Overview—harnessing technologies for sustainable development

The greatest single problem and danger facing the world of the Third Millennium…is the gap in wealth and health that separates the rich and poor…The only other worry that comes close is environmental deterioration, and the two are intimately connected, indeed are only one.

– David S. Landes, *The Wealth and Poverty of Nations*

Poverty is multidimensional and widely spread in Africa. Incomes and consumption levels are low and volatile. The available productive assets, particularly for the poor, are few and meagre, increasing vulnerability to shocks. Illiteracy, malnutrition, and ill health are prevalent, with mortality and morbidity rates high. All these conditions have led to short life spans. Worsening the situation in recent years are the spread of HIV/AIDS and the resurgence of malaria and tuberculosis.

The pervasiveness of low levels of well-being is caused by, and in turn perpetuates limited productive capacity. Undercapitalized, the production of goods and services in large parts of Africa has yet to benefit significantly from modern technological advances. Average years of schooling are inadequate, while the incidence of illness is high, contributing to low aggregate and agricultural output per worker. The low agricultural productivity is simultaneously a cause and an outcome of the degradation of an already fragile natural environment.

The low and in some cases declining productivity, the deterioration in the natural resource base, and the rapid population growth mean that development is unsustainable in most African countries. Corroborating this is the index of overall sustainability developed by the Economic Commission for Africa. The index jointly measures the economic, environmental, and institutional sustainability of African countries. Combining 27 key economic, environmental, and institutional indicators, it tracks the performance of 38 African countries in 1975–2000. The scores reveal that the number of countries with low sustainability increased (from 16 in 1975–84 to 19 in 1995–2000), while the number of those with high sustainability remained the same (only 3). More telling, within the group of 38 countries the fraction of the population living in the countries with low sustainability rose from one-third in 1975–84 to half in 1995–2000.

So, the continent urgently needs a rapid, sustained, and broad-based economic transformation that is equitable within and across generations—in short, it needs development that is sustainable. The key to achieving the transition to sustainability is realizing and enhancing

the capabilities of individuals and their communities. People who are ill, poorly fed, and living in a fragile environment can neither function effectively nor improve their capabilities. Moreover, in part because of rapid population growth, the severity of ill health, food insecurity, and environmental stress is likely to increase in the coming decades. Africa must therefore explore new and radical solutions to these problems.

The development challenge facing Africa is enormous, but it can be overcome. The development of Western Europe and the United States and, more recently, that of East Asian economies (including Japan, the Republic of Korea, and Taiwan, Province of China) corroborates this. Given the right circumstances, advances in and diffusion of technology can pull Africa out of its current state of low development. African countries can emulate the processes and policies that have promoted transitions to sustainability in other regions. Indeed, these processes and policies are better understood today than ever before. In Africa the achievements in Mauritius, for example, and the recent trends in policy reforms and economic growth in large parts of the continent signal the possibilities.

This report maintains that combating ill health (particularly that caused by HIV/AIDS, malaria, and tuberculosis), tackling food insecurity, and reducing environmental stress should be prominent objectives of the endeavour to reduce poverty and achieve sustainable development in Africa. It identifies the epidemiological and agricultural productivity transitions as the current priorities in the continent's striving towards sustainability. Recognizing that modern technology is indispensable to such transitions, the report then focuses on how the "new" technologies—particularly medical and agricultural biotechnology—can contribute.

Sustainability—on the decline

Overall sustainability has been worsening in Africa over the past three decades. This is confirmed by the Economic Commission for Africa's index of overall sustainability, combining economic, environmental, and institutional dimensions. Cluster analysis was used to classify countries into three relatively homogeneous groups characterized as having high, moderate, and low sustainability. Only three countries, accounting for about 6.5% of the continent's population, recorded relatively high overall sustainability throughout the period (table 1).

In the decade after 1975–84 fewer countries achieved moderate overall sustainability, with more falling into the cluster for low overall sustainability. The main explanation is that the significant progress in health and education in 1985–94 was more than offset by a worsening institutional and environmental situation. In that period institutional constraints on chief executives weakened considerably in several African countries—the Democratic Republic of Congo, Ethiopia, Nigeria, and South Africa—while they remained the same in Egypt, Kenya, and Tanzania. In addition, both population density and carbon dioxide emissions increased substantially in several large countries, including Algeria, Egypt, Ethiopia, Morocco, Nigeria, and South Africa.

In the most recent period, 1995–2000, the number of countries with low overall sustainability remained about the same as in the previous one, but the share of the population

Table 1

Overall sustainability clusters for 38 countries, 1975–2000

Period	High		Moderate		Low	
	Number of countries	Population share (percent)	Number of countries	Population share (percent)	Number of countries	Population share (percent)
1975–84	3	7.0	19	58.9	16	34.1
1985–94	3	6.7	15	52.8	20	40.5
1995–2000	3	6.4	16	39.5	19	54.0

***Source**: Calculations by Economic Commission for Africa.*

living in such countries rose—an outcome largely explained by the deterioration of economic, institutional, and environmental management in Nigeria during most of 1995–2000. In many other African countries a recovery, though still tentative, has begun. In particular, output per worker and capital per worker rose in Egypt, Ethiopia, Morocco, Tanzania, and Uganda, and civil and political rights improved significantly in many countries.

When the 38 African countries are ranked by their average overall sustainability score for all of 1975–2000, Mauritius, South Africa, Botswana, Zimbabwe, and Tunisia emerge as the top five (figure 1). At the bottom are Burundi, the Democratic Republic of Congo, Guinea, Chad, and Burkina Faso.

