2

Gearing up

Platform technologies with wide applicability

Most developing country governments acknowledge that science, technology, and innovation are important tools for development. But their policy approaches differ considerably. Most countries still distinguish between science, technology, and innovation policies designed to focus on the generation of new knowledge through support for R&D and industrial policies that emphasize building manufacturing capabilities. Convergence of the two approaches would focus attention on the use of existing technologies while building a foundation for long-term R&D activities.

This approach requires that attention be paid to existing technologies, especially platform (generic) technologies that have broad applications for or impacts on the economy. Until recently, countries relied on investment in specific industries (textiles, automobile manufacturing, chemicals) with broad linkages in the productive sector to stimulate economic growth. Policy attention has now turned to ICT, biotechnology, nanotechnology, and new materials as platform technologies whose combined impacts will have profound implications for long-term economic transformation. Their role in meeting the Goals requires policy attention.

Information and communications technology

ICT has created a new way of viewing the ways in which different industrial, agricultural, and service elements link together so that more than just the economic contribution of these different growth segments can be identified. These technologies challenge us to find new ways in which human efforts can enhance institutional life and sustain technological learning in developing economies so that gains in one area can be translated and multiplied as gains in learning in another (box 4.1).

ICT can be applied to meeting the Goals in at least three areas. First, ICT plays a critical role in governance at various levels. Because of the fundamental

Box 4.1

How much can ICT help countries meet the Goals?

While there are many examples of the transformational impact of ICT, there is still much debate about how and to what extent its application relates to the achievement of social goals and economic growth. There is considerable interest in identifying ways of measuring the socioeconomic impacts of ICT and its potential contributions to the implementation of the Goals. Anecdotal claims about the impact of ICT on development need to be accompanied by strong conceptual and methodological foundations. Toward that end, the United Nations' ICT Task Force is working on defining precisely how ICT can be used to further achievement of basic development objectives. Building on the foundation provided by the Goals and the indicators already developed by the United Nations, the task force is conducting a qualitative and quantitative analysis of the role of ICT in supporting each of the Goals. This exercise will identify a series of ICT-specific targets and suggest possible indicators for measuring progress. The overall objective is to design a progress-tracking tool that could be used to illustrate how ICT can help meet each of the Goals.

The initial results of this work were presented at the World Summit on the Information Society in Geneva in December 2003. Work is continuing, in particular by identifying a group of pilot countries in which the proposed indicators could be used to help governments assess their progress in using ICT to achieve the Goals.

link between technological learning and the ways societies and their industrial transformations evolve, it is important to situate technological innovation and the application of ICT at the center of governance discussions. Second, ICT can have a direct impact on efforts to improve people's lives through better information flows and communications. Third, ICT can enhance economic growth and income by raising productivity, which can in turn improve governance and the quality of life.

The benefits of the new technologies are the result not only of an increase in connectivity or broader access to ICT facilities per se. They accrue from the facilitation of new types of development solutions and economic opportunities that ICT deployment makes possible. When strategically deployed and integrated into the design of development interventions, ICT can stretch development resources farther by facilitating the development of cost-effective and scalable solutions.

Networking technology can be deployed to enable developing countries to benefit from new economic opportunities emerging from the reorganization of production and services taking place in the networked global economy. ICT will become one of the main enablers in the pursuit of poverty alleviation and wealth creation in developed and developing countries alike. At the same time, as a facilitator of knowledge networking and distributed processing of information, ICT can be used to foster increased sharing of knowledge.

ICT differs from other development sectors and technologies—and not simply because of its status as a lucrative source of revenue and taxation for business and government. As accelerator, driver, multiplier and innovator, both established ICTs (radio, television, video, compact disc) and new ICTs (cell

Central to the Goals is ICT's power to store, retrieve, sort, filter, distribute, and share information

phones, the Internet) are powerful if not indispensable tools in the massive scaling up and interlinkage of development interventions and outcomes inherent in the Goals.

ICT is a powerful enabler of development goals because it dramatically improves communication and the exchange of knowledge and information, strengthening and creating new social and economic networks. ICT is pervasive and cross-cutting and can be applied to the full range of human activity, from personal use to business and government uses. It allows people with access to networks to benefit from exponentially increasing returns as network usage increases (network externalities). It fosters the dissemination of information and knowledge by separating content from physical location.

ICT can also radically reduce transactions costs. Central to the Goals is ICT's power to store, retrieve, sort, filter, distribute, and share information, which can lead to substantial efficiency gains in production, distribution, and markets. ICT is also global in nature, transcending cultural and linguistic barriers as it challenges policy, legal, and regulatory structures within and between countries.

Given current rates of progress many countries and regions will be unable to meet the Goals by 2015 (World Bank 2003). To catalyze progress, new models and modalities of operation and implementation are required in key areas, ranging from policy to partnership to resource mobilization. ICT, a fundamentally generic technology, will likely have the greatest impact on achievement of the Goals, because it anticipates and foreshadows many of the critical socioeconomic growth and development models and modalities of the future.

Even within the science, technology, and innovation community itself, the seismic changes continuing to occur in computing and communications are often underestimated. For example, progress in computing is providing the foundation for innovation in industries as far afield as wireless communications and genomics. This "ripple effect" will continue to expand with the exponential growth of processing power, storage capacity, and networking bandwidth. The processing power available at a given price currently doubles every 18 months, storage capacity per unit area doubles every year, and the volume of data that travels across a fiber optic cable doubles every 9 months. The impact of this technological progress has only just begun to be felt. It will be profound.

The ripple effects from the Internet are at an embryonic stage of development. Already the fastest-growing communications medium in history, the Internet marks the beginning of the technological convergence between telephone, television, and computer. Reversing the relations between quality, functionality, and price, it has already turned telecommunications orthodoxy on its head. Today the Internet is being run on top of the telephone network. Tomorrow telephony will run on top of the Internet.

Not only is an almost entirely unregulated network threatening to topple its highly regulated predecessor, but the Internet and other ICTs embody

New network economics and dynamics have combined multiple "positive feedback mechanisms" and "network effects"

many of the elements of the future communications marketplace—the arrival of local-global calls, the onset of freeware, the separation of networks and provision of services, the availability of affordable mass access, and the provision of scalable broadband communications. The implications for developing countries of a global Internet grid—cheap, reliable, and always on—are too compelling to ignore.

Converging fields, common interests

The field of ICT for development is at a turning point. The past decade has witnessed the most dramatic growth in the history of global computing and communications, with the near ubiquitous spread of mobile telephony and the Internet. But the gap between people with access to local and global networks and people without such access is widening.

Narrowing this gap represents an enormous challenge. The means to meet this challenge are already within reach; failure to urgently and meaningfully exploit them may consign many developing countries, particularly least developed countries, to harmful and possibly permanent exclusion from the network revolution.

Within the development community, there is growing awareness that failure to include developing countries in the ICT revolution will have serious consequences for achievement of the Goals. Harnessing the strategic and innovative use of ICT in development policies and programs may enable the world to meet the Goals. Without such technology, doing so by 2015 will be impossible.

In 2000, the same year as the Millennium Summit, two major multistakeholder initiatives were launched, the G8 Digital Opportunity Task Force and the UN ICT Task Force, in an attempt to address the growing digital divide and its repercussions for social and economic development. With the planned comprehensive review of the progress made in the fulfillment of all the commitments in the United Nations Millennium Declaration by the United Nations in 2005 and the second phase of the World Summit on the Information Society in 2005, the global ICT and Goal initiatives are set to converge. A unique opportunity therefore exists to focus on practical initiative and action to use ICT to meet the Goals.

The network revolution

In recent years the network revolution has forced a radical transformation of both developed and developing economies. New network economics and dynamics have combined multiple "positive feedback mechanisms" and "network effects" with disruptive and discontinuous change. This change encompasses rapidly decreasing technology costs with volume and innovation; vastly increased system development costs, risks, and timescales; new competitive market forces; heightened user expectations; uncertain industry restructuring

ICT cuts across all seven Goals targeted at specific objectives and appears as an Goal itself within the eighth

and financial market behavior; and standardization that is often nonproprietary. In addition, additional network benefits, such as electronic commerce, have appeared.

The economics and dynamics of networks are complex and only partially understood; development is also a complicated process. Analyzing the interaction between the two is therefore very difficult. ICT is multidimensional in nature. It is primarily for this reason that the debate over poverty reduction and the broad and systematic use of ICT in development policy and programs has until quite recently been polarized between skeptics and enthusiasts. Given the need to focus on basic development needs and priorities, such as food, clean water, education, and disease eradication, some view ICT as a luxury. Others view it as almost a panacea for development problems. With the shift from anecdotal to empirical evidence of its full development impact, a more balanced perspective has emerged, in which ICT is no longer seen as an end in itself but rather as a critical enabler in the development process, particularly in the context of the Goals.

There is already a strong correlation between ICT and the Goals based on a mutually shared objective: the efficient, scalable, affordable, and pervasive delivery of services to the masses. ICT cuts across all seven Goals targeted at specific objectives and appears as an Goal itself within the eighth goal ("develop global partnerships for development"), which focuses on how to achieve the first seven goals.

