality international experts.

6.1.3 Rewarding and supporting entrepreneurship

If public organizations are to play a key role in adopting bioscience applications and transferring them to market actors, there is a need to develop mechanisms that reward staff engaged in innovation, technology and knowledge dissemination. This would entail:

- Creating a dynamic, flexible, competitive R&D sector where entrepreneurship and efforts to move knowledge to the market are rewarded and supported.
- Strengthening entrepreneurial skills at public R&D organizations and developing structures that encourage entrepreneurship, and putting in place rules, policies, and incentives that encourage innovation and entrepreneurship, such as rewards, competitive salaries and career development opportunities. This may require strategies and mechanisms that guide researchers on how to commercialize public R&D, which could be in the form of institutional policies and a person or a small office assisting researchers with marketing and negotiating contracts and agreements.
- Governments investing in their own innovation/competitive R&D grants schemes that promote bioscience innovation.
- Encouraging the development of public R&D spin-out companies.
- Establishing institutional policies that enable university staff to start spin-out companies and to disseminate technologies or knowledge.

6.2 Building business: linking public R&D with market actors

An enabling environment at national level consists of several interlinked components, combined with support and guidance from government in many areas. The first component is the funding of well-managed public research and the promotion of tight links between the public and private sectors. These links could be supported through university-based and/or government-supported business incubators, linking academia and the private sector. Mechanisms to fund and support the

crucial early product development phase of an innovation, is another important area for governments in the region to support.

The private sector plays an increasingly important role in moving R&D to the market through innovation partnerships. However, in Eastern Africa, few private sector actors are investing in R&D, and close collaboration between academia and the private sector is uncommon in the region. The public sector is, at the same time, often unaware of market and private sector needs. Consequently, there is a great need for support and activities to link up public sector and market actors. However, linking is not enough: there is also a need for incubation mechanisms that ensure all actors are interlinked and supported to play complementary roles.

Below, we summarize key interventions that would support tighter links between R&D and market actors.

6.2.1 Strengthening public private partnerships

Improving the public sector's ability to collaborate with private sector partners, including SMEs, could be promoted in the following ways:

Supporting public and private actors to meet and discuss opportunities for collaboration and development of consortia for technology transfer, adaptation and commercialization of public R&D. This could be done through initiatives like technology fairs and workshops. In such fora, public sector institutions and the private sector could negotiate and manage contracts and collaboration. In the long run, this may also include developing mechanisms through which the private sector would support staff in academia to carry out applied R&D.

Training and raising awareness of innovation opportunities: as well as training private sector partners and entrepreneurial scientists, grassroots advocacy groups play a critical role in innovation and promoting technology. These groups also need to be strengthened and trained in entrepreneurship.

Helping the private sector at the local level to engage in disseminating technology and collaborating on and R&D. Governments in the region could stress the importance of implementing policies to encourage innovation and private sector investment in R&D. This could be done through education and training, informing the private sector of opportunities and establishing mechanisms to reduce the business risks for the private sector. This may include tax incentives, targeted credit facilities and venture capital and transparent liability arrangements.

Supporting institutional offices for technology transfer at research institutions and universities. Experiences in many countries have shown that Technology Transfer Offices (TTO) play an important role in facilitating the commercialization of R&D developed by R&D institutes and universities. A problem in the region is that management teams at emerging institutional TTO's are often university researchers or lecturers with limited experience of the commercial sector. It is therefore important that the staff managing the TTOs have a deep understanding of market issues.

6.2.2 Business incubator services linking academia and market actors

Professional business incubation services can provide substantial assistance with technology and business incubation, including:

- business case development, viability analysis and strategy refinement
- market assessment and market access
- business model validation and market testing
- technology assessment (including IP assessment)
- business plan development (feasibility; strategies), and
- assistance with finding financing for up-scaling and commercialization.