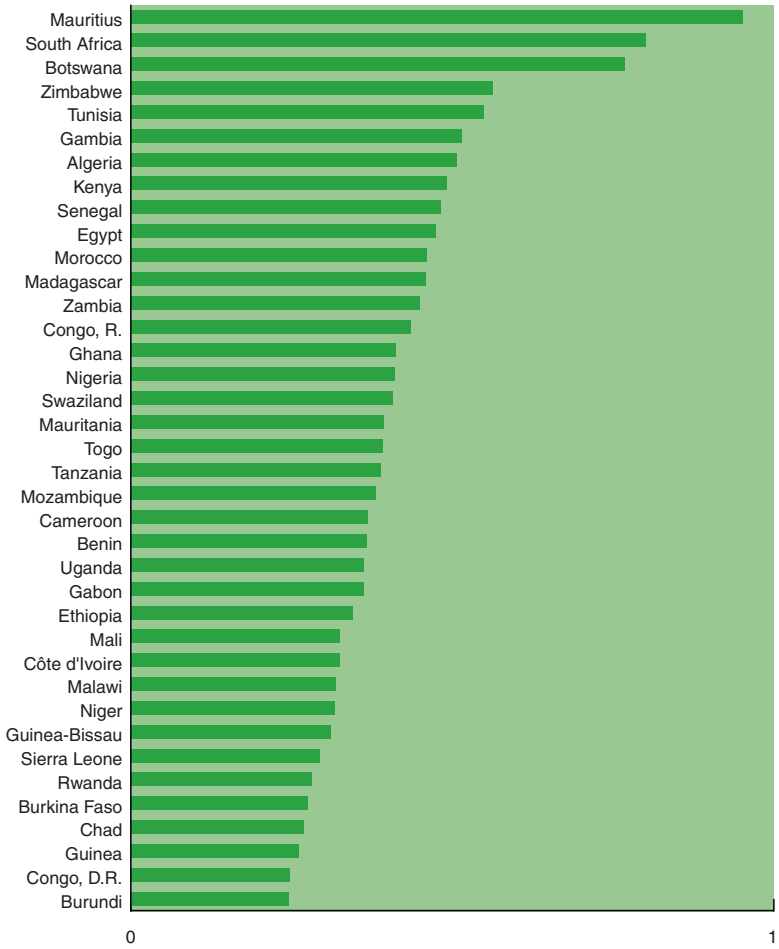
There is little surprise in the make-up of the top five. South Africa, with its large and mainly industrialized economy, is quite distinct from other African economies. Indeed, it tops the economic sustainability rankings. But Mauritius and Botswana were the star performers in economic growth for the last three decades. Socio-political stability was also quite good in these countries, with Mauritius and Botswana ranking as the top two in institutional sustainability. Similarly, Tunisia and, until recently, Zimbabwe made reasonable progress in the economic and institutional dimensions.

That Zimbabwe ranks among the top five may be puzzling in light of its recent performance. The reason for this outcome is that until recently the country had been doing rather well, particularly in economic and institutional terms. Thus while Zimbabwe ranks only 12th in overall sustainability and 23rd in institutional sustainability in 1995–2000, it ranks 4th and 6th on these measures in 1985–94.

A blemish on the sustainability record of the top five is their performance in environmental sustainability. Mauritius, Tunisia, and Zimbabwe rank among the bottom five countries in environmental sustainability, and Botswana 30th among the 38 countries. Only South Africa, ranked 19th, does better in this dimension of sustainability. For these top performers, environmental concerns increasingly are becoming binding constraints on further improvement in the overall well-being of their populations. One lesson from this experience is that countries can do well for a while without giving due consideration to environmental factors, but this may not last long.

Figure 1

Overall sustainability index scores by country, 1975–2000



***Note**: The index scores shown are averages of the scores for 1975–2000. The scores are standardized to range from 0 to 1.*

***Source**: Calculations by Economic Commission for Africa.*

The bottom five countries are also broadly consistent with expectations. Despite its huge potential, the Democratic Republic of Congo has been misgoverned for decades. More recently it has been crippled by civil war. Burundi's history is punctuated by ethnic tensions and civil conflict. Until recently Chad suffered from similar problems of instability. For Burkina Faso the main problem is an unsatisfactory economic growth record. Indeed, almost all these countries rank low in economic and institutional sustainability. Burundi, the Democratic Republic of Congo, and Chad rank among the bottom five in institutional sustainability, while Guinea ranks 30th and Burkina Faso 27th. In economic sustainability Burkina Faso ranks 38th, Guinea 37th, Chad 32nd, Burundi 30th, and the Democratic Republic of Congo 29th. But these countries rank relatively high in environmental sustainability—from 2nd to 11th. This contrast highlights the fact that economic performance (or the lack of it) has a negative (or positive) impact on the environment.

The transitions

To move rapidly to sustainable development, Africa needs to achieve two critical transitions: an epidemiological transition, to combat ill health, and an agricultural productivity transition, to address food insecurity.

The epidemiological transition

Good health is the first and greatest of all blessings and the first of all liberties.

—Laura D'Andrea Tyson paraphrasing Lord Chesterfield

Once a disease like AIDS reaches the kind of proportions we see in Sub-Saharan Africa, it is no longer a disease—it is a disaster.

—Peter Walker, Director of Disaster Policy, International Federation of Red Cross and Red Crescent Societies

The epidemiological transition delivers longer and healthier life to human society, primarily through reductions in morbidity and mortality due to infectious and parasitic diseases. Through its impact on fertility behaviour, this transition also contributes to the demographic transition from high birth and death rates to low ones.

The epidemiological transition in Africa progressed appreciably in the decades after World War II. Over the past 40 years the incidence of infectious and parasitic diseases has been reduced enough so that today fewer infants and children die, people live longer, and birth rates are lower. Despite these improvements, the state of health in the continent remains unsatisfactory. Mortality rates are the highest in the world, and overall life expectancy and disability-adjusted life expectancy the shortest.

