RIS
Research and Information System
for Developing Countries

Asian Biotechnology and Development Review
Vol. 11 No. 3, pp 11-33

Secrets to Developing a Successful Biotechnology Industry: Lessons from Developing Countries

Victor Konde*

Abstract: A handful of developing countries have successfully built some of the necessary scientific, technological and industrial capacity to take advantage of the opportunities presented by biotechnology. The early enthusiasm and expectation that biotechnology will address some of the challenges of poor countries has not translated into the successful diffusion and use of the technology to meet the economic and social needs of most countries, especially in Africa.

This paper discusses four strategies or approaches that have been used to develop biotechnology industry in some developing countries. The paper argues that it may be necessary to start with small demonstrative initiatives and build the necessary capacities using inspiring initiatives; encourage partnerships and joint-ventures; narrow the focus of biotechnology programmes in the beginning; and encourage participation and commitment of all the key ministries and the private partners in designing and implementing national biotechnology strategies.

Keywords: Africa, alliances best practice, biotechnology, development, strategies.

Introduction

Widespread optimism was expressed in the early development of biotechnology that it will contribute immensely to meet some of the global challenges. During the United Nations Conference on Trade and Development in Rio in 1992, biotechnology was seen as a possible tool that could "make a significant contribution in enabling the development of, for example, better health care, enhanced food security through sustainable agricultural practices, improved supplies of potable water, more efficient industrial development processes for transforming raw materials,

* Economic Affairs Officer, United Nations Conferences on Trade and Development (UNCTAD),Geneva, Switzerland. Email: victor.konde@unctad.org.

support for sustainable methods of afforestation and reforestation, and detoxification of hazardous wastes".[1]

Since then, the global biotechnology industry has grown tremendously. For example, it is estimated that over 400 biotechnology health products targeting over 200 diseases[2] were in use. The revenues from products and services in the health sector alone has increased from about US$8.1 billion in 1992 to about US$58.5 billion in 2008. It is estimated that publicly trade biotechnology firms in the US alone were worth about $360 billion as of 2008.

Similarly, about 125 million hectares were planted with genetically modified (GM) crops in 25 countries (three from Africa) by about 13.3 million farmers.[3] This is thought to be the fastest adoption rate of any agricultural technology in history. Most of the GM crops being planted especially in developed countries carry more than a single trait in one variety or hybrid. In terms of benefits, GM cotton is thought to have increased yields, reduced insecticide use and increased income of farmers by up to 50 per cent in China and India.[4]

Industrial and environmental biotechnology has also been growing at a very fast pace over the last decade driven by fuel insecurity, environmental concerns (climate change), rapid technological developments and business opportunities. The surging oil price since 2003 presented a perfect storm that drove policy makers, industrial leaders and scientists to invest in biotechnology platforms, especially in alternatives to petrofuels.

For example, the bioethanol and biodiesel production and consumption have grown rapidly over the last few years. The global bioethanol production nearly doubled between 2000 and 2005 while that of biodiesel nearly quadrupled in the same time. Brazil and the United States account for nearly 90 per cent of the 62 billion litres global production of bioethanol in 2007. The total bioethanol production is expected to reach 127 billion litres in 2017 according to the *OECD-FAO Agricultural Outlook: 2008-2017*. Biodiesel production is expected to reach some 24 billion litres by 2017.[5] In terms of feedstock, Brazil derived all its bioethanol from sugarcane while the United States derived most of bioethanol from corn.

There is a greater policy push for development of domestic biofuel production capacities in developing countries as a way of eliminating excess agricultural produce as well. For example, it is thought that India increased the mandatory blending levels of petroleum with bioethanol from 5 per cent to 10 per cent to get rid of excess sugar which, if dumped on the international market, would have depressed international market prices further.[6] However, both developed and developing countries have been investing heavily in industrial biotechnology with a great focus on second-generation biofuel production technologies using non-food raw materials.

It is, thus, not surprising that the number of industrial biotechnology patents were estimated to have increased from 6,000 in 2000 to 22,000 in 2005. Currently, about seven per cent of the products in the chemical sector, worthy about $77 billion, are produced using industrial biotechnology platforms (biobased feedstocks, fermentation or enzymatic conversion) in 2007.[7] Sugar is seen as an important feedstock in chemical industry that could be converted into bioethanol and a variety of basic building blocks for various chemicals.

The growth of biotechnology in developing countries has been equally impressive. Countries such as Brazil, China, Cuba, India, Singapore, South Korea and South Africa have committed significant resources and provided policy directions for the development of a domestic biotechnology industry. Countries such as Singapore and Korea have even emerged as global centres for cutting-edge stem cell research. These countries are offering modern facilities and support similar to the strategies they employed during the development of information technology.

Many of trends in the global biotechnology industry could greatly benefit Africa. In many areas, Africa could become an influential player and exploit the technology to meet its own economic and social development. Currently, the continent is largely being bypassed.

In this paper we argue that part of the challenges that continue to prevent Africa from benefiting from biotechnology include the lack of focus and coordinated strategies, and failure to identify clear and realistic opportunities that inspire and induce sustained public support for biotechnology.

The paper is structured as follows: Section 2 presents a broad overview of selected characteristics of the biotechnology industry, section 3 highlights selected national examples that have successfully been used to build some biotechnology capacity while section 4 points out some of the critical elements and lessons learned from the policy strategies implemented by the discussed developing countries (Brazil, Cuba, Korea and South Africa).

Some Common Features of the Biotech Industry

It is important to remember that biotechnology is both a multidisciplinary and knowledge-intensive field as much as it is a business that requires good regulatory and market structures. Here we look at selected key characteristics of the biotechnology industry by providing an overview of the need to attract the right investment, to seek ways of cutting costs and sharing risks and to design favourable government policies that encourage research and investment.