Professional business incubation services are an important part of the innovation framework in the United States and Europe and also in Brazil and India²⁶ (Akçomak, İ. S. 2009). Biotechnology business incubators have also been established in South Africa, including the GODISA initiative, Acorn Technologies and eGoliBio²⁷ (Morris et al. 2015). In Uganda, an incubator (Bio-Biz incubator) has been established at the National Agricultural Research Laboratories (NARO) with support from the National Agricultural Research Organization (NARO).

Most incubators operate on a non-profit business model. Sponsors include universities, economic development organizations and other community-based groups, often with help from government. In developing countries, most incubators are government-funded.

The lack of professional incubator managers in the region is a challenge and it may be necessary to collaborate with incubating actors and services in countries with a more developed innovation and business-incubating market. Financing incubator services is also often a problem and multiple sources are often required. Operational costs could be shared by users, or outsourced.

6.3 Establishing conducive policies, strategies and rule frameworks

Countries in Eastern Africa have put significant effort into developing national science, technology and innovation STI policy frameworks. These policies are, however, often general and poorly implemented. Well-implemented policies, functional incentives and guiding frameworks are needed for bioscience R&D to flow from the public R&D sector to the market. We recommend that governments in the region take more action to implement effective regimes for priority-setting regimes, action plans and roadmaps for supporting bioscience innovation and in developing knowledge-based bioeconomies.

Below is a list of policy measures that governments and institutions in the region could follow to move towards a bioeconomy.

6.3.1 Policies and regulations at national and regional level

Long-term policies and effective and efficient national regulatory systems are important for countries to benefit from bioscience innovation. These include:

- Policies and regulatory frameworks that support entrepreneurial activity and public sector start-up companies.
- Policies and regulatory frameworks that create incentives for market actors to use bioscience technologies. These could be designed to improve resource effectiveness, environmental management and sustainable agro-processing using renewable energy.
- Standards and certification regimes that would assist innovation and new technologies (e.g. seed certification standards for the production of improved seeds/cultivars). Another example is the harmonization of genetic resource policies (e.g. seed laws, Plant Variety Protection (PVP) systems) and actions to enable formal and informal seed systems to reinforce each other.

26 The United States has probably the longest and most successful track record in incubating business between academia and the private sector. There are over 100 bio-incubators in the U.S.; the majority have been established with a mix of university and government funding, and most are associated with a single university or a network of universities. In Europe, the development of business incubators has been slower, and today there are 20 incubators in the United Kingdom. There are also systems for business incubation in Brazil and India.

27 Both eGoliBio and Acorn have had problems funding their activities for a host of reasons, including inadequate government funding, management problems and limited engagement from academia.

- Effective and supportive regulation that fosters rather than stifles innovation. An example of such regulation is the way biosafety regulatory frameworks are stifling the adoption of genetic modification (GM) and other novel bioscience technologies. A clear, transparent, practical and sustainable biosafety regulatory and compliance-monitoring framework is needed to ensure that regulations and applications are applied, reviewed and monitored in a science-based and predictable manner.

Ensuring bioscience and biosafety policies are consistent across government departments including those responsible for agriculture, environment, energy, industry, science and education. This would help to ensure an integrated and holistic approach to the utilization of modern biosciences and biotechnology from both an investment and a regulatory perspective.

Ensuring national policies are consistent with those of sub-regional and regional trade, economic, agriculture and innovation communities. The policies of organizations such as **Southern African Development Community (SADC)**, The Common Market for Eastern and Southern Africa (COMESA) and East African Community (EAC) need to reflect and be aligned with a common vision that utilizes bioscience innovation in the member states.

Implementing policies on antitrust, IP protection and standards that collectively encourage the entry of new companies and actors. This has been demonstrated in both the United States and Europe, where new actors, testing new technologies, new ideas and new ways of doing business have greatly stimulated innovation and technology dissemination (Fagerberg and Srholec 2008; Hillman et al. 2011).