Moreover, the gains achieved by Africa are being undermined by the emergence of new diseases, such as the acquired immunodeficiency syndrome (AIDS), and the re-emergence of old ones, such as malaria and tuberculosis, as leading causes of death. Both malaria and tuberculosis have developed strong resistance to existing drugs, making current treatments ineffective. AIDS, which is caused by the human immunodeficiency virus (HIV), became the leading killer in Sub-Saharan Africa at the end of the 1990s (Medilinks 2001). Since the epidemic began, more than 20 million people worldwide have died of HIV/AIDS-related causes (UNAIDS 2000, 2002). Moreover, HIV compounds tuberculosis. People infected with HIV are more vulnerable to other infections. In some countries in Africa up to half the people living with HIV also suffer from tuberculosis (Medilinks 2001).

Together, HIV/AIDS, malaria, and tuberculosis have devastated populations through human losses and suffering. In at least 15 Sub-Saharan countries the population is expected to be as much as 3.8% smaller in 2005 than it would have been without HIV/AIDS, with the working-age population the most affected. In addition to the human cost, these diseases cause work loss and school dropouts, hinder savings and investment, and overwhelm

health services, undermining the productive capacity of a country, furthering social distress, and perpetuating poverty.

As a direct result of HIV/AIDS, the growth of gross domestic product (GDP) in Africa is expected to fall by 0.5–2.6% a year on average (Greener 2002). If malaria had been eliminated years ago, Africa's GDP would be as much as $100 billion greater (Medilinks 2001). And in countries with a high burden of tuberculosis, annual productivity losses due to the disease amount to an estimated 4–7% of GDP (Stop TB Initiative 2002).

The combined socio-economic burden of these diseases has led Sub-Saharan countries towards major crises that threaten to reverse decades of development gains and undermine national security. The damage from these diseases clearly calls for accelerating the epidemiological transition in Africa. Indeed, that is the most important development challenge for many African countries. Meeting it requires a prudent exploitation of techniques and products developed by recent advances in medical biotechnology.

The agricultural productivity transition

A person who has food has many problems. A person who has no food has only one problem.

—Chinese proverb

The agricultural productivity transition involves increasing agricultural production by raising output per unit of land through advances in knowledge and technology rather than by expanding the area cultivated. Historical evidence clearly shows that for most countries this transition is essential for securing access to enough food for a healthy life for all people and at all times.

Agricultural productivity is low in Africa, particularly in Sub-Saharan Africa. In the late 1990s cereal yields in Sub-Saharan Africa were about 40% of the world average—having fallen by 0.7% a year between 1985 and 1995—and milk yields about 16% of the average. Other crops and agricultural products showed similar gaps in yield. With about 70% of all Africans earning their livelihood from agriculture, low and in some cases falling agricultural productivity means serious poverty and food insecurity. Exacerbating the situation are rapid population growth and urbanization.

About a third of Africa's population is undernourished, while a similar share of its children are underweight. Of those who survive their childhood, many will suffer from impaired immune systems, poor cognitive development, and lower productivity throughout their lives. As adults, their ability to ensure good nutrition for their children will be compromised, perpetuating the vicious cycle. Indeed, it is only in South Asia and Sub-Saharan Africa that the number of malnourished people is projected to increase in the current decade.

The growing demands for food and nutrition are not being met in a sustainable manner. Farmers have tried to overcome declining yields by expanding croplands and grazing areas, an environmentally unsustainable option. Given limits on crop area expansion and increased demands on land already in production, physical and chemical soil degradation becomes a greater concern. Africa's tropical forests are fragile, quickly losing productive potential when under stress. Roughly 5 million hectares of forest are lost annually, most to

crop area expansion (Paarlberg 2001). This is not a sustainable solution for the continent's agricultural production problems.

Low agricultural productivity, rapid population growth and urbanization, diminishing reserves of unused arable land, extensive and increasing degradation of land (both soil and vegetation), and large deficiencies in food and nutrition—all these call for an accelerated agricultural productivity transition in Africa. They also imply that such a transition is unlikely without substantial changes in the technology of agricultural production. Thus the next phase of yield increases in African agriculture cannot ignore new techniques and products offered by biotechnology.

The new technologies

Modern technologies are indispensable in achieving the epidemiological and agricultural productivity transitions. They bring tremendous hope to those who live in fragile environments, depend on marginal lands, are exposed to health hazards and natural disasters, and have little coping capacity and almost no assets to fall back on in a crisis. But the new technologies are no panacea. They involve potential risks. And their benefits will not spread automatically to the poor and vulnerable. Minimizing the risks and realizing the full benefits of the technological revolution will require critical analysis and careful planning.

Medical (red) biotechnology

Modern biotechnology and genetics are expanding opportunities for developing new drugs and improving the efficacy of existing drugs and treatment. Genomics and its applications (genetic engineering) to health care—"red" biotechnology, in contrast to "green" biotechnology in agriculture and the environment—is creating a wide range of powerful new tools that are changing how common diseases are diagnosed, managed, and treated. These include gene therapy, DNA-based vaccines, and novel vaccine delivery systems. These new technologies are capable of enabling African countries to stem the devastation caused by the three leading causes of death—HIV/AIDS-related infections, malaria, and tuberculosis.

New applications of biotechnology to diagnostic tests are speeding and simplifying the identification of diseases, while advances in pharmacogenics are providing greater understanding of how the body responds to drugs, making it possible to develop more accurate and effective medication. Gene therapy holds promise for directly correcting genetic disorders, providing a cure rather than simply a treatment of symptoms of these disorders. And new genetic engineering techniques are revolutionizing vaccination.

Modern biotechnology is creating the possibility of soon developing vaccines capable of tackling a wider range of diseases, including sexually transmitted diseases, and with greater efficiency. Equally important are technological improvements to the delivery of existing vaccines. New forms of vaccines are being designed to overcome problems of access—scheduling, storage, stability, and cost. These new forms could avoid such requirements as the cold chain that is needed to keep vaccine doses at the correct temperature, which restricts the distribution of the oral polio vaccine.