Biotechnology: The Science and The Business

Jong (2009) summed up the business of biotechnology simply as "cash plus pipeline equals new company". In a nutshell, many biotechnology start-up companies have no product on the market but promising potential products of interest to investors. Similar sentiments were echoed by Stelio Papadopoulos, Vice Chairman of the SG Cowen – a financier of biotechnology – who was quoted saying "Genentech (the first biotechnology company to go public) showed that people invested on the hope that new technology or ideas could make a big difference".[8]

The continuous generation of new knowledge keeps public or private investors excited about future growth prospects in the biotechnology industry. Biotech companies, in turn, have to keep innovating if they want to ensure increasing returns through new products and attract more investment.

However, most investors do not necessarily invest in the products alone but take the bet on an entrepreneur's management capabilities too. The risks of bringing the product to market involve the navigation of complex regulatory procedures and hurdles that could be expensive. Thus, in addition to exciting opportunities, investors take a bet on a sound *management team* [9] that they can trust to bring the product(s) successfully to market. This is not necessarily unique to biotechnology but is common to most other sectors.

Like other areas of business, the opportunities need to pass at least two basic tests to be of interest to investors: 1) A general trend towards improving or changing the status of the entrepreneur(s) and investors involved 2) Management teams that have the capacity to develop and believe they can successfully realise the venture.[10] Therefore, it is not surprising that biotechnology seems to flourish in regions and countries where resources are available, possess talented and experienced successful entrepreneurs willing to invest in the projects of other community members and continuous reinvention of the industry is encouraged.[11]

Many of the biotechnology clusters are among the regions where resources (finance, R&D and management) are mobile and success is celebrated. For example, the biotechnology clusters of California and New England (Boston area) have generated a number of biotechnology firms due to the high concentration of top life research universities. As a consequence, a number of firms founded elsewhere tend to migrate to these centres for several reasons, including access to knowledge and finance. They are homes to some of the key biotechnology investors and are rich in qualified and experienced scientists, managers and service providers that have been involved in the development of biotechnology firms over the last three decades.

In 2007, for instance, Targanta Therapeuticals moved from Montreal to Boston just ahead of its Initial Public Offering (IPO) while Logical Therapeutics moved from Pittsburgh to Boston as well following a $30 million in venture capital funding. Even though Boston is an expensive place for growing a start-up, it offers the innovation ecosystem that few other places can provide.[12]

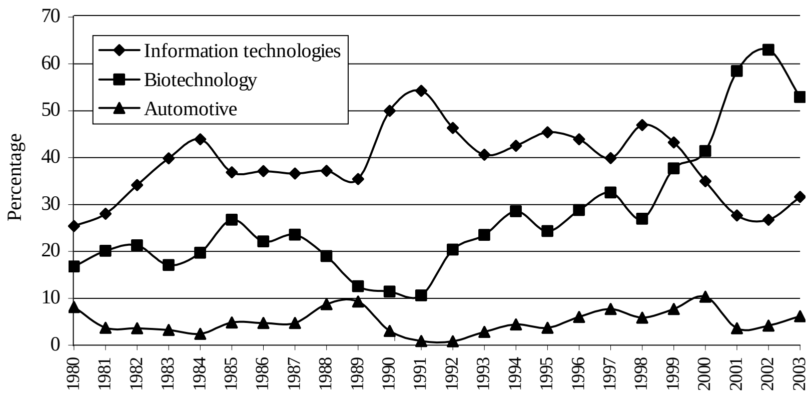
Industrial Technology Alliances

Industrial technology alliances, as defined by the US National Science Foundation (NSF), are "industrial technology linkages with the aim of co-developing new products or capabilities through R&D collaboration".[13] There are at least four factors that promote the development of industrial alliances in biotechnology: (1) the multidisciplinary nature of R&D activities; (2) the increasing complexity of R&D; (3) the uncertainty of commercial success of R&D products; and (4) the cost of R&D activities.[14]. Firms may seek alliances to spread the cost, risks and uncertainty, especially in fields where there are restrictive and often lengthy regulatory regimes.[15]

Globally, the number of industrial technology alliances developed per year has grown rapidly from about 185 in 1980 to about 695 in 2003. In the last three decades, most of the industrial technology alliances have involved firms in the United States, Europe and Japan. About 50 per cent of the industrial technology alliances in 1980 involved firms in biotechnology, information technology and automotive firms. The share of alliances in these three industries increased to 64 per cent in 1990 and 91 per cent in 2003 (see Figure 1). One study that looked at the number of research alliances signed by the top 22 pharmaceutical firms in the world revealed that their partnership arrangements increased from 27 in the 1982-87 period to about 87 in the 1987-92 period and 112 in the 1993-1997 period.[16]

Similar trends are also emerging among developing countries. For instance, Cuban biotechnology firms have increasingly entered

Figure 1. Industrial Technology Alliances (as a proportion of total)



Source: Based on NSF Science and Engineering Indicators

into joint ventures and other collaborative arrangements with other firms in developing countries. However, it seems most of the collaboration in biotechnology are marketing seeking in nature. Small emerging firms with good biotechnology products lack the marketing and financial resources needed to exploit their products in emerging markets abroad.

For instance, Heber Biotech of Cuba has entered into various strategic alliances with Brazilian, Chinese, Indian and South Africa firms. In many cases, Heber contributes a number of its biotechnology products and the production platforms while the partners contribute the financial, institutional and operational resources needed to produce and market the products in agreed markets (For details see page 24).

This is not surprising as most partnering arrangements could, potentially, play a key role in the development of technological capabilities in start-up firms. Such capacity would be specialized and related to specific products and services. Furthermore, such partnering would also be useful in promoting the adoption of good management and industrial production standards especially in new and emerging fields.