Rapid progress to date has been made toward Goal 8, target 18, which is on track. The International Telecommunications Union estimates that access to telephone networks in developing countries tripled in the 10 years between 1993 and 2002, rising from 11.6 subscribers per 100 inhabitants to 36.4. By the end of 2002 there were more mobile cellular subscribers than fixed telephone lines in the world. Growth has been particularly strong in Africa, where an increasing number of countries now have more mobile phones than fixed telephones.

Growth in personal computers and the Internet has been equally impressive. By the end of 2002 there were an estimated 615 million computers in the world, up from only 120 million in 1990. In 1990 just 27 economies had direct connection to the Internet; by the end of 2002, almost every country in the world was connected, and some 600 million people worldwide were using the Internet. Growth has been most rapid in developing countries, where 34 percent of users resided in 2002, up from only 3 percent in 1992 (ITU 2003).

ICT has obvious benefits for economic growth, including pro-poor growth. But it is as a generic technology and development enabler (Goals 1–7) rather than a stand-alone production sector (Goal 8) that it will most affect the Goals: by creating new social and economic opportunities, promoting greater participation in development policies and processes, and increasing the efficiency, accountability, and delivery of public services.

Making the case for the strategic deployment of ICT to support the Goals requires demonstrating the technology's impact

Missing links

Ironically, the great self-sustaining, self-replicating, and multistakeholder enterprise that constitutes the global Internet seems to have acquired the attributes of a global public good almost by accident. The missing links in the Internet value chain not only mirror the missing links in the development value chain, they also impinge on precisely the areas of difficulty and contention faced by the Goals in meeting the 2015 agenda: intellectual property rights, the integration of infrastructure, empowerment of youth and women, and viral growth models for very large-scale projects and initiatives. Most experts concede that the Goals can be attained only if initiatives are promoted at the global level and that these global initiatives must embed growth models based on sustainability, self-replication, and broad partnerships, as evidenced in Internet-based efforts today.

The fact that ICT can act as a powerful development enabler does not mean that it will necessarily do so. In order for ICT to foster development goals, it must be employed where relevant, appropriate, and effective. Perennial cross-sector complexities and issues must be overcome within existing approaches to ICT for development. These include full demonstration of development impact, integration and prioritization within national development and poverty reduction programs, policy realignment on basic infrastructure deployment, improved government and donor coordination and cooperation, increased private sector engagement; and enhanced mechanisms for resource mobilization.

Making the case for the strategic deployment of ICT to support the Goals requires demonstrating the technology's impact. Few studies or strategies outline a strategic programmatic vision with regard to ICT and development in terms of benchmarks, goals, and indicators. It is generally agreed that the indicators proposed by target 18 of the Goals—the number of telephones and personal computers—are inadequate as measures of development impact on poverty, health, education, empowerment, or the environment.

Awareness of the development potential of ICT is often not fully reflected in the formulation of national e-strategies, many of which lay primary emphasis on the development of ICT as a new growth and export sector or focus on ICT as enabler in a piecemeal fashion. National development strategies in general and poverty reduction strategies in particular provide the framework for focusing on core development priorities, but they fail to fully integrate or mainstream ICT. According to the OECD (2003), of the 29 Poverty Reduction Strategy Papers (PRSPs) of Heavily Indebted Poor Countries (HIPC) in 2003, only 12 defined or positioned ICT as a strategic component of poverty reduction and addressed it as an independent item in their PRSPs.

With the trend toward deregulating and privatizing the global telecommunications industry in the 1990s, development banks and national donor agencies effectively withdrew from public infrastructure finance, ceding the way to the private sector. In hindsight, this decision was premature. Market and

Development projects using ICT have had difficulty moving beyond pilots to mass-market deployment

regulatory failures, particularly in Sub-Saharan Africa, have led to privatized state entities that retain monopoly control, limiting competition and reducing network investment. While mobile cellular networks are believed to have brought some 80 percent of the world's population within reach of a telephone, licensing conditions have failed to extend coverage to rural and remote areas. Reappraisal of the role of the private sector in the provision of basic telecommunications infrastructure is urgently needed.

Development projects using ICT have had difficulty moving beyond pilots to mass-market deployment. This has been due partly to lack of coordination and duplication by donor agencies and government initiatives within countries, with competition for volume taking precedence over impact. Local actors and local content have also been underemphasized in many initiatives. Both donors and governments have been slow to foster the requisite private sector participation at the earliest stage of project implementation, which is essential to ensure buy-in and long-term investment. Innovative public-private or broad partnerships between government, business, and civil society, which combine core complementary competencies and share financial risk, are increasingly viewed as essential for large-scale ICT for development projects. But the number of such partnerships remains small.

The private sector has an enormous role to play in ICT for development, in advocating for pro-poor growth strategies; integrating private sector development and poverty reduction strategies; helping create enabling legal and regulatory environments; providing finance and mitigating risk; developing human and social capital and innovation; developing product, commodity markets, and trade; investing in and deploying infrastructure; and interacting with donors and donor organizations. Although the role played by the private sector has significantly increased in the digital era, investment shortfall due to the global technology downturn means that nurturing of their involvement by donors and governments will be required for some time to come.

The most important issue concerning mainstreaming ICT to help achieve the Goals is resource mobilization. The developing countries believe that enough evidence exists to justify a massive billion dollar financial contribution and a special fund aimed at bridging the digital divide. The developed countries remain reticent to commit to this level of contribution and unwilling to establish a new financial mechanism. In this context, the UN Task Force on Financial Mechanisms for ICT for Development will attempt to play a catalytic role.

Applying information and communication technology to specific Goals

ICT and technology "push" projects are generally ill suited to fulfilling the requirements of the Goals. "Pulling" ICT into development projects where appropriate and relevant at an early stage—often with a mix of traditional and new media—to achieve greater efficiency and service delivery will have greater

Consensus is building in the development community on the need to focus attention on ICT interventions that match local needs and conditions

impact on poverty reduction. The success of the shift from push to pull will depend on fully integrating ICT into national development plans and PRSPs at an early stage and prioritizing ICT in sectors in which the potential benefits are greatest.

Research has shown that the greatest Goal benefits have accrued to countries that have adopted and implemented bottom-up and holistic e-strategies that are aligned with overall national development strategies. These countries have brought ICT to bear on all of the diverse components of national development agendas, such as governance and institution building; infrastructure and access; and health, education, and capacity building; local content development. They have created enabling policy and regulatory environments that stimulate competition, entrepreneurship, commerce, investment, job creation, and growth. Their success suggests that when a set of interrelated conditions is pursued simultaneously, the interplay among them becomes catalytic, creating a development or Goal dynamic (UNDP 2001).

One of the difficulties of comprehensive acceptance by government and business of the role of ICT in supporting the Goals is the continued lack of hard data on the impact of ICT interventions and of its potential to scale and replicate. What would be the impact on pro-poor growth strategies of blanket, national mobile cellular coverage or broadband in a country? How would Internet access in and between major cities and global connectivity affect the Goals? What is the role of knowledge and information in achieving the first seven Goals? What can ICT do to contribute to empowerment and the PRSP process, to improve the efficiency of public service delivery, and to enhance livelihoods?

Eradicating poverty and hunger. The multidimensional nature of poverty has complex causes. Apart from lack of material wealth and possessions, poor people are often deprived of basic nutritional, educational, and healthcare needs. In addition, they are denied access to knowledge and information, a primary source of economic opportunity and political empowerment, rendering them vulnerable and prey to social exclusion. ICT can be viewed as both an accelerating and driving force as well as an outcome of human development.

Promoting opportunities for the poor is an essential element of poverty reduction. Consensus is building in the development community on the need to focus attention on ICT interventions that match local needs and conditions and concentrate efforts in four principal areas (World Bank 2003):

- Stimulating macroeconomic growth, through the contribution of the ICT sector to the economy and the effect of investment in ICT on economic growth and job creation.
- Increasing the market access, efficiency, and competitiveness of the poor through microlevel and people-oriented interventions (using village payphones, for example, and knowledge centers that improve

Box 4.2

Village phones in Bangladesh are bringing telephone access to 70 million people

Source: OECD 2004.

An impressive example of the development impact of ICT partnership comes from the OECD's updated analysis of Bangladesh's village payphone operator, GrameenPhone. Originally held back by local regulatory constraints and overambitious growth forecasts, the venture has since taken off. Since 1997 GrameenPhone has provided some 45,000 telephones to 39,000 villages in Bangladesh, bringing telephone access to some 70 million people. The village phone model has been successfully replicated in Uganda.

In 2003 GrameenPhone was the largest source of foreign direct investment ($230 million) and the second-largest corporate taxpayer ($280 million) in Bangladesh. The company is now leveraging its market power to lobby the government to ease punitive taxation so that it can boost network investment (as a provider of flood disaster relief, the company provides a public good) and introduce innovations, such as $0.50 prepaid scratch cards.

agricultural practices through access to information on crop selection, irrigation, fertilizers, and fishing and livestock conditions) (box 4.2).