Four new concepts for delivering vaccines are under development (CVI 1999; Fell 1998):

- *Naked DNA vaccines,* created by genetic coding for key antigenic components of viruses or bacteria.
- *Trojan horses,* produced by introducing genes into organisms that enable them to carry a vaccine into the body.
- *Edible vaccines,* developed by engineering seeds that produce plants capable of forming vaccines in their fruit or leaves and thus of acting as vaccines themselves.
- *Sugar glass vaccines,* kept in crystalline form so that they are easy to transport and store and can be "revived" with just a few drops of water.

With these innovative vaccine technologies, prospects for controlling and eradicating infectious diseases in the coming century are greater than ever.

Indeed, these and other advances in biotechnology offer hope that the three leading causes of death in Africa can be brought under control. A decade ago an HIV diagnosis was akin to a death sentence. Today the means exist to fight HIV/AIDS. Antiretroviral therapy is prolonging life and restoring health for HIV-infected individuals. Several HIV vaccines are showing positive results in advanced stages of clinical trials, including some directed towards the HIV strains prevalent in Africa. A malaria vaccine too may soon be developed, and research to transform the malaria-transmitting mosquito into a harmless insect has reached advanced stages. Beyond these, many other new discoveries in medical biotechnology fuel expectations of finding cures for many of the diseases directly implicated in Africa's poor economic performance. In short, these medical technologies have the potential to reverse the damage by HIV/AIDS, malaria, tuberculosis, and other diseases and put the continent back on the path of the epidemiological transition to sustainability.

Ethical issues in medical technology. Ethical concerns surrounding gene manipulation are so important that many countries, industrial and developing, have set up bioethics committees to determine general principles of research and application and monitor compliance with them.

The concerns are many. The potential impacts of human gene manipulation on research strategy and the enormous power conferred on the scientific community raise questions about rights to information and civil society participation. Major ethical questions also arise about equity and what is considered the common heritage of mankind. In particular, questions are raised about whether the ownership and economic benefits of gene discoveries can be privatized. These questions point to contradictions between the recognized right of intellectual property protection and the recognized universal ownership of genetic material, based on the principle that the DNA structure of human beings is the heritage of all and should be registered as the property of all.

Disequilibrium in research priorities. Worldwide, there is a huge disequilibrium between research devoted to the diseases of the poor and that focusing on the diseases of the rich: less than 10% of global spending on health research is directed to the health problems accounting for 90% of the world's disease burden—the 10/90 disequilibrium (Global Forum for Health Research 1999). As measured by disability-adjusted life years (DALYs), the global

burden of communicable diseases, concentrated in low- and middle-income countries, is 13 times the global burden of non-communicable diseases, the main health concern of the developed world. Yet non-communicable diseases receive by far the most research attention, while communicable diseases are neglected. For example, malaria accounted for 2.7% of the global disease burden in 2000, with 90% of cases in Africa, but it accounts for only 0.17% of the $60 billion spent globally on biomedical research each year (CMH 2001; Global Forum for Health Research 2002).

This inequality in research is also reflected in medical products. Of the 1,233 drugs that reached the market between 1975 and 1997, only 13 were for tropical diseases (Global Forum for Health Research 2002).

Inaccessibility of new drugs. Two main factors are preventing Africa from benefiting fully from the new scientific and technological advances in medicine. First, African countries, with annual per capita health spending as low as $10, have difficulty purchasing vaccines and drugs. Thus even though the prices of antiretroviral drugs have dropped substantially, many African countries still cannot afford them. As a result fewer than 1% of Africans infected with HIV/AIDS have access to antiretroviral therapy today (UNICEF and others 2001).

Complicating the problem of the high cost of drugs are the generally weak health systems in Africa. The treatment and care of HIV/AIDS and tuberculosis patients require highly trained doctors and nurses to ensure strict compliance with the complicated drug regimens. But health systems in Africa are often poorly equipped to serve as effective conduits for care. About 95% of Africans infected with HIV/AIDS have no access even to basic health care.

Agricultural (green) biotechnology

The biotechnology or gene revolution is the third green revolution. It offers possibilities for further amplifying the gains from the first two through technologies involving reproductive biology and the manipulation of the genetic material of living organisms. These technologies cover a wide range, including molecular DNA markers, gene transfer, and vegetative reproduction.

Agricultural biotechnology is likely to have a significant impact in several ways:

- Improving the ability to diagnose plant and animal pathogens.
- Quickening the pace of research through new biotechnological techniques.
- Expanding the spectrum of potential products and traits through genetic engineering of plants and animals.
- Transferring genes from wild relatives of a crop as well as from unrelated crops.
- Improving the nutrient content of foods and thus addressing the serious nutritional problems of the poor.

Of particular importance to Africa are the recent advances in biotechnology that promise to produce crop varieties with higher yields, greater resistance to pests and disease, and better nutritional, health, and environmental attributes. The distinctive promise of the gene revolution for Africa is that it can provide a better way to extend productive potential to poor farm communities, pre-packaged in genetically engineered seeds rather than delivered haphazardly in many separate purchased inputs.

The gene revolution also offers the potential for reducing yield variability through improved pest and disease resistance. And it holds out possibilities of higher production on previously unusable lands through crops that can tolerate drought, salinity, and aluminum. Under the right circumstances, modern biotechnology could speed Africa's agricultural productivity transition to sustainability—and expedite reductions in poverty and food insecurity.