Biotechnology Clusters and Centres of Excellent

The importance of clusters in biotechnology cannot be overemphasized. In Europe, Japan and the United States of America, biotechnology programmes to foster national competitiveness seem to have been based on well established and managed national public research institutions in agriculture, environment, mining and human health. Some of these institutions developed biotechnology research centres that accumulated considerable technological capabilities in the field and served as major sources of scientific knowledge in various aspects of biotechnology.

Biotechnology clusters, as already mentioned above, have generally formed in locations with excellent life science and biomedical research universities and centres, sufficient financial support, talented entrepreneurs and other support institutions. These include large and well established technology clusters in New England and California in the United States, the Biovalley (France-German-Swiss border), West Havana scientific biopole in Cuba and the Cape Town biotechnology cluster in South Africa among others. The presence of excellent research centres seems to be a prerequisite but is not sufficient by itself to stimulate the emergence of a vibrant biotechnology industry.

Favourable Government Policies

There are many factors that are driving the growth of the biotechnology industries but none has been as decisive as favourable government policies. Government policies have been instrumental in the growth of the agricultural, industrial, environmental and health biotechnology sub-sectors. For instance, research in the bioenergy sector has been driven largely by favourable government policies in the European Union, Brazil and the United States. The policy differences in these countries, for instance, have influenced private and public investment.[17]

The successful bioethanol production in Brazil and Zimbabwe and the successful co-generation of electricity from bagasse (and coal) by sugar mills in Mauritius are just among many examples where government interest played a greater role in bio-energy sector.[18] Governments in these countries guaranteed to either buy the excess electricity or pass policies that required blending of petroleum with ethanol by all oil marketing firms and production of motor vehicle that were tailored to use such fuels. Several countries, including Brazil, Columbia, Cuba, India, Thailand, Mexico and the Philippines, provide incentives to their sugar industries to promote co-generation of electricity from bagasses, a technology that was pioneered in Mauritius and Hawaii.

Similarly, biorefineries in the US benefit from government support. The Energy Bill passed by the US Senate in December 2007 is an example. The bill seeks to boost production of fuels, power and other products from biomass through an investment of about US $ 3.6 billion and mandates that 36 billion gallons of biofuel will be consumed by 2022, of which 15 billion gallons may be bioethanol derived from corn.[19] To achieve this target, the Farm Bill passed in 2007 also provides $1.1 billion to encourage farmers to grow biomass crops and $1.1 billion in tax credits for biofuels, including from cellulosic materials with a target of 7.5 billion biofuel production by 2012.

Public interests or concerns are also playing an important role in biotechnology policy and its evolution. The increasing consumer concerns over antibiotics used in animal production and consumer interests in natural products are fuelling the growth of the market for bio-based products (e.g. probiotics and nutraceuticals). On the other hand, public concern on the use of GM crops and animals is limiting the adoption of transgenic crops and animals for industrial use.

Perhaps nowhere has government policy been more important to biotechnology development as in agriculture and health where differences in perception of risk have had a major impact. The moratoriums imposed by government on field trials and cultivation of genetically modified crops have hampered investment in biotechnology. The ban by the US administration on use of public funds in stem cells research is thought to have encouraged migration of researchers to Korea and Singapore – propelling the research capabilities of these countries to new levels.

Other areas of governance such as intellectual property rights (IPR) and technology commercialization have also been essential to the development of biotechnology.[20] This is important as industry and public research institutions and universities have worked very closely in the development of biotechnology products and services. In initial stages, most biotechnology start-up seem to emerge from or with some input of research universities and their scientists. Clear technology commercialization regulations and intellectual property ownership rules are key to securing private investment, seeking partnerships and defining equitable sharing of the benefits of such activities.[21]

Strategic Approaches to Develop the Biotechnology Industry

Many African countries are unlikely to possess the human, institutional and financial resources needed to apply biotechnology in all sectors of the economy and the level of investment and regulatory procedures required to successfully develop and bring innovative biotechnology products to market. One of the challenges in recommending strategies lies in setting priority areas for biotechnology research, product development and use due to the number of competing urgent needs in agriculture, nutrition, health, industry and environment, to mention but a few. This is made more difficult by the long list of support measures that are needed in order to enable biotechnology deliver, such as human capital, R&D investment, industrial and market regulations, infrastructures and their related policies, among others.

To tackle these challenges, we discuss simple but effective approaches that have successfully been used by a number of developing countries, including some Africa countries. These approaches are not mutually exclusive and they are less complex and within the current institutional set-ups and constraints of many African countries. They do not necessarily involve creation of new centres but rather smart use of incentives that may save resources, create jobs and propel Africa to a new stage of development.

The Project Approach: The Cases of Genomics Development in Brazil

One of the common ways of acquiring technology is through challenging projects. For example, very few will argue with the assertion that the human genome project launched in 1990 "spurred a revolution in biotechnology innovation around the world and played a key role in making the United States the global leader in the new biotechnology sector".[22] It revolutionized methods for genome sequencing and analysis and led to the development of tools for designing and developing biotechnology-based diagnostic, management and treatment of diseases.

In the same vein, the scientific community was stunned when a Brazilian team of scientists announced they had completely sequenced the first plant pathogen genome using a virtual institution - Organization for Nucleotide Sequencing and Analysis (ONSA). *The Economist* wrote "SAMBA, football and...genomics... The list of things for which Brazil is renowned has suddenly got longer".[23] At the time genome sequencing was the preserve of centres of excellence such as The Institute of Genomic Research (TIGR - now Craig Venter Institute) and the Sanger Center, among others.

The project was not triggered by some national consensus or special workshop but a suggestion by one Brazilian scientist to the São Paulo State Research Support Foundation (FAPESP) to consider financing a genome sequencing project. FAPESP is entitled by law to one percent of all the revenue collected in the State of São Paulo, Brazil's richest state, and FAPESP is required not to spend more than 5 per cent of the funds on administration.