6.3.2 Incentives, goals and strategies

Incentive systems, national goals, and strategies are important for creating an enabling environment for innovation. These include:

- Defining national priority areas and goals for bioscience research and innovation, with public investment in biotechnology research in public institutions guided by a long-term vision. Developing a short-, medium- and long-term strategy on how governments in Eastern Africa could support the agricultural sector to benefit from the bioscience revolution. A broad range of actors should participate in priority setting.
- Government procurement of innovations to initiate market demand.
- Establishing a prestigious and well-marketed bioscience innovation prize funded by governments in the region.
- Regular studies on the economic, environmental, resource-effectiveness and health effects of the adoption of bioscience-derived products in Eastern Africa. These would address some of the concerns about the safety and socio-economic effects of using bioscience technologies and support future policies and funding strategies. These studies should be carried out by interdisciplinary consortia of scientists in the region and possibly undergo peer review by high quality international experts.

6.3.3 Institutional policies

Policies and management routines at R&D institutes and universities are important in functional innovation systems. These include:

- Policies and administrative routines that support the flow of bioscience R&D to the market. This would include more effective procurement regimes for technical equipment.

- Organizational reforms and policy development at public R&D institutions that facilitate broad-based participation in regional and international research consortia and technology transfer initiatives. Such reforms and development would include institutional policies, structures and mechanisms for networking, R&D management, contract arrangements, IP management, financial accountability, transfer of funds, and exchange of staff.

6.3.4 Communication

Communication plays an increasingly important role in innovation. Communication and marketing are necessary to build relationships and establish trust and legitimacy with future product-development partners and end-users of the technology. They are also an important mechanism for obtaining information and feedback about preferences and needs, which can be built into the R&D programme to improve the chances of uptake and acceptance of the technology.

Innovation can be greatly enhanced by a cross-disciplinary approach to developing technologies and knowledge that brings together networks of researchers and practitioners from different backgrounds to share ideas and exchange experiences. Good communication is essential for this cross-disciplinary approach to be effective.

Thus, information exchange at meetings, seminars, workshops and hearings is essential and helps stimulate innovation. It could be promoted by scientists but also by governments, providing and promoting meeting venues and swapping ideas in key R&D areas. In summary, actors in the innovation system need to be trained to effectively communicate with various market actors and end-users.

6.4 Financing innovation

Funding partnerships, in which costs are borne by several parties, are usually needed to bring R&D to market. Creative models for this cost sharing need to be explored in any innovation and technology dissemination process. Public funding is often the base for R&D efforts in the region. But, to successfully bring the R&D products to market, new funding partnerships are going to be necessary, in which these costs are borne by several different parties. For example, matched funding programmes could be developed, in which R&D institutions co-invest with industry partners, thereby ensuring commitment from the industry partner and reducing the risks for all parties.

The type of innovation, for example whether it is an agricultural or environmental technology, will determine the type of funding mechanism that is needed. Whether or not the innovation is likely to be developed and diffused in a market or non-market context (such as disseminating a technology for the public good) will also be an important factor. In most Bio-Innovate projects, funding remains concentrated in the R&D phase of the innovation cycle, with inadequate provision made for large-scale application and commercialization of technology or products.

A range of funding models for sharing costs and raising necessary capital are needed for bioscience innovation to have an impact and help the region move towards a modern bioeconomy. These models include:

- *Government innovation funds.* New funding mechanisms for innovation are being developed in the region. Examples include the Kenya National Innovation Agency and increased funding for applied R&D in Tanzania and Ethiopia. This type of funding could be targeted to areas prioritized by the government and undergo peer review and strict evaluations. This could include government-supported programs that initiate and support effective innovation consortia that link universities and research organizations with market actors. The donor community may also play an important role, because funding aid can complement and strengthen government innovation funds.