- Increasing interactivity, making ICT continuously available, reducing its cost and global reach, and making social inclusion of poor and disadvantaged groups more feasible.
- Facilitating political empowerment, with improved planning in the PRSP process through inclusive, informed priority setting, increasing accountability, and good governance.

Improving primary education. More than 370 million of the world's 1.3 billion school-age children (28 percent) are not in school. Most live in Sub-Saharan Africa, South Asia, and parts of Latin America, the Caribbean, and the Middle East.

The problem of poor schooling and lack of schooling is unlikely to improve without major interventions. An additional 15–35 million educated and trained teachers will be needed over the next decade if all countries are to achieve the Goal of universal primary education by 2015.

The basic building blocks of a good education system—teachers, infrastructure, curriculum and content, teaching and learning tools, and administration—are missing in many developing countries. ICT can help overcome many of these deficits in an efficient way (Hepp and others 2004). ICT-based distance training can overcome the shortage of well-trained teachers by accelerating their training. Ineffective distribution of content can be tackled through ICT-based delivery of content. Administration can be streamlined through basic ICT applications.

Although pilot projects in the Researching ICT for Education in Africa Program (ICT4E) have shown the potential of ICT in schools, it is essential to move beyond these pilots and create comprehensive, demand-driven, coordinated "end-to-end" systems. Creating such systems will require bringing together coalitions of stakeholders in each country or region to plan and

ICT promotes gender equality by providing online opportunities that are not always available in the off-line world

implement national or regional e-schools initiatives. These initiatives will require technical, financial, and other support from global players, especially donors and relevant private sector companies.

The Global eSchools and Communities Initiative (GeSCI), founded by the United Nations and the governments of Canada, Ireland, Sweden, and Switzerland, will aim to catalyze and support national and regional e-school initiatives that bring together local actors under the leadership of the local ministries of education and ICT. GeSCI will help countries plan and connect to global partners who can provide expertise or financial support. Currently working in Bolivia, Ghana, Namibia, and Andhra Pradesh in India, GeSCI emphasizes the fact that ICT in schools has impact far beyond the classroom, yielding enormous benefits to local communities in the form of employment, adult education, health, business services, communication, and e-government.

The role of ICT in education is limited by the absence of business models that take advantage of the emergence of a wide range of versatile devices that can be adapted to various uses. For example, satellite technology could be combined with memory and audio devices to create libraries of educational materials in rural areas in developing countries. What is missing is not devices but the lack of content development. Partnerships between the ICT, media, and entertainment industries and actors from developing countries could help find ways to put existing technologies to educational uses. In addition to building the foundation for participation in creative industries, such partnerships could also revolutionize education through the use of animation in the design of teaching material (Lowe 2003).

Although the Goals focus on primary education, the role of education at other educational levels is also important (de Ferrranti and others 2003). A good example of the use of ICTs to promote tertiary learning is the African Virtual University, created in 1997 as pilot project of the World Bank (box 4.3).

Working toward gender equality. Goal 3 seeks to "eliminate gender disparity in primary and secondary education preferably by 2005 and in all levels of education no later than 2015." ICT can be used to influence public opinion on gender equality, increase economic opportunity, improve women's education and conditions for women as educators, and enhance women's ability to know their rights and participate in decisionmaking.

ICT promotes gender equality by providing online opportunities that are not always available in the off-line world. The Internet allows women to interact with men from remote locations, without face-to-face contact. ICT helps female entrepreneurs reduce transactions costs, increase market coverage, and expand across borders. The Self-Employed Women's Association (SEWA) of India use mobile village phones, the Internet, satellites, and television to promote the artisan handicrafts of the 5,000 women who belong to the network and to provide them with access to market information.

Box 4.3

The African Virtual University is reaching thousands of young Africans—including many who might not have attended a traditional university

Source: http://www.avu.org/.

Headquartered in Nairobi, Kenya, the African Virtual University (AVU) represents an important approach in using ICTs for educational purposes. In its first phase (1997–99), the AVU used the expertise and facilities of the World Bank, with additional support from vice-chancellors from universities in various African countries. In its transitional phase, the AVU established 31 learning centers in 17 African countries. More than 23,000 people were trained in journalism, business studies, computer science, languages, and accounting. Enrollment of women was more than 40 percent, a result of the flexibility offered by distance learning.

Since 2002 the AVU has expanded its activities to all African regions, offering degree and diploma programs. The program is focusing simultaneously on research and development of its technology delivery model. It aims to disseminate the pedagogy model as well as the general technology infrastructure in partner universities.

The AVU has created a network of 33 partner institutions in 18 African countries and registered more than 3,000 students in semester-long courses. It has enrolled a large number of African women in its specialist programs and is affiliated to a global network of leading universities. It is possible that the AVU model could be adopted at the national level, linking national universities and possibly helping universities offer training to neighboring pre-university schools.

Primary responsibility for childcare, cooking, and other household tasks have impeded women's ability to attend school. In some countries social customs make it difficult for women to participate in activities that involve mixing with men. In most developing countries, female school enrollment declines after childbearing age. ICT can help overcome these problems, through distance learning. Women's enrollment for ICT–based teacher training has outnumbered that of men in many countries.

Promoting health. ICT has already had an enormous impact on healthcare in developing countries. It has enabled healthcare workers to conduct remote consultation and diagnosis, access medical information, and coordinate research activities more effectively in the past two decades than in the history of medicine. ICT is an essential component in providing remote health care services, storing and disseminating healthcare information, conducting research, and training and networking health workers. Through both traditional (radio, television, video, CD) and new (wireless, Internet) media, ICT also provides an effective and cost-effective channel for disseminating information on healthcare and disease prevention to the masses.

The role of ICT in achieving health-related Goals is indispensable. ICT is an invaluable tool for both healthcare workers and the international development community in reducing child mortality (Goal 4), improving maternal health (Goal 5), and combating HIV/AIDS, malaria, and other diseases (Goal 6). Childhood diseases prevented 9 percent of the world's children from living to see their third birthday. Healthcare workers can use ICT to establish

ICT plays a key role in environmental management in activities ranging from optimizing clean production methods to decision-making

databases to track vaccination programs, coordinate shipments of antibiotics, and inform communities of medical services that can prevent child mortality.

Maternal death is the leading cause of death for women of reproductive age in the developing world. ICT can critically reduce the incidence of maternal death numbers by facilitating access to information and healthcare services.

In the fight against HIV/AIDS, ICT can strengthen disease monitoring and management, drug distribution systems, disease monitoring and management, drug distribution, training of caregivers, patient education and monitoring, and support networks for people living with HIV/AIDS and the people who care for them. The potential to enhance the response to HIV/AIDS has not yet been fully leveraged in the countries most affected by the crisis. Many of these countries lack the infrastructure and the human capacity (weakened by the toll taken by brain drain and HIV/AIDS) required to implement comprehensive ICT strategies that could improve prevention, treatment, and policy support. The potential of ICT as a cross-cutting tool across the Goals that can add value in addressing the pandemic has not been widely recognized.

Several initiatives to use ICT to prevent and treat HIV/AIDS are currently under way. These initiatives range from networks aimed at enhancing access to knowledge on HIV/AIDS treatments to the use of geographic information systems to map the spread of the disease in relation to socioeconomic variables and treatment (Committee on the Geographic Foundation for Agenda 21 2002). In some cases, clinical information infrastructure systems and simple mechanisms have been used to address the logistics of distribution and monitor the use of essential drugs. Virtual forums and lists have facilitated the discussion of access and treatment, enhanced advocacy, and raised awareness. Evaluations of effectiveness and the identification of good practices and mechanisms to scale up interventions and systems have not yet been conducted. The HIV/AIDS response needs to be cross-sectoral to address the pandemic's multiple dimensions. A more widespread coordination and strategic deployment of ICT that create new synergies and enhance overall response effectiveness are overdue.

Improving environmental management. Goal 7 proposes integrating the principles of sustainable development into country policies and reversing the loss of environmental resources, halving the proportion of people without access to safe drinking water, and achieving significant improvement in the lives of slum dwellers. Managing and protecting the environment improves human health conditions, sustains agriculture and other primary production sectors, and reduces the risks of natural disasters.

The effects of ICT on sustaining the environment are multidimensional. ICT facilitates greater participation by the population in activities to protect the environment through networking and information exchange. It provides researchers with critical tools for observing, simulating, and analyzing environmental processes. It promotes environmentally friendly work habits, by reducing

Molecular diagnostics present a powerful set of methods to address the health-related Goals

paper consumption and facilitating telecommuting; raises awareness of the environment, through knowledge sharing; facilitates environmental monitoring and associated resource management and risk mitigation; enables greater environmental sustainability in other industrial, commercial and agricultural sectors; and improves communication and implementation of policies.