The choice of *Xylella fastidiosa,* an organism with a genome size of 2.7 megabases, was based on its economic importance and its relatively small genome size. The organism causes losses of approximately US $ 100 million to the citrus industry in Sao Paulo. The State of Sao Paulo accounts for about 87 per cent of Brazil's orange production, corresponding to 30 per cent of the world production.

From the outset, FAPESP decided to fund the genome sequencing project to involve as many laboratories and scientists as possible in the acquisition and development of modern biotechnology tools. Therefore, they settled for a virtual institute composed of about 34 independent laboratories and teams belonging to universities and research institutions with some basic knowledge of sequencing. For this reason, the initial $11.6 million budget helped to set up two central sequencing laboratories and a bioinformatics unit that serve to coordinate the project while all the other selected laboratories received the necessary equipment and training.

The management of the institute was tailored to encourage the generation of high-quality data in the shortest possible time. The selected laboratories agreed to generate a minimum number of high quality sequences in a fixed time. Laboratories that deposited more good quality sequences got more money. Further, the representatives of the participating laboratories, about 200 participants, met once every four to five weeks in person to review progress and make fresh plans. This was important as daily management was performed via the Internet.

ONSA was so successful that the Ludwig Cancer Research Institute invested US $ 15 million in ONSA for its Human Cancer Genome Project. ONSA deposited over 1 million sequences which made the team one of the main contributors to the Human Cancer Genome Project. Similarly, the United States Department of Agriculture (USDA) contracted ONSA to sequence a strain of *X. fastidiosa* that afflicted vineyard in Californina. The ONSA project also spun-off two companies and exposed more than 200 scientists to cutting-edge genome sequencing tools. The knowledge acquired has enabled many participating laboratories to attract contracts and funding and seek partners.

One can argue that carefully selected projects could easily stimulate innovation and technological development and catapult a selected number of centres to a new level of development. In Africa, the African Malaria Network Trust (AMANET) is playing an important role in building capacity in research institutions to undertake malaria vaccine clinical trials by providing training, equipment and developing the trial sites as well as promoting collaborations. A number of these centres are already participating in vaccines clinical trials.[24]

Strategic Sequencing of Biotechnology Industry Development: The Case of Korea

One of the challenges faced by Africa countries with limited resources in developing a biotechnology industry is deciding which sectors or fields to support. It is for this reason that the Korean biotechnology initiative is a good example of how to harness limited resources to focus on common areas that play a key role in all sectors. Here we place focus on the Korean Biotech 2000 plan to draw some lessons.

In 1993 the government developed the Korea Biotech 2000 plan[25] of action with three main phases and a total investment budget of US $ 15 billion by 2007. The first phase (1994-1997) aimed at acquiring and adapting bioprocessing technologies and improving performance of R&D investment. A total of US $ 1.5 billion was earmarked for the first phase: $ 482 million from the government and $1 billion from the private sector. The main goal of this phase was to establish the scientific foundation for the development of novel biotechnology products.

The second phase (1998-2002) focused on consolidation of the scientific foundation to develop platform technologies and improve industrial R&D capabilities. A total of US $ 2.3 billion ($1.6 billion for the private sector and $ 720 million from public sector) was earmarked for this phase. The last phase (2003-2007) targeted development of commercialization capabilities to achieve increased global market share of Korean development biotechnology products. The target was to achieve a 5 per cent global market share for Korean novel biotechnology products. An investment of $10.5 billion (of which US $ 4.3 billion was to come from the public sector) was envisioned as necessary to achieve the objectives of the third phase.

In order to achieve these goals, a management and operating committee was put in place consisting of the public and private sector. Each of the ministry involved indicated their level of investment and the key technologies to be acquired or developed. For example, during the second phase, the Ministry of Science and Technology focused on screening and development of new drug, genomics and integrating information technology and nanotechnology in life science while the Ministry of Agriculture and Forestry focused on bioprospecting and biodiversity screening and protection, transgenic technologies and plant and animal genome research.[26] In a way, they sought to target technology platforms that could be used for more than just one set of products.

It is now estimated that the biotechnology industry in Korea has an annual turnover of $4 billion a year and has been growing at approximately 10 per cent per year.[27] It was also recognized that most of the Korean biotechnology firms focused on stem cell, cell therapy and anti-cancer drugs followed by nutraceuticals or functional foods with health enhancing properties.[28] Some of the major products include Hepatitis B vaccine (40 per cent of world the market), amino acids (20 per cent of the world market) and rifamycin (10 per cent of the world market). A number of key technologies developed in Korea have been licensed to some of the top firms such as GlaxoSmithKline and Johnson & Johnson.

The creation of a platform where public research institutions and the private sector interact was one of the key elements for the commercial success of research outcomes. Another key element is central planning where the government ministry responsible for promoting biotechnology in the country does not necessarily control most of the research centres or provide incentives to industry directly. Getting the commitment of other ministries to promote human resource development, technology transfer and development and to support industrial growth in the areas of interest may be important.

Another interesting element is that the Korean biotechnology sector imported most of the enabling technologies such as fermentation, vaccine and drug screening and production capabilities from developed countries to enable it to develop and export drugs, vaccines and diagnostic kits. In addition, the biotechnology strategy has been focused and goal-oriented. They chose where and what they needed to build their industry as well as whom to work with. For instance, Korea had biotechnology innovation partnerships with Denmark (2006), Israel (2008) and United Kingdom (2008) in addition to science and technology research centres in Germany (Korean Institute of Science and Technology, KIST-Europe, 1996) and in Russia (Korea-Russia Scientific and Technological Cooperation Center, 1991).

Biotechnology as Part of National System: The Case of Cuba

In 1980, a small team of Cuban scientists set out to produce alpha-interferon. Within 42 days, the team had accomplished the task. Encouraged by the results the Government funded the establishment of a host of institutions, which included the Center for Biological Research in 1982, which was later replaced by the Center for Genetic Engineering and Biotechnology (CIGB) in 1986. It also established centers that specialized in immunology, biomass conversion, animal production and tropical medicine.