- *Funding product development.* New funding mechanisms to support the crucial early product-development phase. Many R&D institutes and universities find it challenging to manage pilot-scale production and early-stage marketing. Support mechanisms and bridging finance through the early product-development phase of an innovation is crucial. This would help to move the innovation far enough along the product development pathway for it to be of interest to private partners. Such funding could be provided through a micro-credit scheme, government credits or soft loans.
- *Attracting venture capital.* Venture capital is scarce in the region, partly because Eastern Africa is seen as a region with high levels of corruption, dysfunctional public administration, fluctuating policies and weak markets. However, this is changing and international investment funds have an increased focus on Eastern Africa and the emerging economic opportunities in the region. To attract venture capital and new financing actors, including through crowd funding, countries in the region need strong institutions and innovation consortia able to respond to investors' expectations around accountability and delivery.
- *Attracting philanthropic investments.* The fate of Africa and the need to increase investment in the African agricultural sector is gaining increasing attention worldwide. At the same time, the number of philanthropic organizations investing in sustainable development is increasing. Thus, there is an opportunity to use philanthropic goodwill to fund Africa-driven bioscience innovation. As well as the need for actors receiving philanthropic support to be accountable, transparent and to deliver, there is a need for social marketing of opportunities and success stories about bioscience innovation.
- *Funding of public-good technologies.* With public-good technologies, funding will be required both for product development and initial dissemination through non-market channels. Funding therefore needs to be more evenly distributed throughout the innovation cycle and should be long-term, with governments taking a large share of the responsibility. However, dissemination through non-market channels also provides opportunities for a "demonstration effect", which, in the long run, may stimulate demand and enhance opportunities for the creation of local, self-sufficient enterprises.
- *Providing incentives for local private sector investment in research.* At present, R&D and innovation relies heavily on external funding from bilateral and multilateral donors and philanthropic foundations. To correct this bias, it would be necessary for governments to increase their own funding or, in parallel, provide incentives for private investment from the domestic private sector for R&D. At the same time, incentives would be needed to stimulate the development of technology markets and, in particular, the creation of local enterprises. These could include providing matching funds for product development, innovation funds, bridging finance and micro-credit in support of local entrepreneurs and farmers, particularly when they are purchasing improved seed or planting material for the first time.

7. CONCLUDING REMARKS

There is no one-fits-all solution for successful technological innovation in biosciences. Indeed, there may be a number of possible pathways to success for each individual innovation system in each country. This report aims to inform the choice of a pathway by identifying essential links, strengths and gaps as early as possible in the R&D and dissemination process.

For the four innovations systems studied, we can conclude that while advances have been made in collaborative research, product and technology development, the potential innovations are yet to be disseminated. However, in all of the systems, Bio-Innovate projects have, to different degrees, moved forward in the innovation process, demonstrating viability of potential products and technologies. Bio-Innovate itself is likely to have been an important factor in some of the improvements observed.

Ultimately, nurturing and strengthening innovation processes requires timeframes and stable mechanisms beyond those of most of the projects studied here. At the time of data collection, Bio-Innovate projects were finalizing their four-year implementation period. They had had all been delayed by slow procurement procedures. None will receive any significant market responses to their technologies and products within the project life. This emphasizes the long-term nature of innovation, although public funding is generally short-term. This is often particularly the case with funding from bilateral aid agencies and some public financing regimes that demand immediate results. It is therefore unrealistic to expect that much of what can be a 10–15 year innovation process is likely to be achieved within a three-five year period – often the time for which funds are allocated.

With all four innovation areas in this study, barriers to up-scaling and commercializing R&D results remain. Market demand is central for any innovation and new innovations will only be successful if the demand for these develops alongside. The R&D carried out in the systems, all of it done by the public sector, is often well targeted to a potential theoretical market demand. However, steep barriers in up-scaling and commercializing R&D results remain. For all four bio-innovation cases, a lack of market actors and potential end users in the early design of R&D, and poor mechanisms for market feedback during the development of R&D products, have resulted in weak market potential and business cases. In summary, much of the R&D in these innovations systems, and also in many areas of R&D and innovation throughout the region, is demand-driven, but not business driven.