Exacerbate income inequality? Whether the potential benefits of genetically modified crops accrue to small farmers is a question of the type of technology and the degree of inequality in a country. Where land tenure reforms are implemented, there is support for small farmers, and other elements of a development-friendly environment are in place, a new technology can benefit all farmers. But where, say, 70% of the land belongs to 5% of the population and agricultural extension and credit services are available only to big landowners, a new technology will widen the income gap between large and small farmers. Thus the social and economic impact of genetic engineering and biotechnology can only be as good as the socio-political soil in which the resulting new varieties are planted.

Some types of biotechnology could deepen poverty in Africa. For example, commercialization of the terminator gene technology, designed to prevent seed reproduction and thus ensure repeated seed purchases, would harm the millions of small farmers who depend on replanting farm-saved seeds. These farmers simply do not have the money to buy new seeds each year. Critics argue that this technology removes one of the foundations of rural agriculture—forcing small farmers into colonial dependence on rapacious multinationals—and raise concerns about the spread of this trait to other plants. Proponents maintain that it is only a concept and that it is not being developed. But it is believed that terminator gene technology is now on the fast track to commercialization (RAFI 2000), though no products are planned for Africa.

Damage human and animal health? There is still no conclusive evidence to show that any of the transgenes found in genetically modified foods are harmful to humans. But one frequent concern is that if foreign genes were present in such foods at excessive levels, they could build up in the consumer's body, increasing the resistance of diseases to several types of antibiotics (Malcolm 1999).

Another potential risk is that people with allergies could suffer reactions after unwittingly consuming genetically modified foods containing allergenic proteins introduced from external sources (Altieri 2000). For example, someone who is allergic to peanuts might suffer a reaction after consuming genetically modified soybeans modified by the insertion of the peanut gene that produces the allergic reaction.

In fact, all the proteins that have been placed into foods through the use of biotechnology and are currently on the market are non-toxic; are sensitive to heat, acid, and enzymatic digestion (and thus rapidly digestible); and have no structural similarities to proteins known to cause allergies. Similarly, current evidence does not support the argument that inserting a new gene can alter the metabolism of plants and animals to produce allergens and toxins (Thompson 2000).

Some of these concerns have also been raised for animal health—concerns much publicized in the North, particularly in Europe. Livestock and poultry consume large amounts of genetically modified corn and soybeans, and some livestock producers have raised the prospect of antibiotic resistance. If genetically modified organisms lead to a buildup of antibiotic resistance, commonly used antibiotics might become ineffective, increasing the cost of maintaining animal health. Concerns have also been expressed about the risk that antibiotic resistance could be passed on to people who consume livestock products. No evidence has emerged to show that consumption of genetically modified feeds has affected animal health. But because such feeds have not been around long enough to carry out effective trials, it would be premature to conclude that the issue has been definitively resolved (Abelson and Hines 1999).

Degrade the environment? Probably the most controversial issues surrounding agricultural biotechnology relate to the long-term impact on the environment. The key issues:

- Whether genetically modified crops lead to genetic uniformity and, as a result, vulnerability to new matching strains of pathogens.
- Whether herbicide-resistant crops reduce agro-biodiversity.
- Whether cultivation of herbicide-resistant plants will result in super weeds by increasing the exchange of genetic information between crops and its spread to weedy relatives nearby.
- Whether *Bacillus thuringiensis* (Bt) crop hybrids destroy non-target insects, as Bt corn was thought to do to monarch butterflies (Losey, Rayor, and Carter 1999).

Only extensive, well-designed, and well-monitored field tests will provide conclusive answers to these questions. But the evidence so far is that the risk of environmental degradation is minimal (McGloughlin 1999). In the past 15 years researchers in the United States have conducted more than 4,000 field tests at 18,000 sites for efficacy, performance, and suitability for release into the environment (USDA/ERS 1999a). These and thousands of similar field tests in other countries have produced no conclusive evidence of danger to the environment.

Nor has biotechnology increased the vulnerability of germ plasm to homogeneous strains of pathogens or led to genetic erosion. For example, more than 1,000 Roundup Ready varieties of soybean are cultivated in the United States alone (USDA/ERS 1999a, b). But more impact assessment studies are needed to expand the empirical evidence, answer unanswered questions, and put the risks and benefits of genetically modified crops and foods into better perspective.

Reduce Africa's comparative advantage in tropical crops? With biotechnology, it will become possible to produce, in the laboratory or in temperate zones, crops that have been grown exclusively in the tropics. This prospect gives rise to concerns that the resulting competitive edge could drive many tropical products off the market. The common example is laboratory production of vanilla aroma, which could threaten the livelihoods of tens of thousands of small farmers in Madagascar, Uganda, and other African countries.

In cocoa production, genetically modified cacao seed varieties could raise yields and lower prices, dislodging smallholder production through plantation-scale farming in the newly industrialized economies of Asia. A similar outcome could occur for vegetable oils. And such countries as Mauritius, which depends on sugarcane for a large share of its export earnings, could find themselves hard-pressed if industrially manufactured low-calorie sweeteners supplant sugarcane.

The challenges—educate, innovate, regulate, deliver

Realizing the expected benefits of both medical and agricultural biotechnology in Africa is challenging in three respects.

First, some of the new technologies may not be readily applicable in Africa. This partly reflects the need for systematic provision of information and training to generate sufficient knowledge about the use of specific technologies. And it partly reflects the high cost of developing technologies and adapting them to a specific location. Effective exploitation of new technologies demands considerable investments in physical and human capital as well as institutions.

Second, biotechnology is not without potential risks, relating mainly to biosafety (risks to human health and safety and to the environment). Regulatory diligence is required, although available evidence suggests that such risks are minimal.

Third, the potential of biotechnology can be realized only if its innovations reach the ultimate beneficiaries. Delivering these innovations to poor and vulnerable individuals and communities (farmers, people suffering from HIV/AIDS, communities at high risk of malaria and tuberculosis infection) is thus as important as generating them.