By 2000, there were at least 33 university departments and 210 research institutions employing about 12,000 scientists and 30,000 workers, respectively, involved in biotechnology. The CIGB alone employed more than 1,200 scientists and technicians in eight divisions and 192 laboratories by 1999.[29] CIGB is composed of individual quality research units that together form a 'centre of excellence'.

Cuba's R&D expenditure as percentage of GDP was estimated at 1.2 per cent and the country invested about $1 billion over the last 20 years in biotechnology. In return Cuba's biotechnology centers have produced at least 160 medical products, 50 enzymes and probes for plant diseases among others.[30] In some cases, Cuba produced unique remedies or products that other nations did not have. For example, the cardiostrep, a product that could be used to dissolve fat clots, was a unique product. By 1998, the biotechnology sector was making up to $290 million in sales and placed the sector as the fourth main foreign exchange earner after tourism, tobacco and nickel exports. Since then, Cuban biotechnology research institutions have developed commercial arms that are increasing seeking partners abroad to increase their market share and expand the benefits from their R&D investments.

The Cuban biotechnology industry is a closed network or cluster of supportive institutions. It comprises R&D, exports and imports, manufacturing, information and communication, maintenance, advisory and policy, and regulatory institutions. This structure promotes recombination of knowledge and is cost-effective. Although Cuban biotechnology is government-managed and driven, it has all the characteristics of a mature privately managed business cluster.

The Cuban medical and health-care biotechnology industry is part of the national health-care system and targets the country's health problems. Most of its research products are generated largely by native scientists. The industry is a closed circle where spin-off firms remain linked to research and production institutions. It is the result of a national endeavour, with proper human and financial resources.

By making biotechnology part of the health-care system, biotechnology policies and support are discussed from a specific national area of interest rather than in general terms. In a way, a country could include biotechnology in an area where it thinks it can make a major contribution. This also departs widely from the approaches used in Africa where biotechnology and biosafety policies have been developed largely with support from outside. While there is nothing wrong with external funding, many good projects are often abandoned once the donor that supported the initiative leaves for reasons not related to biotechnology.

Technology Transfer through Joint Ventures and Alliances

As stated earlier, strategic alliances are a common feature in biotechnology but are largely concentrated in developed countries. However, there is increasing evidence that developing countries' biotechnology firms are seeking partners both in developing and developed countries for different reasons. For example, the Cuban biotechnology firm Heber is establishing joint-ventures with other firms in developing countries such as Biocon of India to exploit their technologies and access markets. Furthermore, Cuba's CIMAB SA entered into a joint-venture with Biocon to develop a state-of-the-art facility to produce CIMAB's monoclonal antibodies for the treatment of headache and neck cancer. The new firm, Biocon Biopharmaceuticals Private Limited (BBPL), will develop and market a range of monoclonal antibodies and cancer vaccines. Under this arrangement, Biocon holds the marketing rights in India, whereas Cuban CIMAB has a licensing tie-up with a US company for marketing of the products in the US, Europe and Japan.[31]

A similar trend is observed in China and South Africa where strategic joint-ventures are being promoted even by government support institutions. For example, South Africa's Public-Private Partnership (PPP)[32] initiative supported the establishment of the Biovac Institute – a joint venture involving British, Cuban, Thai and local interests (jointly called the Biovac Consortium) and the government of South Africa's former State Vaccine Institute. Similarly, government supported biotechnology funds have facilitated the acquisition of technology by local firms. BioPAD secured the transfer of recombinant expression technology (strains of micro-organisms and cell lines) from the Swiss based firm - Solidago AG – to produce Bioclones at a cost of $ 5.3 million investment. This facilitated the development of Ribotech Pty as a joint-venture between Bioclones and Solidago AG with government support.[33] BioPAD is a Biotechnology Regional Innovation Centre (BRIC) established by the Department of Science and Technology to promote the development of the biotechnology industry in South Africa in 2006.

These arrangements are seen as crucial in enabling countries lagging behind to quickly gain access to knowledge, learn and run a business without needing to rediscover the "wheel". The risks of developing, producing, distributing and marketing new products is drastically reduced in such joint-ventures because even the least developed country party may easily obtain exclusive access to its market especially where the government has a stake in the firm. Key to these arrangements is the government playing a facilitating role in technology transfer through joint ventures by completing science and technology agreements. For example, South Africa is already coaching Zambia on how to redesign its biotechnology policy. To do this, South Africa insisted in including biotechnology as one of the areas of cooperation between itself and Zambia in the science and technology agreement. A similar push is also seen in the recent science and technology agreements between Brazil, India, Nigeria and South Africa. With rapidly developing economies and growing markets, some developing countries are strategically seeking joint-ventures to position their firms to benefit from these trends. It illustrates the different options for joining the biotechnology revolution by riding on the R&D investments made by others.

Reselling the Promise: Common Elements in Success Strategies

All the strategies given above have succeeded by selling a better future upon which the people and their government could bet on. Just like the private sector, governments are unlikely to put resources in programmes that do not seem to promise returns to their electorates or tax payers. To achieve this, research institutions may have to demonstrate their ability to deliver once they get support for exciting small demonstration projects, or well-planned and coordinated large initiatives. Scientific and technological successes should be duly awarded in order to encourage the private sector to continue to invest and governments to address other national issues through biotechnology.

Starting Small to Showcase

As discussed earlier, the Brazilian genome sequencing project, ONSA, demonstrated what could be achieved and how it could be done. ONSA enabled Brazil to join the exclusive club of genome sequencing powerhouses. It is this success that gave birth to the Brazilian National Genome Project Consortium in 2003. As of 2007, a number of the key crops and a host of pathogen genomes had been sequenced by several sequencing teams in Brazil that were designed and managed almost in the same fashion as ONSA.[34] In a way, the success of the small projects was important in encouraging and scaling up of the genome sequencing project.