A common feature of the four innovation systems is that most have weakly functioning innovation processes. The exception is the case of micro-propagation of disease-free cassava, sweet potato and potato, which is a more mature field of innovation where many of the processes are stronger. A visible, though not distinctive, pattern, is that improvements are taking place. For instance, the number of actors involved and knowledge formation is improving in all cases except industrial enzymes.

Processes such as entrepreneurial activity, market creation, guidance/policies and resources are weaker functions in all four innovation systems. Thus, a more pronounced focus on, and investment in, linking R&D with market actors, building business and up-scaling financing and marketing capability, would be more effective than strengthening R&D efforts alone. Continuous support for linking the processes in innovation systems is important. There also needs to be continuous feedback between the market, knowledge development and entrepreneurial activity. This would ensure that actors in the system are able to adjust the product or technology to the customer and the market. In many innovation processes, the actors never experience the positive loop in which a product on the market creates a response, enabling the development of a better product and improving the market creation and legitimacy.

The public R&D sector in Eastern Africa plays a strategic role in adapting and moving bioscience technology to the market. For the public R&D sector to succeed in this role, highly trained academic staff, competitive remuneration and career opportunities are needed. Additionally, public organizations need certain minimal capacity to be effective in technology transfer and dissemination. Public organizations also need to develop policies and structures that reward and foster entrepreneurship and innovation. All of this requires commitment and increased investment in strategic R&D and the development of innovation structures by governments.

Finding and developing the respective roles and responsibilities of the various actors along the value chain is crucial in an innovation process. The key to a successful innovation process lies in forging links among key actors at the appropriate time in the innovation cycle and, more particularly, in the life of the innovation. These links will differ according to the type of technological innovation²⁸ and whether the innovation will be disseminated through the commercial market or, as in the case of public-good technologies, non-market channels.

Not only is it important to carefully identify potential and necessary partners, it is also important to clearly define the roles of the different partners involved in the innovation process and to clearly agree on their roles and responsibilities in order to avoid misunderstanding or disappointment. Professional incubation services can greatly assist innovation actors with technology and business incubation.

Lack of capital and funding to move products to the market is a major barrier for all of the four innovation systems studied. For bioscience innovation to have impact and help the region to move towards a modern bioeconomy, a range of funding models for sharing costs and raising capital are needed. Action to mobilize support for innovation from agencies such as development banks, donors and venture capitalists is critical. It is promising to see that in countries such as Tanzania, Ethiopia and Kenya, new funding mechanisms for innovation are being developed. Although emerging and still weak, these funding mechanisms could also be targeted to the later parts of the innovation process to help bring products to the market. Governments could prioritize areas to receive this funding, which could be subject to peer review and strict evaluations. The donor community may also play an important role in future by providing funding aid to complement and strengthen government investments.

28 Agricultural, environmental or industrial sectors

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APPENDIX 1

Table 4, below, quantitatively defines the various levels for each function in the innovation systems.