ICT plays a key role in environmental management in activities ranging from optimizing clean production methods to decisionmaking. Spatial information is information related to a particular geographic location or area. It allows analysts to view the distribution of income across a country as a grid in order to target areas for action, understand demographic trends, and monitor progress. Spatial information collected by satellite or airborne remote sensing can be used to understand the capability of the land to support economic activity and water use efficiency. This information can help ensure that natural resources are used efficiently and sustainably.

New technologies are being developed that provide more accurate and timely estimation of risk. Spatial information about fire, rainfall, wind, and salinity may help countries identify and estimate risk more accurately.

A great deal of information is currently available to developing countries for use in making policy decisions. Some of this information (such as that obtained from satellites) is not released. Often the systems or skills needed to manage the data are lacking. Capacity building and information donation or exchange would address this issue.

Biotechnology

Biotechnology has emerged as one of the tools that can be used to address development challenges (Acharya, Daar, and Singer 2003). The realization of this potential, however, depends on a diverse set of policy instruments aimed at translating scientific discoveries into goods and services.[1] A study by the University of Toronto identified 10 biotechnologies as most likely to improve health in developing countries within the next 5–10 years (Daar and others 2002).[2] These biotechnologies included molecular diagnostics, recombinant vaccines, vaccine and drug delivery, bioremediation, sequencing pathogen genomes, female-controlled protection against sexually transmitted infections, bioinformatics, nutritionally enriched genetically modified crops, recombinant therapeutic proteins, and combinatorial chemistry (table 4.1).

Molecular diagnostics

Molecular diagnostics use recent advances in biology to diagnose infectious disease by detecting the presence or absence of pathogen-associated molecules, such as DNA or protein, in a patient's blood or tissue. They present a powerful set of methods to address the health-related Goals.

While improving public health infrastructure to prevent disease is crucial, diagnosis and treatment methods are also essential. Rapid and accurate diagnosis

Table 4.1

Genomics and related biotechnologies that can help countries meet the Goals

Millennium Development Goal	Statistics	Biotechnology to address Goal
Goal 1: Eradicate extreme poverty and hunger	Malnutrition plays a role in more than half of all child deaths.	• Productivity-enhancing biotechnologies • New biotechnology products • Product quality–improving technologies
Goal 3: Promote gender equality and empower women	Women account for 57 percent of HIV cases in Sub-Saharan Africa. Average HIV infection rates in teenage girls are five times higher than rates among teenage boys.	• Female control over sexually transmitted disease protection • Vaccine and drug delivery
Goal 4: Reduce child mortality	About 11 million children die before reaching their fifth birthday (WHO 1998).	• Molecular diagnostics • Vaccine and drug delivery • Recombinant vaccines • Female control over sexually transmitted disease protection • Enriched genetically modified crops • Combinatorial chemistry
Goal 5: Improve maternal health	More than 500,000 maternal deaths occur every year.	• Molecular diagnostics • Vaccine and drug delivery • Recombinant vaccines • Female control over sexually transmitted disease protection • Enriched genetically modified crops • Combinatorial chemistry
Goal 6: Combat HIV, malaria, and other diseases	HIV/AIDS, malaria, and tuberculosis are responsible for about 40 percent (5 million) of all deaths in the developing world. In 2002, 2.8 million people died of AIDS, 1.6 million of tuberculosis, and more than 1.2 million of malaria.	• Molecular diagnostics • Vaccine and drug delivery • Recombinant vaccines • Female control over sexually transmitted disease protection • Bioremediation • Sequencing pathogen genomes • Bioinformatics • Enriched genetically modified crops • Combinatorial chemistry
Goal 7: Ensure environmental sustainability	Waterborne diseases cause 5 million deaths a year.	• Bioremediation

increases the chances of survival, prevents resources from being wasted on inappropriate treatments, and helps contain disease. Many diagnostic tools currently in use in developing countries are cumbersome, time-consuming, and expensive.

Molecular diagnostics can be simple to use and relatively cheap, and produce quick results. These technologies include polymerase chain reaction

Antigens feature in simple handheld test devices capable of providing a diagnosis in minutes

(PCR), monoclonal antibodies, and recombinant antigens. PCR is a quick way of producing millions of copies of a specific sequence of DNA. PCR tests are extremely sensitive and can provide results in a few hours (as opposed to days for culturing methods). They can also be used to detect infectious organisms that are difficult or impossible to grow in culture (such as tuberculosis and malaria) or are dangerous to handle (such as HIV/AIDS).

Antibody-based applications are well suited to the developing world. Antibodies are molecules produced by the immune system in response to infection. They recognize and bind antigens, which are produced by pathogens. The fact that every antibody recognizes and binds to a specific type of antigen makes antibody-based applications excellent tools for diagnosing infectious disease. The recent development of simple antibody-coated dipstick tests, like those used to diagnose malaria and HIV, has increased the relevance of this technology for the developing world, since these tests can be used where clean water and electricity are not accessible and people may have to travel long distances to reach a medical facility.

Recombinant antigens are genetically engineered antigens that are mass-produced by fast-replicating organisms such as bacteria or yeast. Like antibodies, antigens feature in simple handheld test devices capable of providing a diagnosis in minutes. The Oswaldo Cruz Institute in Brazil has developed a commercial diagnostic kit for Chagas disease based on recombinant *Trypanosoma cruzi* antigens.

Recombinant vaccines

Recombinant vaccines can play an important role in achieving Goal 4 (reducing child mortality), Goal 5 (improving maternal health), and Goal 6 (combating HIV/AIDS, malaria, and other diseases). Vaccines stimulate the body to produce a protective immune response against infectious organisms. They are arguably the most important medical advance of the past hundred years. Vaccination has resulted in the eradication of smallpox, the control of polio, and a dramatic reduction in the prevalence of many other infectious diseases.

Until a few decades ago, all vaccines consisted of either killed or inactivated (attenuated) pathogens. Injection of these vaccines stimulated the person's immune system to produce antibodies against the foreign organism, making the person resistant to future infections. Because inactivation is sometimes insufficient, however, the vaccine carries some risk of causing a fatal infection.

Genetic engineering makes it possible to produce single proteins of the pathogen in nonpathogenic microorganisms. This approach produces safer vaccines, since the individual foreign proteins cannot cause the disease. Recombinant vaccines made with only part of the genome of a pathogen are known as *subunit vaccines.*

Recombinant vaccines may also prove cheaper than traditional vaccines, because of innovative production methods and because improved storage characteristics may allow some of them to be maintained without refrigeration.

Scientists are exploring a number of alternatives to needle-based delivery of drugs or vaccines

Much progress is being made in recombinant vaccine development. A major roadblock is the long time it takes to run clinical trials and obtain regulatory approval, which has limited the number of products on the market.

Researchers are working to develop techniques to overcome some of the difficulties with recombinant vaccines, such as the correct presentation of recombinant antigens to the immune system and the limited lifetime of the engineered protein in the body. In 1997 Shantha Biotechnics (www.shantha-biotech.com), an Indian company, launched a recombinant hepatitis B vaccine, which it sells for $0.40 per dose—a fraction of the $8–$10 per cost of the of imported vaccine. The vaccine recently received WHO certification, and UNICEF has ordered 8.5 million doses of it for distribution worldwide.

Viral vector vaccines consist of a benign virus that has been genetically modified to contain genetic material belonging to the pathogen. Upon injection, the virus delivers the genetic material into the cell's nucleus, where the new genes get incorporated into the cell's genome. Naked DNA vaccines, or plasmid DNA vaccines, use a plasmid to introduce the antigen genes into the individual's cells. Plasmids are small circular molecules of DNA normally found in bacteria that can easily enter cells and recruit the cell to translate their genetic information into protein. DNA vaccines are potentially faster, cheaper, and easier to use than other types of vaccines, and because DNA is heat stable these vaccines may be able to bypass refrigerated transport and storage, a major cost barrier to efficient vaccine delivery. Plants such as tomatoes and potatoes can easily be engineered to express foreign proteins. These vaccines can be produced, stored, and transported relatively inexpensively, and they can be grown locally, making them attractive for applications in developing countries.

Vaccine and drug delivery

Closely related to advances in vaccines are improved methods of vaccine and drug delivery, which will help meet Goals 4, 5, and 6. Thousands of children die each year from vaccine-preventable diseases because the logistics of vaccine delivery are prohibitively expensive. Refrigerated transport and storage are a major expense in all vaccine programs. The need to hire trained medical personnel to deliver vaccinations also adds to their cost.

Unsanitary drug and vaccine injections are associated with the spread of bloodborne diseases, particularly HIV and hepatitis. The reuse of needles causes an estimated 80,000–160,000 new cases of HIV/AIDS, 8–16 million new cases of hepatitis B, and 2–4 million new cases of hepatitis C each year (Kane and others 1999). Long and complicated drug regimens are difficult for people to comply with, especially if they involve visits to medical facilities. Partial treatment can lead not only to death but to the emergence of drug-resistant strains of disease.