This is not particularly unique to biotechnology. The successful development and application of tank bioleaching process for gold in South Africa in 1980s and commercial application of solvent extraction electron-wining of copper in the 1970s in Zambia led to the wide adoption of both technologies in the mining sector in both developed and developing countries.[35] In countries where government support may not be so strong, demonstration of the application and benefits of biotechnology could be very important.

It is difficult to choose one or two projects to embark on in developing a biotechnology sector in a country. Some of the key lessons from the cases discussed in this paper include the need to: (1) identify an institution around which the project could be anchored (e.g. the three sequencing and bioinformatics laboratories in the ONSA model) and supported (e.g. FAPESP in Brazil), (2) ensure the project is exciting to entice the participation of top scientists, is of economic or social relevance, manageable and likely to stimulate further growth in the field and, finally, (3) build in sufficient and targeted incentives designed to encourage all participating institutions to deliver.

Phased and Well Coordinated Development

In the case of Korea, clear goals were set and managed in a coordinated manner with every ministry involved indicating how much investment will be made at each stage of development in close partnership with the private sector. This is particularly important in a multidisciplinary, knowledge-dependent and highly regulated industry to ensure that the national strategy is implemented in a coherent manner. In a way, one can promote both collaboration and competition during the implementation – both of which could speed up the process and efficiency of implementing the program.

In Africa, the Organization of African Unity (OAU), now African Union (AU), launched the Pan African Rinderpest Campaign (PARC)[36] in

1986 to completely eradicate Rinderpest, a viral disease that could wipe out up to 90 per cent of the cattle in an area, on the continent. With about $200 million investment from the EU and technical support from various institutions PARC developed a vaccination campaign in 22 African countries, four regional emergency vaccine banks, two regional coordination centres and centres for vaccine quality control and disease diagnosis in African countries. With 35 participating countries, PARC was successful because of its communications unit that helped sensitize farmers, veterinary experts, policy makers and donors. By 1999, the disease was confined to a few locations in Africa.

The key components in all these cases include the involvement of key players, the clear identification and communication of the targets and performance, sharing of responsibilities and promoting the projects. In a phased approach, ensuring that all the parties understand their roles and responsibilities is important.

Narrowing the Focus to a Few Challenges

It is never easy to pick winners or undertake technology forecast. However, with a bit of careful planning, perfect timing and careful search, one can try to focus on a few challenges as was the case in Cuba. Though Cuba already had a larger pool of scientists than most developing countries, it is often thought that the outbreak of meningitis, dengue fever and conjunctivitis accelerated the development of the biotechnology industry in the early 1980s. With no vaccines to many of these diseases anywhere in the world, the Cuban teams spent time studying work in the developed countries to identify where they could make quick progress. However, this process was first facilitated by the Biotechnology Front- a multidisciplinary team of professionals that was exploring the potential of biotechnology in partnership with the government.[37] Since then, the Cuban biotechnology sector has been seen as part of the ministry of health than the ministry of science and technology.

One can argue that part of the success in the development of the biotechnology industry in Cuba is its narrow focus which quickly enabled it to achieve critical mass and concentrate its limited financial and institutional resources. It may prove difficult for many African countries with limited human and financial resources to achieve success if they target all areas where biotechnology can potentially make a contribution. Even where resources are available, it is difficult to imagine how South Africa is going to achieve its “Ten Year Plan” of the Department of Science and Technology to be "among the global top ten nations in the world in terms of the pharmaceutical, nutraceutical, flavour, fragrance and biopesticide industries" in the next 11 years time. Especially when its own audit of the biotechnology sector in South Africa in 2007 revealed that about 58 per cent of the biotechnology products are in agriculture rather than health or pharmaceuticals[38] and South Africa is not exactly among the top 20 producers of pharmaceuticals.

Selecting a Specific Field: The Case of Biofuels

One area where Africa is likely to be competitive is biofuels derived from sugarcane. Other than Brazil at number one, Zimbabwe (2), Malawi (3), Swaziland (4), Sudan (6), Zambia (8), and South Africa (9) and Tanzania (13) are all in the top 15 lowest cost sugar producing countries out of 77. Therefore, there is great potential for Africa to produce biofuel at production costs that could compete with petroleum at a price of $30 per barrel. Other reasons for pursuing biofuels in these countries include: enabling more people to gain access to cleaner cooking fuels, reducing dependency on imported petroleum, acquiring technical know-how for producing biofuel, lowering the cost of transportation and creating an alternative market for surplus sugar and, for some of the country, lowering the high transportation costs (especially in landlocked countries).

Africa also has plenty of biomass for biofuel production. Some of which is a nuisance, such as the water hyacinth that is choking river and lakes in Kenya and Zambia. The continent could also grow plenty of different types of energy and oil crops. As enzyme technologies to convert cellulose into glucose continuously improve, the cost of producing biofuels will fall. For example, Genencor, a biotechnology firms specializing in enzyme design and production,[39] has released a host of enzyme cocktails that eliminates pH adjustment, reduces heating and saves enzymes in the production of ethanol even from whole grain and from cellulosic materials.

There is also a great interest by the private sector to invest in biofuels production in Africa. For example, Zambia has seen an increased and renewed interest in the biofuels through new investments by the private sector. A Chinese and Zambia joint-venture seeks to invest about $3 billion in a 700,000-hectares jatropha plantation and related extraction facilities[40], Zambia Sugar is expanding its production capacity of sugar by 70 per cent through a $150 million investment that includes production of bioethanol (about 30,000 tons per year).[41] In this context, Oval Biofuels[42] has already commissioned a refining plant in Lusaka and Biomax limited is planning to invest over US $50 million in a palmoil processing facility.[43] There are many other private and international initiatives promoting the use of biofuels to meet various development challenges in a continent whose energy consumption per capita is the lowest.