Table 4: Definitions of functions

Functions	Definition of levels			
	1. Very poor Not functioning	2. Poor Some function, but still major problems	3. Fair Function acceptable, but still significant weaknesses	4. Good All functions/ structures adequate
Actors	No known/ visible public R&D programme; No known private sector actor active in technology or product dissemination. No networks of actors formed.	One to two public R&D visible programmes. At least one private sector actor active, engaged or involved in technology or product dissemination. Some attempts to form network of actors.	Three to five public R&D programmes involved. At least three private sector actors active, engaged or involved in technology or product dissemination. Network of actors functioning.	More than five public R&D programmes. More than three private sector actors active, engaged or involved in technology or product dissemination. Network of actors an active force in shaping an enabling environment.
Knowledge development	No known person or group of scientists working in the technology or product area; No proof of concept on knowledge generated. No knowledge on market conditions.	At least one group of scientists working in the technology or product area. Proof of concept completed. Little or no innovation by private sector partners or through public private partnerships. Some knowledge of market potential. No feedback ²⁹ from market.	More than five or at least two groups of scientists known to be working in the technology or product area. Some innovation/ and or technology dissemination by private sector partners or through public private partnerships. Limited market- feedback.	A firm and steadily improving platform of knowledge. Substantive innovation/ and or technology dissemination done by private sector partners or through public private partnerships. Positive market feedback.
Entrepreneurial activity	No known firm attempting to commercialize technology or product, nor any effort made at commercializing the product or the technology.	Technology embedded in the R&D sector. Few ³⁰ attempts to commercialize technology made and no techno-economic evaluations. No development of new start-up companies.	Attempts to commercialize technology started and a serious, ongoing collaboration with private sector. Techno- economic evaluations and business plans under development. Start-up companies emerging.	Commercializing technology well under way. Private sector partners engaged in market assessment and business development. Business plans being implemented. Start-up companies entering a market.
Guidance/ policies	Overall policies too general and not implemented. No specific policies/ guidance in place to foster development of technology. Existing policies/regulations or lack thereof stifling innovation. No, or very limited, discussion of policy gaps and barriers.	Some overall and specific policies developed having a positive impact on technology development. Awareness of policy gaps and attempts to address gaps and barriers.	Both overall and specific policies having a substantive positive impact on technology development. Attempts to address policy gaps and barriers. Active discussion among policymaker and stakeholders on the importance of creating an enabling environment for technology development.	Both overall and specific policies having a clear and catalyzing impact on technology development.

Market creation	No specific attempts by stakeholders or government to create a market. Market conditions unfavorable.	Attempts ³¹ made by actors (private and public) to create a market. Market potential established, but not yet utilized. ³²	Actors (private and public) successful in creating a market. Market potential established and initial feedback from market received. Government creating specific policies ³³ creating market incentives.	Actors (private and public) highly successful in creating a market. Solid feedback from market received. Government creating specific policies ³⁴ creating market incentives.
Getting legitimacy	Little acceptance by potential users of the technology. No reasons or rationale for using the technology. No legislation/policies or government priorities in favor of the technology. The value base in industry and society not in favor of the technology.	Acceptance by potential users of the technology. Some reasons/rationale for using the technology. Government legislation/ policies or government priorities create a limited demand for the technology. The value base in industry and society compatible with the introduction of the technology.	Demand from potential users of the technology. Strong reasons/rationale for using the technology. Government legislation/ policies or government priorities create a substantive demand for the technology. The value base in industry and society in favor of the technology.	A strong demand from potential users of the technology. Very strong reasons/ rationale for using the tech. Government legislation/ policies or government priorities create a strong demand of the technology. The value base in industry and society in strong favor of the technology.
Resources	No, or very limited, human resources or infrastructure ³⁵ available. No financial resources/venture capital/funding possibilities.	Limited human resources or infrastructure ³⁶ available. Limited financial resources available. No venture capital available. Some funding options available, but difficult to access	Adequate human resources or infrastructure. Sufficient financial resources and venture capital potentially available. Potentially good funding possibilities.	Strong human resources and infrastructure. Financial resources available. Good possibilities for venture capital. Good funding possibilities.

29 Enabling improvement of the innovation.

30 Only initial attempts, no serious attempts to engage private sector partners

31 Marketing attempts, informing end user/market.

32 Meaning that a potential market has been identified and evaluated but not tested in reality.

33 E.g. feed-in tariffs for electricity from biogas electricity generation using agro-waste.

34 E.g. feed-in tariffs for electricity from biogas electricity generation using agro-waste.

35 Laboratory infrastructure, R&D infrastructure, industrial infrastructure.

36 Laboratory infrastructure, R&D infrastructure, industrial infrastructure.

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