Injection-free and controlled-release delivery systems could help solve many of these problems. Scientists are exploring a number of alternatives to needle-based delivery of drugs or vaccines. The skin is an attractive route into the

Reduction of pollution in water supplies and the food chain can help reduce mortality and improve health

body because of its easy access. Needle-free injections propel the vaccine or drug through the skin and into the body with a high-speed jet of gas. Solutions, rubbing gels, and skin patches rely on simple diffusion to introduce agents into the body. Another avenue into the body is the mucus membrane, which lines all of the inner cavities of the body, including the intestines and the lungs. Vaccination through nasal sprays and inhalers in the lung membranes generates immunity in the rest of the body's mucus membranes, inducing systemic immunity.

The refrigeration required to store and transport conventional vaccines and drugs is costly. The discovery that some microorganisms can be rejuvenated after complete dehydration has led to the development of powdered vaccines and drugs that are heat stable. These organisms contain a nonreactive sugar (trehalose), which stabilizes them while they are desiccated. With this and other stable sugars, researchers have been able to dehydrate liquid vaccines and drugs and store them at room temperature for up to several months without affecting their potency. Injection devices for dried vaccines have been developed. Some involve the reconstitution of the dried substance into a liquid just before injection, others introduce the substance into the body through the skin as a powder using needles or a high-speed jet of gas.

Improved drug delivery can also help reduce the length and complexity of drug treatment regimens. Controlled-release drugs and vaccines can be introduced into the body in association with a biodegradable polymer that gradually releases its contents as it is broken down by the body. One disease for which this would be very useful is tuberculosis. Sustained-release treatments would lower the number of doses a patient must receive, thereby increasing compliance and limiting the emergence of drug-resistant strains of tuberculosis. Preliminary studies of controlled release antibiotics have been promising. Recently a group has reported the development of temperature-stable, controlled-release formulations using oligosaccharide ester derivatives of trehalose and a synthetic peptide analogue of hepatitis B surface antigen. The ability of these novel delivery systems to induce strong immune responses in mice without the requirement for multiple doses or cold-chain storage is encouraging.

Bioremediation

Bioremediation refers to the use of biological agents like bacteria or plants to clean up the environment (box 4.4). It has direct significance for Goal 7 (ensuring environmental sustainability), but it also has an impact on the health-related goals.

Reduction of pollution in water supplies and the food chain can help reduce mortality and improve health. Two main types of pollution threaten the health and well-being of human populations: organic waste and heavy metals, such as lead, mercury, and cadmium. Bacteria can detoxify both. Plants can break down most forms of organic waste, but, with very few exceptions, they are usually unable to metabolize heavy metals. They can, however, store harmful metals in their tissues, making it easier to collect, harvest, and even recycle metal waste.

Box 4.4

Bangladesh is using bacteria to treat contaminated groundwater

Source: Santini and others 2000.

Naturally occurring contamination of Bangladesh's groundwater is causing what some have called the largest mass poisoning of a population in history. At least 100,000 people have already been affected, and another 50 million people are at risk. A bacterium called NT-26, recently discovered in a gold mine in Australia, may be able to help. NT-26 has the natural ability to transform arsenite, a soluble form of arsenic, into the much less toxic arsenate. The Australian Research Council is supporting research to investigate the potential of NT-26 to reduce the toxicity of arsenic dissolved in water. Knowledge of the genomic sequence of NT-26 could enhance bioremediation tools. Genome Canada plans to sequence the genomes of two arsenic-metabolizing bacteria, including NT-26.

Water contaminated by human waste harbors large amounts of pathogenic organisms and has been implicated in the transmission of cholera, typhoid, hepatitis A, and other waterborne diseases. Sewage treatment can dramatically reduce the incidence of these diseases. Bioremediation techniques can augment conventional chemical sewage treatment.

Several low-cost alternatives to conventional sewage treatment have been developed. One system is in use in southern China. It uses floating rafts, called *restorers*, to supply beneficial microorganisms to a canal contaminated with human waste. This floating ecological treatment engine has been transformed into a garden featuring a dozen species of native Chinese wetland plants.

Bioremediation can also help clean up mosquito-infested water and control the spread of malaria, especially where other control methods have become less effective. The malaria-carrying *Anopheles* mosquito has developed resistance to several chemical insecticides. Many antimalarial prophylactics are losing their efficacy, and they remain too expensive for many people in developing countries.

Canada's International Development Research Centre has supported research at the Instituto de Medicina Tropical Alexander Von Humboldt in Lima to explore the use of bacteria and coconuts in controlling malaria. Researchers at the institute have developed a method of biologically controlling mosquitoes that is a simple, inexpensive, and environmentally safe alternative to insecticides. Coconuts are used to culture bacteria that are toxic to mosquito larvae but harmless to people and other organisms. *Bacillus thuringiensis* var. *israelensis* H-14 *(Bti),* a bacterium that produces a toxin lethal to mosquito larvae, is introduced into the coconut through cotton swabs and allowed to incubate inside the coconut for a few days. The nut is then broken and tossed into ponds where mosquitoes breed. The mosquito larvae eat the bacteria and are killed. A typical pond needs only two or three coconuts for each treatment, usually lasting two months.

Sequencing of pathogen genomes

The sequencing of pathogen genomes has direct relevance to Goal 4 (combating HIV/AIDS, malaria, and other diseases). Pathogen genomics can also contribute to the search for a cure for these diseases.

Genomics and other biotechnologies are enabling the development of new forms of female-controlled protection against sexually transmitted diseases

Sequencing a genome involves discovering and recording the entire sequence of nucleotides in an organism's DNA. DNA codes for proteins, the mainstay of structure and biochemical function in all organisms. Knowledge of the genomic sequence of a pathogen is helpful in unraveling its biology and discovering ways of controlling its relationship with humans.

Most sequencing strategies are based on a technique known as the dideoxy, or Sanger, method. Small-scale sequencing projects can be conducted manually, but large-scale projects (such as the sequencing of an entire genome) require high-throughput automated DNA sequencing machines. Major sequencing projects use many automated sequencing machines simultaneously, yielding millions of bases of sequence data per day. These data must be stored, managed, and analyzed by computers. (This requirement has given rise to an entirely new field in biology, bioinformatics, discussed below.)

Knowing the sequence of a pathogen's genome can accelerate the process of drug discovery. Comparative genomics compares the genomes of different organisms in order to apply information known about one organism to another. In a comparison of disease-causing and benign strains of the same organism, genes unique to the pathogenic strain are likely to play an important role in pathogenesis, and the proteins for which they code may make excellent drug targets. Analysis of pathogen genomes could also identify genes that play a role in helping pathogens develop drug resistance and point researchers toward treatments that can prevent these genes from functioning. Scientists can compare the genomes of resistant and nonresistant strains or analyze the genes at work in the drug-resistant stage of an organism's lifecycle.

Genomics and bioinformatics helped resurrect the little-used antibiotic fosmidomycin as a novel antimalarial drug. Scientists successfully searched the *Plasmodium falciparum* genome for the gene of an enzyme targeted by fosmidomycin (Jomaa and others 1999). Fosmidomycin inhibits the growth of multiresistant strains of *P. falciparum*. It was found to be safe and effective when administered to adults in Gabon with malaria.

Recently, scientists in Brazil and China sequenced two species of the parasite that causes schistosomiasis, *Schistosoma mansoni*, found in Africa and South and Central America, and *Schistosoma japonicum*, prevalent in Asia. The genomic sequences point to potential therapeutic and vaccine targets to manage the disease, which affects more than 200 million people in 74 countries (Hu and others 2003; Verjovski-Almeida and others 2003).

Female-controlled protection against sexually transmitted infections

Genomics and other biotechnologies are enabling the development of a number of new forms of female-controlled protection against sexually transmitted diseases. These biotechnologies include recombinant vaccines, monoclonal antibodies, and new approaches to the development of vaginal microbicides. These technologies can help meet Goal 6 (combating HIV/AIDS, malaria,

Bioinformatics can be used to identify drug targets and vaccine candidates

and other diseases) and Goal 3 (promoting gender equality and empowering women).

The global burden of sexually transmitted diseases is borne most heavily by women. Despite the urgent need to protect themselves against these diseases, women have few options. The condom requires male consent, which many women living in patriarchal societies find hard to negotiate. The female condom's indiscreetness makes it a less than ideal option. Vaginal microbicides are an attractive alternative. These gel or cream formulations of chemical compounds block the transmission of infection across the vaginal wall. Six first-generation vaginal microbicides are now in safety and efficacy trials.[3]

Bioinformatics

Bioinformatics is the use of computer hardware and software to store, retrieve, and analyze large quantities of biological data (box 4.5). High-throughput technologies (DNA sequencers, DNA and RNA microarrays, combinatorial chemistry, two-dimensional gel electrophoresis, and mass spectrometry) have resulted in an explosion in the volume of biological data available. Bioinformatics organizes this sea of data into meaningful databases and conducts sophisticated computer analyses (data mining) to generate answers to research questions.

Bioinformatics applies computer algorithms to transform large-scale biological data sets into useful information. For example, an algorithm could be applied to quickly identify potential drug targets in pathogen genomes. Without bioinformatics, this task would be extremely laborious and prone to error, and it would take scientists years to realize the potential of genomic sequencing.