Despite these interests and opportunities, national biofuel strategies are still emerging and have no clear objectives. It is not clear whether biofuels are being pursued to expand and diversify exports, reduce imports, encourage use of modern energy resources, create jobs, build the necessary knowledge base or divert excess agricultural raw materials to bioenergy production. This is important as the next generations of biofuel processing facilities, or biorefinery, seek to integrate the production of biofuels with that of high-value products. Work is now focusing on generating specialty chemicals for animal feed, functional foods (nutraceuticals), pharmaceuticals and industrial alcohols, among others, from common crops such as maize, cocoa, soyabeen, sorghum, sunflower and wheat, among others.

While Africa may not compete in generating the next technology platforms, clear strategies could help the continent adopt, integrate and use the emerging technologies to generate new products and services for its citizens and export. It is here where research and development work could help shape the future, create markets and technologies opportunities that excite investors and contribute to national development.

Conclusion

For many African countries, biotechnology remains an undeveloped industry that seems out of reach. The central argument in this paper is that African countries can develop their biotechnology sectors using several strategies that meet their own needs. Central to all the strategies described is the need to narrow the focus to a few feasible challenges for which alternatives solutions may not be competitive. They would inspire scientists and industry to respond to an economic or social challenge and provide learning opportunities or a platform to launch future undertakings.

Coordination is often the main challenge in national and regional initiatives. This stems from the fact that institutional roles and responsibilities are often defined by one agent that wishes to own and coordinate the project. Therefore, it is important that projects are seen as national in character, involve all the key ministries, institutions and private sectors and each assumes roles and responsibilities as well as commitments to deliver. Further, a central coordinating committee with selected focal points may be more useful in ensuring all parties feel involved than a single agent seeking to own and coordinate the initiative.

There is sometimes an obsession with the creation of centres of excellence and national or regional innovation hubs. This stems from the observation that a high concentration of excellent R&D institutions with the necessary intellectual capital has been critical to the emergence and growth of a biotechnology sector in advanced developed countries. However, biotechnology R&D in these countries is concentrated in regions that combine excellent research with a good ability to commercialize research output.[44] It is highly unlikely that many African countries can afford to build such embedded centres of excellence in biotechnology in the initial stages. Secondly, steady investment will be required to ensure the continued success of the centres. This can only be assured if the research outputs are relevant to national needs or exciting to private investors.

African countries often lack the market structures, appropriate and supportive regulation and good partnership arrangements. A survey of African biosafety regulations showed that support for biotechnology products in agriculture remains low. This affects research interests in plants and animals even for non-food purposes, and hinders the building of the necessary capacity that would have benefited other sectors.

The example of bioethanol, given above, highlights a few exceptions where public goals may coincide with private interests. For instance, the locations of some of the biofuel refineries in rural areas of Zambia meet both private interests to cut costs of production by eliminating the cost of transportation for raw materials, and public goals to develop rural areas with few optional income generating ventures. One exciting development is the use of portable biofuel refineries that could be located closer to markets (e.g. new mining sites located far from modern amenities such as electricity) and/or closer to sources of raw materials through manage-and-operate models.[45]

There is evidence that countries can quickly build up capacity by seeking partners with the necessary technologies and products with the aim of learning to innovate and manage biotechnology through joint-ventures. Friendly governments that wish to promote their relationships with Africa for various reasons such as Brazil, China, Cuba, India, Korea, Malaysia and South Africa could provide both product and process technologies for projects that benefit both parties.

The High Level Panel on Modern Biotechnology rightly stated that the "report is about the role of biotechnology in the transformation of

African economies"[46] and made excellent recommendations on regional and local innovation hubs. However, these hubs are unlikely to emerge without targeted efforts, coordination and commitment of all the government ministries (not just ministers of science and technology) and incentives for the private sector to participate in a joint initiative to improve the future economic opportunities for the African continent.

Endnotes

1 Agenda 21: Chapter 16 Environmentally sound management of biotechnology, 1992 Earth Summit, UN Conference on Environment and Development (UNCED).
2 www.bio.org
3 ISAAA (2008).
4 ISAAA (2008).
5 Worldwatch Institute (2006).
6 Lane (2007).
7 Riese (2006).
8 Papadopoulos (2005).
9 De Rubertis., Fleck and Lanthaler (2009).
10 Stevenson and Gumpert (1985).
11 Stevenson (2000).
12 Ernst & Young (2008).
13 NSF (2006).
14 Gomes-Casseres, Hagedoorn, and Jaffe (2005) and Suarez-Villa (2004).
15 Ernst and Young (2002).
16 Tapon and Thong (1999).
17 Zarrilli (2007).
18 Konde (2005).
19 New Energy Bill: http://www.salon.com/news/feature/2007/12/20/biofuel/
20 Watal (2000).
21 To Promote Innovation: The Proper Balance of Competition and Patent Law and Policy", October 2003, available at http://www.ftc.gov/
22 http://www.nih.gov/about/researchresultsforthepublic/HumanGenomeProject.pdf
23 Collins (2000).
24 http://www.edctp.org/forum2007/presentations/Plenary_session_II_-_Roma_Chitengi.pdf
25 Ministry of Science and Technology (1993).
26 Rhee (2004).
27 Cho (2008).
28 Bio Korea 08 Expects 350 Companies, 25,000 Visitors, BioSpectrum Asia Edition (July 18, 2008).
29 Schulz (1999).
30 Elderhorst (1994).
31 http://blog.biopeer.com/biopeer/2006/09/new_drug_brings.html
32 South African law defines a PPP as a contract between a public sector institution/municipality and a private party, in which the private party assumes substantial financial, technical and operational risk in the design, financing, building and operation of a project.
33 http://www.dst.gov.za/media-room/speeches/speech.2007-05-22.8873281211
34 Brazilian Genome sequencing projects: state-of-the-art (2008) Available at http://bioinfo.cpqrr.fiocruz.br/files/pdf Xavier%20Brazilian%20genome%20sequencing%20projects.pdf