In short, the successful use of new technologies depends on efforts to educate, innovate, regulate, and deliver—a course of action with mutually reinforcing components that should be embedded in the broad development strategy of each country.

Educate

Individuals—farmers, consumers, policy-makers, and scientists—are the agents and the beneficiaries of technological innovations. So, enhancing the capacity of these stakeholders to generate and adopt the new technologies is essential. There are two key parts to this:

systematic provision of information, and expanded training and education (formal and informal as well as general and specialized).

First, knowledge has to be systematically generated and disseminated about the technologies and about their appropriateness to African communities where they are going to be used. Information needs to be provided to all stakeholders about the benefits and risks of the technological innovations. Equally important, knowledge should be furnished about the needs, endowments, and constraints of target communities, particularly to policy-makers and research and development specialists. Such systematic generation and provision of knowledge is particularly essential for the new innovations in medical and agricultural biotechnology, given the impassioned debates about the biosafety, food safety, and other risks.

Information contributes to the successful adoption of these technologies in a number of ways. It helps potential users (such as poor farmers, consumers, and patients) and policy-makers to set priorities for research and development, particularly for the choice of crops and desirable traits, disease targets and treatments, and product delivery systems. It also helps researchers and product developers tailor their efforts to the needs of their target population (poor farmers, for example) in a way that reflects local endowments and constraints. The benefits from effective participation of stakeholders and context-specific innovations cannot be overemphasized.

Second, the stock of human capital in Africa needs to be further expanded and deepened. Human capital makes two critical contributions. It is a major determinant of the continent's capacity to absorb the knowledge associated with new technologies. And it is an essential input into the creation of new knowledge and technologies appropriate to the region. So, general education needs to be expanded to boost the analytical and adaptive capacity essential to the adoption of technologies. Advanced or specialized training is also indispensable, to build the expertise required for developing, regulating, and delivering biotechnology products. Education investments and curricula should reflect these demands.

Innovate

Research and development efforts in medical and agricultural biotechnology have been concentrated in industrial countries, with most conducted or funded by private companies motivated primarily by profits. As a result most biotechnology products are intended for use in industrial countries and controlled by a few multinational corporations. The evolving system of intellectual property rights complicates the situation by extending protection to certain types of innovations (such as the isolation of a gene, protected by a patent) while ignoring others, particularly indigenous knowledge and biodiversity. These circumstances call for technological and institutional innovations if Africa is to reap the benefits of biotechnology.

African countries need to direct their research and development efforts towards filling the gaps created by biases in multinational-led research and development, making advances in biotechnology relevant to African countries and their poor citizens. One urgent concern is HIV research and vaccine development focused on the strains of the virus prevalent in Africa. Much attention should also go to research on staple foods in African settings, local resource-intensive technologies, and crop and animal traits relevant to poor farmers.

It is important that the research and development efforts in Africa strike the right balance between fundamental research and product development. The capacity for fundamental research needs to be built gradually. Initially, however, resource constraints suggest that African countries are likely to benefit more from innovative adoptions of fundamental research technologies developed elsewhere. An important avenue is to combine discoveries in biotechnology with more conventional techniques and indigenous knowledge. For example, genes corresponding to desirable traits could be inserted into local varieties to further enrich them while preserving their good qualities. Appropriately exploited, such innovations could boost the productivity of poor farmers at reasonable cost.

Institutional innovations are also necessary. High transaction costs, considerable initial and fixed costs, imperfect information, and enforcement problems mean that thin markets and market failures are common in most African countries. Policy failures were also common until recently. To realize the potential benefits of biotechnology, these countries therefore need to initiate innovative institutional changes:

- *Ensure that biotechnology policies are African-owned.* The future of biotechnology lies in public awareness and acceptance: good technology alone is not enough. Diverse stakeholders should be involved in the formulation of national biotechnology policies, strategies, and plans. Continuous networking and monitoring by civil society groups are fundamental. And the participation of African research centres in the production process is vital to ensure that the final outputs are appropriate for Africa.
- *Develop intellectual property rights regimes.* Legislation should be enacted as needed to establish intellectual property regimes compatible with international agreements and national circumstances. This would encourage the expansion of private sector research and development capacity and ensure the protection of indigenous knowledge and local biodiversity while also benefiting users.
- *Expand public sector biotechnology research.* Market failures and institutional weaknesses mean that the public sector will continue to play the main role in research and development in Africa for the foreseeable future. So, it is critical to formulate a public sector strategy for biotechnology research, setting priorities and identifying areas and mechanisms for partnerships. Public investment in biotechnology research needs to be expanded and redirected accordingly.
- *Build innovative partnerships*. Public-private partnerships need to be developed, building on complementarities. Regional and international partnerships should be strengthened, and new ones formed. In agriculture, it is essential to build collaboration and support among national agricultural research systems in Africa and between these systems and public and private research establishments in industrial countries. In medicine, partnerships among pharmaceutical companies, governments, and international organizations have proved vital in speeding the production and distribution of drugs and vaccines. Cooperative arrangements—such as the Consultative Group on International Agricultural Research and the International AIDS Vaccine Initiative—could play a key role in facilitating such collaboration and support (box 1). Also useful would be to explore the potential benefits and feasibility of regional or subregional common research areas, designed along the lines of common markets. These could

Box 1

Best practice in research and development cooperation—for an HIV-1A vaccine

The clinical trial in Kenya to test a vaccine candidate for HIV-1A, one of the most common strains of the virus in East Africa, is an encouraging example of how research and development partnerships can work:

- *Funding*. The International AIDS Vaccine Initiative (IAVI) is funding the trial.
- *Collaboration*. The research is part of the larger initiative to develop a simple, effective, and affordable HIV vaccine, the basis of the unparalleled partnership among IAVI, the University of Oxford, and the University of Nairobi in Kenya.
- *Research approach*. The research approach was inspired by the seemingly natural immunity to the HIV virus witnessed in prostitutes in Nairobi slums. Researchers have designed a vaccine to simulate the natural immune response of these women.