Many bioinformatics algorithms are available free over the Internet, along with basic tutorials. Many can be found on Web sites with public bioinformatics databases. Their accessibility to scientists helps promote R&D. To help meet the worldwide demand for skilled bioinformaticians, a consortium of six universities is offering a free accredited Web-based course in bioinformatics.

Bioinformatics can be used to identify drug targets and vaccine candidates. The genes that encode most antigens have characteristic sequences. In their

Box 4.5

Researchers can access biological databases over the Internet free of charge

Several biological databases have been established as public resources available to all over the Internet. GenBank is a massive online database of all publicly available gene sequencing. The database, which is maintained by the National Center for Biotechnology Information of the U.S. National Institutes of Health, can be accessed free of charge over the Internet. GenBank exchanges data daily with the DNA DataBank of Japan and the European Molecular Biology Laboratory. SWISS-PROT is a protein sequence database developed by the Swiss Institute of Bioinformatics and the European Bioinformatics Institute. The Molecular Modeling Database, maintained by the National Center for Biotechnology Information, contains three-dimensional biomolecular structures, including information on biological function and the evolutionary history of large molecules.

Vitamin A–enriched golden rice is a well known example of a nutritionally enhanced genetically modified crop

analysis of *Chlamydia pneumoniae* (a cause of respiratory infections), researchers identified 147 cell surface proteins, 58 of which produced an immune response when injected into mice. Bioinformatics techniques helped researchers tackle an organism that had been a challenge to study using conventional laboratory techniques (Grandi 2001).

Nutritionally enriched genetically modified crops

Nutritionally enriched genetically modified crops can help meet the three health-related Goals (reducing child mortality, improving maternal health, and combating HIV/AIDS, malaria, and other diseases). This potential, however, must be viewed against a background of concerns related to environmental, human health, and socioeconomic risks associated with new and existing technologies (J. López, Friends of the Earth International, personal communication, 2004). More than half of all infant deaths in developing countries are associated with a lack of essential vitamins and nutrients. Malnutrition also impairs cognitive and physical development and is associated with multiple illnesses attributed to specific nutrient deficiencies. These include blindness due to Vitamin A deficiency, which affects an estimated 500,000 children in developing countries. Anemia, caused by iron deficiency, is one of the leading causes of maternal mortality. Pregnant women with anemia are more likely to give birth to low birthweight infants and are at increased risk of death during childbirth. Malnutrition, which affects about one in five people in developing countries, amplifies the effects of infectious diseases. Lack of essential vitamins and minerals impairs the immune system, increasing the likelihood that infection will develop into disease and impairing the ability of the body to recover.

Genetically modified crops are crops whose composition has been altered by genetic recombination. The crops are altered by inserting a gene—with a gene gun or a carrier organism, such as a benign virus—into a plant very early during its development so that all of the plant's cells acquire the gene. Various traits can be introduced into crops through genetic modification. One application of genetic modification in crops is to enhance their nutritional value. This type of modification might involve insertion of genes that encode for enzymes that synthesize vitamins.

Vitamin A–enriched golden rice is a well known example of a nutritionally enhanced genetically modified crop, although its future benefits continue to be disputed. Researchers in India have developed a potato rich in all essential amino acids (Chakraborty, Chakroborty, and Datta 2000). The potato contains the gene AmA1, which codes for the protein albumin, which contains high levels of all of the amino acids the body is incapable of making on its own.[5] The gene gives potatoes a third more protein than normal. This enriched potato is particularly important in India, where a large percentage of the population is vegetarian. Scientists believe the protein-rich genetically modified "protato" could help combat malnutrition among India's poorest children.

Some recombinant therapeutic proteins would be useful for developing country diseases

Both genetic modification and traditional breeding change the characteristics of an organism. Both forms of breeding can cause unexpected results. In traditional breeding the introduction of a gene into an organism by cross-breeding different strains of the same species is a trial and error process that takes a long time. Genetic recombination makes it possible to complete the process more rapidly and more precisely, and it enables the introduction of new genes from different species. One disadvantage is that that the introduced foreign genes may cause unknown gene-gene or gene-environment interactions. Ecological concerns include risks to human and animal health, food safety, and unforeseen consequences of the spreading of foreign genes into the natural environment. Gene-flow, the natural spread of genetic traits when a plant variety is introduced into the environment, is in itself not alarming, but the potential introduction of cross-species genes and the spread of genes that produce novel traits in related weeds or crops could be. Some scientists believe that extensive testing and careful monitoring are necessary for the world to reap the benefits of this technology while avoiding any potential risks.

Recombinant therapeutic proteins

Therapeutic proteins, such as insulin, are used to treat many noncommunicable diseases. The technology to make recombinant therapeutic proteins is therefore significant for meeting Goal 6. As poorer countries develop, they face a double burden of disease: the burden of infectious diseases as well as the burden of noncommunicable diseases more commonly associated with the developed world. Affordable and sustainable sources of therapeutic proteins for treating these diseases are therefore critical.

Using recombinant technology, researchers can insert a gene or genes for a therapeutic protein into an organism. As the organism grows, it reads and translates the foreign gene with its own genes and produces the therapeutic protein, which can be harvested for use. Bacteria, particularly *Escherichia coli*, were the first organisms to be drafted for the production of therapeutic proteins. Under the right conditions, the bacteria grow and divide rapidly, accumulating the recombinant protein in their interior fluids. Protein purification processes harvest the protein from the bacterial culture.

Bacteria have one main disadvantage: they are extremely simple organisms and lack the ability to make specific chemical modifications to the proteins after the proteins have been formed. Most human therapeutic proteins require these modifications to function normally. As more complex organisms, yeasts can carry out many forms of protein modification, and, like bacteria, they reproduce quickly and easily. Because of its safety and familiarity, *S. cerevisiae* is the most popular yeast for making recombinant proteins. Mammalian cells are still a more attractive source of recombinant therapeutic proteins, since they are capable of almost all posttranslational modifications. Mammalian cell cultures are difficult to maintain, however, and they have a relatively low protein yield. One way

Combinatorial chemistry has a bearing on the health-related Goals, particularly combating HIV/AIDS, malaria, and other diseases

around these limitations is to use transgenic animals that are engineered to secrete the protein in an easily harvested body fluid, such as milk, urine, or semen.

Some recombinant therapeutic proteins that would be useful for developing country diseases include erythropoietin for the treatment of anemia, alpha interferon for the treatment of viral infections and leukemia, and insulin for the treatment of type I diabetes. Insulin from the pancreas of pigs and cattle varies slightly from human insulin, so it may induce an allergic reaction in some diabetics. Recombinant technology has made nonallergenic human insulin available in abundance. Wockhardt, an Indian company, recently became the first firm outside the United States or Europe to develop the technology to produce recombinant human insulin, which it is now selling for less than imported insulin. The patent on recombinant human insulin expired in January 2003, allowing developing countries to manufacture the product locally and at more affordable prices.

Combinatorial chemistry

Combinatorial chemistry has a bearing on the health-related Goals, particularly combating HIV/AIDS, malaria, and other diseases. There are many diseases prevalent in the developing world for which effective and affordable treatments are lacking. And some pathogens, such as those that cause malaria and tuberculosis, are acquiring resistance to the only treatments available. Child mortality is caused in large part by pneumonia, diarrhea, and malaria, three diseases that are acquiring drug resistance. Combinatorial chemistry can be used to provide new or more effective medications for these diseases. It may also help industries in developing countries become competitive and economically viable in the global market. The increase in efficiency also potentially decreases costs, wastes less material, and creates fewer by-products, all of which help protect the environment.

Combinatorial methods are easily automated techniques for making many different kinds of chemical compounds. The resulting collection of compounds, known as a library, is biologically screened to select the compounds with the most therapeutic promise. First developed in the early 1980s, combinatorial chemistry has become a mainstay of drug discovery and development in industrial countries. In many cases, it has replaced the much more costly and time-consuming one-compound-at-a-time method.

Two features make combinatorial chemistry exceptionally efficient for drug discovery and development. First, robots can be used to do most of the preparation and screening of compounds. Second, many unique compounds can be produced from fewer experiments.

Nanotechnology

Nanotechnology is the study, design, creation, synthesis, manipulation, and application of functional materials, devices, and systems through control of

Cost-effective agricultural applications of nanotechnology could decrease hunger, malnutrition, and childhood mortality

matter at the atomic and molecular levels and the exploitation of novel phenomena and properties of matter at that scale.[6] At this scale, matter is affected by quantum effects. Matter at the nanoscale can be more chemically reactive than other matter; sometimes materials that are inert at the macroscale become reactive at the nano-level. Quantum effects at the nano-level can also affect the strength and the optical, electrical, and magnetic properties of materials.

The use of nanotechnology applications for water treatment and remediation; energy storage, production, and conversion; disease diagnosis and screening; drug delivery systems; health monitoring; air pollution and remediation; food processing and storage; vector and pest detection and control; and agricultural productivity enhancement will help developing countries meet five of the Goals. The convergence of nanotechnology with other emerging technologies, such as biotechnology, genomics and information technology, will help implement the Goals.