[35] Juma and Konde (2004).
[36] D'Huys (1998).
[37] Mola, Silva,, Acevedo, Buxado, Aguilera, and Herrera (2006).
[38] *ibid* .
[39] http://www.genencor.com/
[40] http://www.lusakatimes.com/?p=9500
[41] http://news.mongabay.com/bioenergy/2007/01/zambia-sugar-plans-major-expansion-to.html
[42] http://www.ovalbiofuels.com/
[43] http://www.lusakatimes.com/?p=6724
[44] Cortright and Mayer (2002).
[45] See www.ovalbiofuels.com
[46] AU (2007).

References

AU (2007). "Freedom to Innovate: Biotechnology in Africa's Development". Report of the High-Level African Panel on Modern Biotechnology African Union and NEPAD.

Cho, Youngguk (2008). "Korean Companies Ready to Take-Off". BioSpectrumAsia.com, January.

Collins, Peter (2000). "Brazilian Science: The Fruits of Cooperation". *The Economist*, Ed. No. 8180.

Cortright, J. and Mayer, H. (2002). "Signs of Life: The Growth of Biotechnology Centers in the U.S", Centre of Urban and Metropolitan Policy, The Brookings Institution.

De Rubertis, F., Fleck R., and Lanthaler, W. (2009). "Six Secrets to Success—How to Build a Sustainable Biotech Business". *Nature Biotechnology* 27(7): 595-597.

D'Huys, P (1998). Communication for Development: The Case of the Pan African Rinderpest Campaign (PARC) SD Dimensions (accessible via www.fao.org).

DST (2007). National Biotechnology Audit, Department of Science and Technology, South Africa.

Elderhorst, M. (1994). "Will Cuba's Biotechnology Capacity Survive the Socio-economic Crisis?" *Biotechnology and Development Monitor*, 20, 11-13/22.

Ernst & Young (2002). Beyond Borders: The Global Biotechnology Report 2003, Ernst and Young.

Ernst & Young (2008). *Beyond Borders: Global Biotechnology Report 2008*, Ernst & Young.

Gomes-Casseres, B., Hagedoorn, J. and Jaffe, A. (2005). "Do Alliances Promote Knowledge Flows?" *Journal Financial Economics*, 80, 5-33.

ISAAA (2008). "Global Status of Commercialized Biotech/GM Crops: 2008". *ISAAA Briefs* 39.

Jong, S (2009). "Building a Business: When Times are Tough". *Nature Biotechnology*, 27 (3): 226-228.

Juma, C. and V. Konde (2004). "The New Bioeconomy: Industrial and Environmental Biotechnology in Developing Countries". UNCTAD/DITC/TED/12.

Konde, V. (2005). "Lighting up Africa: Energy for Development". *African Technology Development Forum Journal*, 2, 3-9.

Lane, J. (2007). "India Mandates E10 Ethanol Blend Effective", *Biofuel Digest*, 19 September.

Ministry of Science and Technology (1993). National Biotechnology Development Program 'Biotech 2000'. Korea Initiative for Biotechnology Development 1994–2007, Ministry of Science and Technology, Seoul, Korea.

Mola, E.L., Silva, R., Acevedo, B., Buxado, J.A., Aguilera, A. and Herrera, L. (2006). 'Biotechnology in Cuba: 20 Years of Scientific, Social and Economic Progress', *Journal of Commercial Biotechnology* 13, 1-11.

NSF (2006). Science and Engineering Indicators, Report of the National Science Foundation, USA.

Papadopoulos, S. (2005). "A Brief History of Biotech". *The Wharton Healthcare Leadership Exchange (WHLE),* 9-14.

Rhee, S. K. (2004). "Korean Initiatives on Biotechnology: Challenges and Opportunities". Expert Group Meeting, BINASIA, 29-30 April 2004, Bangkok, Thailand.

Riese, J. (2006). Industrial Biotechnology — Turning Potential into Profits, McKinsey & Company.

Schulz, W.G. (1999). "News Focus; Cuba at a Crossroads". *CENEAR* , 77, 8-13, also accessible via http://pubs.acs.org/ho tartcl/cenear/990111/7702newfocus.html.

Stevenson, H.H and D. E. Gumpert (1985). "The Heart of Entrepreneurship". *Harvard Business Review*, 85-95.

Stevenson, H.H. (2000). "Why Entrepreneurship has Won!". *Coleman White Paper*, USASBE Plenary Address, 17 February.

Suarez-Villa, L (2004). "Collaboration in Biotechnology; How Inter-firm Relations Strengthen Research Efforts in the USA". *International Journal of Technology Management*, 27:452-464.

Tapon and Thong (1999). "Research Collaborations by Multi-national Research-oriented Pharmaceutical Firms: 1988-1997". *R&D Manangement*, 29 (3), 219-231.

UNCED (1992). Agenda 21: Chapter 16 Environmentally Sound Management of Biotechnology, 1992 Earth Summit, UN Conference on Environment and Development.

Watal, J. (2000). "Intellectual Property and Biotechnology: Trade Interests of Developing Countries". *International Journal of Biotechnology*, 2 (1/2/3): 44-55.

Worldwatch Institute (2006). *Biofuels for Transportation: Global Potential and Implications for Sustainable Agriculture and Energy in the 21st Century,* Worldwatch Institute.

Zarrilli, S. (2007). "Global Perspective on Production of Biotechnology-based Bioenergy and Major Trends". FAO Biotechnology and Bioenergy Seminars, FAO, Rome.