***Source**: IAVI 2002.*

facilitate technology transfer, help coordinate research and development priorities, secure and disburse funding, and organize the monitoring and evaluation of research and development through trials, peer review, and journals. A European Research Area is being established in the European Union to reduce the fragmentation of research activities and to improve efficiency in the use of financial and intellectual resources. The logic of establishing such areas in Africa is much more compelling.

Regulate

Government regulation of the diffusion of biotechnology is necessary for two reasons. It is required to safeguard against the risks associated with some innovations in biotechnology, including threats to biosafety and consumer safety. And it is required to enforce intellectual property rights.

In designing regulatory procedures, African governments should set coherent guidelines outlining where the responsibility for the introduction of new biotechnology products begins and ends. And they should ensure that risk assessment has a built-in system of checks and balances to safeguard the independence of test results—so that the potential risk of new products is not assessed by those wanting to release the products on the market. In some cases it may be advantageous to build regional regulatory arrangements that address common regulatory problems, leveraging scarce institutional and human resources through economies of scale.

Although the need for regulation applies generally, the extent and forms of regulation are likely to vary across countries. A key consideration is the institutional capacity and stock of human capital at a country's disposal. A country with limited resources for regulation may prefer to promote less risky biotechnology products, though the rewards may be smaller. In determining what forms of regulation to adopt, each African country needs to weigh the urgency of achieving its development goals and its capacity to regulate against the potential risks of biotechnology.

Deliver

The successful application of emerging technologies requires building effective delivery systems and creating and strengthening the complementary infrastructure. The aim should be low-cost delivery not only of biotechnology products (such as improved seeds, drugs, and vaccines) but also of complementary inputs (such as pesticides, fertilizers, irrigation water, improved management practices, and relevant and up-to-date information and advice). There are three priorities.

First, innovations in biotechnology must be made affordable to potential adopters and users. The research and development costs of biotechnology products are considerable, and the prohibitively high prices of those now available partly reflects that. As a result many of these products are beyond the reach of those who need them most—such as poor farmers and HIV/AIDS patients. Well-designed government support schemes are needed to increase access for these groups. Current arrangements involving drug companies, international agencies, and individual countries should be strengthened to further extend access. And similar arrangements should be initiated to promote access to agricultural biotechnology.

One proposal that warrants international dialogue involves establishing an innovation purchase fund that would buy patents for innovations from private innovators (Kremer 2000). These innovations would be put into the public domain, thus ensuring adequate diffusion. The fund could be designed to be pro-poor, to have priorities specific to regions or country groups, to cover biotechnological and other relevant innovations, and to promote innovations other than those already patented.

Second, potential adopters and users of biotechnology products must have the incentives to adopt them. This is particularly important for agricultural biotechnology products. Such incentives, reflecting returns from adoption or use, are determined largely by market and institutional structures and physical infrastructure. So, investments aimed at developing incentives are essential. These might include an effective agricultural extension service and a well-equipped health infrastructure—or efficient transport, communications, and electricity networks to facilitate the delivery of the biotechnology products as well as access to factor and product markets. Efficient credit schemes for the poor (including micro-finance) are also critical. Equally important are investments to build institutions that ensure the rule of law and improve contract enforcement. All these investments are essential to provide potential adopters and users the opportunity to realize the potential benefits of innovations and thus the incentive to adopt them. They would also encourage the private sector to provide goods and services to poorer areas.

Third, because the resource requirements of building effective delivery systems are substantial, cooperation between the public and private sectors is essential, and generous assistance from Africa's development partners indispensable.

The need for collective action

An important message emerging from the report is the need for regional approaches and strategic partnerships to complement national measures. The report shows that achieving sustainable development will require the production of regional and global public goods—services or resources whose benefits are shared among the countries in a region or more broadly.[1] Regional approaches can effectively deliver regional public goods. Strategic international partnerships can help deliver global public goods.

Regional and global public goods include the knowledge, the regimes, and the standards and rules required to address cross-border problems such as infectious disease control and use of genetically modified crops; the institutions that monitor and enforce the rules and regimes; and the benefits that arise and are shared indiscriminately among countries. To ensure the provision of these goods in sufficient quantity, international collective action will be critical, because no individual country has an incentive to pay for such things as the prevention of contagious diseases, the preservation of biodiversity, or research to develop new crops, vaccines, or drugs to treat tropical diseases.

Regional and global public goods arise when individual countries take actions leading to beneficial cross-border spillovers. One example is a public health policy that improves domestic health while reducing the transmission of pathogens and disease across borders. The production of regional public goods typically requires cross-border collective action engaging all or most members of the spillover group.

Many of the failures to tackle the underprovision of regional public goods result from a lack of collective action, high coordination costs, or lack of trust and political will. Regional approaches can stiffen the political will and avoid costly policy reversals. They can also minimize the transaction costs of sharing information. Cooperation among neighbouring countries is often simpler because the countries know one another better and find it easier to share information.

Optimal provision of regional and global public goods demands an open, consultative process of bargaining, to ensure that all countries and regions receive the benefits. A regional approach can be an efficient means of coordinating action, setting priorities, reviewing progress, mobilizing resources, allocating funds, and monitoring contribution levels.

The provision of regional public goods will require new and innovative financing at the regional level. Development assistance remains anchored in country-based projects and programmes. Greater flexibility will be needed to finance regional programmes for providing regional public goods.

Around $16 billion is allocated annually to international resource transfers for global public goods in health, environment, and knowledge creation. Roughly $11 billion of this goes to support national infrastructure for public goods provision—such as basic health care systems and environmental management—leaving only a small share for regional and global public goods. Thus much more needs to be done at the regional level. Regional agencies, in collaboration with other development partners, can play an important role in the provi-

sion of regional public goods through their ability to convene and their capacity to generate and transfer knowledge.