Nanotechnology may have a significant impact on all areas of human endeavor. According to Richard Smalley, a nanotechnology pioneer who was awarded the Nobel Prize in chemistry in 1996 for his discovery of fullerenes, "the impact of nanotechnology on health, wealth, and the standard of living for people will be at least the equivalent of the combined influences of microelectronics, medical imaging, computer-aided engineering, and man-made polymers in this century" (Smalley 1999). Nanotechnology is likely to be particularly important in the developing world, because it involves little labor, land, or maintenance; it is highly productive and inexpensive; and it requires only modest amounts of materials and energy. Nanotechnology products will be extremely productive, as energy producers, as materials collectors, and as manufacturing equipment.

Nanotechnology can contribute new tools with which to address sustainable development problems, and it can strengthen the technologies already available and make them more efficient. It will coexist with rather than replace established technologies. Its impact will be felt in multiple ways, depending on how other technologies converge and align themselves around it.

Advances in nanotechnology tend to be geared toward the interests of industrial countries. Applications for cosmetics, sports apparel, and various digital gadgets do not address the pressing needs of the more than 5 billion people in developing countries.

Significant nanotechnology activity is already occurring in developing countries (table 4.2). This activity may be derailed by a debate that fails to take account of the perspective of developing countries. The evolution of nanotechnology can benefit from the lessons learned from previous technologies. The aim should be to encourage public discourse and consider potential benefits for the developing world.

Reducing hunger

Cost-effective agricultural applications of nanotechnology could decrease malnutrition, and childhood mortality, in part by increasing soil fertility

Table 4.2

Research and development on nanotechnology in selected developing countries

Nanotechnology status	Countries	Nanotechnology activity	Example
Frontrunner	China, India, Republic of Korea	• National government-funded nanotechnology program • Nanotechnology-related patents • Commercial products on the market or in development	*China* • National Center for Nanoscience and Nanotechnology • Clinical trials of nanotechnology bone scaffold *India* • Nanomaterials Science and Technology Initiative • Commercialization of nanoparticle drug delivery *Republic of Korea* • Nanotechnology Development Program • World's first carbon nanotube field emission display
Middle ground	Brazil, Chile, the Philippines, South Africa, Thailand	• Development of national government-funded nanotechnology program • Some government support (research grants) • Limited industry involvement • Numerous research institutions	*Brazil* • Institute of Nanoscience, Federal University of Minas Gerais *Chile* • Nanotechnology Group, Pontificia Universidad Católica de Chile *Philippines* • University of the Philippines/Intel Technology Philippines optoelectronics project *South Africa* • South African Nanotechnology Initiative *Thailand* • Center of Nanoscience and Nanotechnology, Mahidol University
Up and comer	Argentina, Mexico	• Organized government funding not yet established • Industry not yet involved • Research groups funded through various science, technology, and innovation institutions	*Argentina* • Nanoscience research group, Centro Atómico Bariloche and Instituto Balseiro *Mexico* • Department of Advanced Materials, Instituto Potosino de Investigación Científica y Tecnológica

and crop productivity. Crop health can be monitored using nanosensor arrays. Nanosensors can raise the efficiency of crop monitoring activities. Sensors applied to the skin of livestock or sprayed on crops can help detect the presence of pathogens. Nanoporous materials such as zeolites, which can form well-controlled stable suspensions with absorbed or adsorbed substances, can be

Nanotechnology can enable rapid, accurate, timely, and affordable methods of diagnosis and prevention

employed for the slow release and efficient dosage of fertilizers for plants and of nutrients and drugs for livestock.

Promoting health

Applications of nanotechnologies addressing health in developing countries are especially promising, particularly for diagnostic tools, drug and vaccine delivery, surgical devices, and prosthetics. Nanotechnology can enable rapid, accurate, timely, and affordable methods of diagnosis and prevention, which can allow more effective treatment with existing drugs. It can help detect pathogens, such as mycobacteria and HIV.

Nanotechnology-based solutions in developing countries will depend on cost, supply, and ease of use, especially where a wide range of screening can occur with relatively inexpensive sensors in local clinics using diagnostic kits. Microfluidic devices (lab-on-a-chip), carbon nanotube-based biosensor arrays, fluorescent semiconductor nanoparticles, magnetic nanoparticles, and quantum dots offer significant diagnostic advantages over conventional fluorescent dyes. Dendrimers, in conjunction with antibodies, have been designed to detect HIV and cancer. Atomic wires and nanobelts can be used to detect cancer, since these nanomaterials are capable of revealing specific malignant agents through changes in their electronic transport characteristics.

Nanotechnology can also be applied to synthesize and target the delivery of drugs. It provides encapsulation systems that can protect drugs while slowly delivering and releasing them. This capability can be very valuable in countries without adequate drug storage capabilities and distribution networks. Long-term delivery obviates the need for patients to take pills daily at well-defined times. Polymers for the slow release of drugs can be especially useful for drug regimens that are long and complex, such as those used to treat tuberculosis. Nanotechnology can also reduce transportation costs and even required dosages by improving the shelf-life, thermo-stability and resistance to changes in humidity of existing medications. A more specific and selective delivery of drugs and vaccines can be obtained by the use of nanocapsules, liposomes, dendrimers, and buckyballs. Other areas of bio-nanotechnology that are being actively researched include regenerative medicine and nanoscale surgery. Nanoceramics can be used to produce more durable medical prosthetics.

Improving water and sanitation

More than 2 million children die each year from water-related diseases, such as diarrhea, cholera, typhoid, and schistosomiasis, which result from a lack of adequate water and sanitation services. Arsenic, fluoride, and nitrates threaten water supplies in many regions. In some cities in the developing world, only 10 percent of sewage is treated. Conventional bacterial and viral filters trap pathogens inside granular carbon or porous ceramic or polymer materials. These filters are often difficult to clean and must be changed frequently.

Harnessing renewable energy sources through cleaner, more affordable, and more reliable technologies can prevent the dependency of developing countries on fossil fuels

Nanomembranes and nanoclays are cheap, easily transportable, and cleanable systems that can purify, detoxify, and desalinate water. Filters made of carbon nanotubes have been developed by researchers at Banaras Hindu University in Varanasi, India, in collaboration with researchers at the Rensselaer Polytechnic Institute, in the United States. Nanosensors for the detection of contaminants and pathogens can improve health, maintain a safe food and water supply, and allow for the use of otherwise unusable water sources. Nanoelectrocatalysts for anodic decomposition of organic pollutants and for the removal of salts and heavy metals from liquids will permit the use of heavily polluted and heavily salinated water for drinking, sanitation, and irrigation.

Other applications of nanotechnology for water recycling and remediation include the use of zeolites and nanoporous polymers to purify water and absorb toxic metals; attapulgite clays to remove heavy metals, oils, organic pollutants, and bacteria from water; engineered membrane technology with biochemical modifications to purify and filter water; magnetic nanoparticles to adsorb metals and organic compounds; and titanium dioxide and iron nanoparticles to catalytically degrade pollutants. By-products of remediation, such as toxic metal ions, can be transformed into useful inorganic nanomaterials.

Developing renewable energy sources

Harnessing renewable energy sources through cleaner, more affordable, and more reliable technologies can prevent the dependency of developing countries on fossil fuels and avert potential energy crises and environmental degradation brought about by the depletion of oil and coal. Improved access to clean energy could play a role in improving health (by reducing indoor air pollution, for example) and increase the efficiency of agricultural production. Applications of nanotechnology such as solar cells, fuels cells, and novel hydrogen storage systems based on nanostructured materials promise to deliver clean energy solutions. Nanophotovoltaic devices, such as those based on quantum dots or ultrathin films of semiconducting polymers, can significantly reduce the costs associated with conventional solar cells. Carbon nanotubes can be used in composite film coatings for flexible solar cells.

A major expense associated with hydrogen as a source of energy is its generation from water, a process that requires energy. Photo- and thermo-chemical nanocatalysts can be used to generate hydrogen from water at low costs. Electricity can also be cheaply produced using green technology from artificial systems that incorporates energy transduction proteins into an engineered matrix. Organic light-emitting devices based on semiconducting nanospheres can be developed to improve rural lighting. Carbon nanotubes used in hydrogen storage systems can provide lightweight materials for pressure tanks and liquid hydrogen vessels. Carbon nanotubes could provide strong, flexible conduits for electricity distribution networks. Ideally, all of these applications will be robust and easily maintained and serviced.

Nanobiotechnology, the convergence of nanotechnology and biotechnology, can be harnessed to enrich biodiversity

Improving environmental management

Many developing countries rely on fossil fuels for most of their energy. Waste products resulting from the use of these fuels have a deleterious effect on both human health and the environment. Almost 800,000 deaths are caused by urban air pollution every year, nearly two-thirds of them in developing countries.