* * *

Modern medical and agricultural biotechnology can contribute much to increased food security and better health in African countries by speeding the agricultural productivity and epidemiological transitions in these countries. For that to happen, it is critical that biotechnology be viewed as one part of a comprehensive, sustainable poverty reduction strategy, not as a technological "quick fix" for Africa's hunger and poverty problems. It is also essential that the necessary innovations and investments be made in institutions. And particularly critical is building national and regional consensus to invest in the future. Indeed, the greatest risk for Africa is to do nothing, allowing the biotechnology revolution to pass it by.

Note

1. International public goods fall into two categories, regional and global public goods, with the difference being the more limited geographic reach of regional public goods. The benefits of pure regional public goods are "non-rival" (one country's consumption does not subtract from the amount available to other countries) and "non-excludable" (no country in the region can be excluded from benefiting, except at prohibitive cost). In reality, most regional public goods are significantly, but not wholly, non-rival and non-excludable. Rather than being "pure," they are "mixed," meaning that they bestow a combination of national and transnational benefits.

References

Abelson, P. H., and P. J. Hines. 1999. "The Plant Revolution." Special issue: "Plant Biotechnology: Food and Feed." *Science* 285 (5426).

Altieri, M. 2000. "Can Biotechnology End Hunger? No. Poor Farmers Won't Reap the Benefits." *Foreign Policy* 119: 123–31.

CMH (Commission on Macroeconomics and Health). 2001. "Macroeconomics and Health: Investing in Health for Economic Development." World Health Organization, Geneva.

CVI (Children's Vaccine Initiative). 1999. "A Plethora of Hi-Tech Vaccines: Genetic, Edible, Sugar Glass, and More." CVI FORUM Secretariat. [http://www.vaccines.ch].

D'Andrea Tyson, L. 2002. "For Developing Countries, Health Is Wealth." *Business Week Online*, 14 January. [http://www.businessweek.com/magazine/content/02_02/b3765071.htm].

Easterly, W. 2001. *The Elusive Quest for Growth: Economists' Adventures and Misadventures in the Tropics*. Cambridge, Mass.: MIT Press.

Fell, A. H. 1998. "Vaccine Technology: An Independent CME Study Course for Healthcare Professionals." ArcMesa Educators. [http://www.arcmesa.com].

Global Forum for Health Research. 1999. *The 10/90 Report on Health Research 1999*. Geneva: World Health Organization.

———. 2002. *The 10/90 Report on Health Research, 2001–2002*. Geneva: World Health Organization. [http://www.globalforumhealth.org/pages/index.asp].

Greener, R. 2002. "AIDS and Macroeconomic Impact." In S. Forsythe, ed., *State of the Art: AIDS and Economics*. International AIDS-Economics Network. [http://www.iaen.org].

IAVI (International AIDS Vaccine Initiative). 2002. "IAVI Database of Preventive AIDS Vaccines in Human Trials." [http://www.iavi.org].
Kremer, M. 2000. "A Purchase Fund for New Vaccines: Rationale and a Proposed Design." Harvard University, Department of Economics, Cambridge, Mass.
Landes, D. S. 1998. *The Wealth and Poverty of Nations*. New York: Norton.
Losey, J. E., L. S. Rayor, and M. E. Carter. 1999. "Transgenic Pollen Harms Monarch Larvae." *Nature 399* (214).
Malcolm, A. D. B. 1999. "Health Risks of Genetically Modified Foods." *The Lancet* 354 (9172): 69–70.
McGloughlin, M. 1999. "Ten Reasons Why Biotechnology Will Be Important to the Developing World." *AgBioForum* 2 (3/4): 163–74.
Medilinks. 2001. "HIV/AIDS in Africa Update 2001." [http://www.medilinks.org/HealthTopics/statistics/statshome.htm].
Paarlberg, R. L. 2001. *The Politics of Precaution: Genetically Modified Crops in Developing Countries*. Washington, D.C.: International Food Policy Research Institute.
RAFI (Rural Advancement Foundation International). 2000. "Suicide Seeds on the Fast Track: Terminator 2 Years Later." News release, 25 February. [http://www.rafi.org].
Stop TB Initiative. 2002. "Economic Impact of TB." [http://www.stoptb.org/tuberculosis/economic.impact.html].
Thompson, L. 2000. "Are Bioengineered Foods Safe?" *FDA Consumer* 34 (1): 1–5.
UNAIDS. 2000. *Report on the Global HIV/AIDS Epidemic 2000*. Geneva.
———. 2002. *Report on the Global HIV/AIDS Epidemic 2002*. Geneva.
UNICEF (United Nations Children's Fund), UNAIDS (Joint United Nations Programme on HIV/AIDS), WHO/HTP (World Health Organization, Health, Technology and Pharmaceuticals), and Médecins Sans Frontières Project. 2001. "Sources and Prices of Selected Drugs and Diagnostics for People Living with HIV/AIDS." [http://www.who.int/medicines/library/par/hivrelateddocs/sourcesandprices31may01.pdf].
USDA/ERS (U.S. Department of Agriculture, Economic Research Service). 1999a. *Genetically Engineered Crops for Pest Management*. Agricultural Resource Management Study. Washington, D.C.
———. 1999b. *Impacts of Adopting Genetically Engineered Crops in the U.S.A.: Preliminary Results*. Washington, D.C.
Walker, P. 2000. Director of Disaster Policy for the International Federation of Red Cross and Red Crescent Societies. Press release, International Federation of Red Cross and Red Crescent Societies, 28. June. [http://www.ifrc.org/docs/news/pr00/1700.asp].