Nanocatalysts can reduce air pollution, especially from waste products of nonrenewable energy sources, decreasing the dependence of developing countries on these sources and preventing health and environmental problems. Metal oxide nanocatalysts, especially TiO_2 nanoparticles in self-cleaning coatings, can be used to photocatalyze air pollutants and reduce fossil fuel emissions. Intense research is being conducted on nanodevices that can absorb and separate toxic gases and on nanosensors that can be used to detect toxic materials and leaks.

Nanobiotechnology, the convergence of nanotechnology and biotechnology, can be harnessed to enrich biodiversity. Researchers at Chiang Mai University, in Thailand, are using nanotechnology to develop a strain of rice that has shorter stems and that is not sensitive to sunlight, thereby reducing vulnerability to wind damage and decreasing storage related costs. The National Aeronautics and Space Administration's Nanopore Project is developing a device that can sequence single molecules of nucleic acid at a rate of 1 million bases per second by using nanopore technology. The device will allow for faster sequencing of the DNA of all living organisms, creating a database of information underlying the biodiversity of the planet and enabling sensible ecosystem management.

Nanotechnology should be used responsibly to avoid compromising environmental integrity. Desirable properties of nanomaterials, such as high surface reactivity and the ability to cross cell membranes, could potentially have negative consequences if these technologies were used inappropriately. Measures must be taken to ensure that nanomaterials are contained and disposed of appropriately. This calls for careful research into the potential hazards of nanotechnology and for the design of appropriate regulatory systems to manage the benefits and risks of this new technology.

New materials

Materials are playing an increasingly important role in technological innovation. Research on materials is of vital importance for technological change and particularly important for developing countries in achieving the Goals. The development of low-cost building materials could boost construction of schools and shelter in developing countries and help meet the Goal of universal primary education. By providing better living environments, low-cost building materials could reduce child mortality, improve maternal health, and improve environmental sustainability. Making the benefits of new technologies available

Devices using solid-state ionic materials could contribute to economic development in developing countries

to developing countries requires formulating a strategy that ensures that they have access to new technologies such as materials science.

Knowledge of the mechanical, electronic, ionic, and nuclear properties of metals, semiconductors, polymers, ceramics and composites, and magnetic and radioactive materials is necessary to use these materials effectively in industry. Investment in higher education and research in materials science should form part of developing countries' strategies for industrial development. Materials—both natural and man-made—are rich with properties that can be harnessed for modern technological needs. Understanding the principles underlying the properties of materials is essential for developing new materials with properties suitable for new technologies.

Most developing countries are in the tropics. The development of cells created from new materials and photo-electrochemical cells could help formulate strategies that could help them exploit renewable sources of energy. Semiconductor research can lead to the development of new generations of integrated circuits and the solid-state memories used in ICT, semiconductor lasers, light-emitting diodes, and light-detecting devices, and technologies like photolithography.

Newer ceramic materials, such as piezoelectric ceramics, bioceramics, and electronic and electro-optic ceramics, provide technologically important alternatives to traditional ceramic materials. Ceramic composites, ceramic coatings, ceramic films, and glass materials (including glass ceramics, glass-ceramic composites, and conducting glasses) are important materials for industry. Special purpose polymers could be used in applications such as artificial muscles and light-emitting devices. Devices using solid-state ionic materials (such as solid electrolytes and electrode materials) form the basis for new types of batteries, fuel cells, and sensors. All these materials could contribute to economic development in developing countries.

Influence of platform technologies beyond 2015

The Goal timeline of 2015 is but the first step in the long march to sustainability in this century. Beyond 2015 the impacts of these platform technologies will be even more marked. The field of energy and vehicle transportation shows just how.

About 80 percent of all climate warming is caused by emissions of carbon dioxide. The installation of large and conventional fossil-fuelled power generating units cannot be continued unabated. The concomitant power grids channel power in one direction from massive power generators through extra-high-voltage transmission systems and then lower voltage distribution networks to consumers. This infrastructure system is very capital-intensive, with a typical 1,000 MW fossil fuel power plant costing about $1 billion. China currently faces acute electric power shortage and needs an additional 30,000 MW of electric power generating plants, which will cost about $30 billion.

Energy experts have suggested that hydrogen fuel cell will be the most positive development for energy and transportation in sustainable development

One promising solution will be to develop small power plants, units, and systems that are environmentally benign. The medium-term prospects are promising. Nanotechnology and new materials can develop small and environmentally benign power-generating devices like hydrogen fuel cells, which will allow electricity to be supplied to rural, remote, and poor urban communities using localized and flexible bidirectional power networks.

Increasing wealth in the developing world could lead to massive increases in car ownership—and thus to much higher levels of local, regional, and global pollution. The developing world, not unreasonably, is reluctant to accept advice that it needs to adopt the pollution-free methods of transportation that the developed world has found it difficult to implement. Transportation is a massive consumer of energy and it has a profound environmental impact, yet modern lifestyles depend on modern transport systems. Cars produce pollutants, which contribute to the greenhouse effect, acid rain, health problems, and a range of issues associated with "quality of life"—including noise, physical division of communities, and visual intrusion. The conflict between economic development and protecting the environment pervades the transportation debate.

Energy experts have suggested that hydrogen fuel cell will be the most positive development for energy and transportation in sustainable development (box 4.6). Millions of hydrogen fuel cell vehicles will be able to feed electricity to the local flexible power networks while they are parked. The huge capital savings in massive power generating plants and transmission systems throughout the world could be better used for development.

Conclusion

Technology presents a vast array of opportunities for improving the human condition. But many challenges lie ahead in harnessing its power. The infrastructure for development in general and technological innovation in particular

Box 4.6
What will automobiles look like in 2050?

Source: www.racfoundation.org/index2.html.

Britain's Royal Automobile Club (RAC) Foundation recently carried out a major study on the future of motoring. It concludes that "the 2050 car will look relatively familiar from outside. The average European car of 2050 will be much the same size as today's car and will weigh about the same. It will, however, embody many features that will make it more versatile. It will have a fuel cell power-train, almost certainly using compressed hydrogen gas as its fuel. Thus its on-road emissions will be zero, except for a small amount of water vapor. Its energy consumption will be substantially less than half that of current cars, and it will be exceptionally quiet, which will highlight the need to extend the adoption of 'quiet' road surfaces to urban areas."

What is even more promising is the active participation of all automobile manufacturers, demonstrating in no uncertain way that fuel cells for cars will be a commercial reality. DaimlerChrysler expects to have fuel-cell cars on the market by 2004. Honda, Toyota, and General Motors also say their fuel cell cars will be ready by then. BMW has recently unveiled a prototype version of its 7-Series car with a hydrogen-powered internal combustion engine.

must be developed. Competence in technical fields needs to be increased. The environment needs to be improved so that it fosters entrepreneurship and the commercialization and wider diffusion of technologies. The capacity to participate effectively in the global trading as well as in the global knowledge system needs to be increased. And the overall policy environment needed to promote the application of science, technology, and innovation to the Goals needs to be improved. The rest of this report addresses these issues.

Adequate infrastructure services as a foundation for technology

One of the problems that hinders the reduction of poverty in the developing world—and the achievement of other Goals—is the lack of adequate infrastructure services.[1] Infrastructure affects economic development in various ways. It affects the production and consumption of firms and individuals by generating substantial positive and negative externalities. Because infrastructure services are intermediate inputs into production, their costs directly affect firms' profitability and competitiveness. Infrastructure services also affect the productivity of other production factors. Electric power allows firms to shift from manual to electrical machinery. Extensive transport networks reduce workers' commuting time. Telecommunications networks facilitate flows of information. As an "unpaid factor of production," infrastructure increases the returns to labor and other capital. The availability of infrastructure may also attract firms to certain locations, which create agglomeration economies and reduce factor and transactions costs (Fan and Zhang 2004).

The challenge of infrastructure for the science, technology, and innovation community is to identify and implement the infrastructure services needed to achieve the Goals. The challenge for policymakers is to undertake infrastructure development in a manner that not only promotes equity, efficiency, participatory decisionmaking, sustainability, and accountability but develops domestic capabilities in science, technology, and innovation as well (DFID 2002).

Infrastructure and technological innovation

Infrastructure development provides a foundation for technological learning, because infrastructure uses a wide range of technologies and complex institutional arrangements. Governments traditionally view infrastructure projects from a static perspective. Although they recognize the fundamental role of infrastructure, they seldom consider infrastructure projects as part of a technological

The development of new innovations and technology also contribute to infrastructure development

learning process. Governments need to recognize the dynamic role of infrastructure development and take a more active role in acquiring knowledge about infrastructure development, through collaboration between indigenous and foreign construction and engineering firms. Building railways, airports, roads, and telecommunications networks, for example, could be structured to promote technological, organizational, and institutional learning.

Infrastructure contributes to technological development in almost all sectors of the economy. It serves as the foundation of technological development; its establishment represents, in effect, technological and institutional investment. The infrastructure development process also provides an opportunity for technological learning.

The creation and diffusion of technology relies on the availability of infrastructure. Without adequate infrastructure, technology cannot be harnessed. The advancement of information technology and its rapid diffusion in recent years could not have happened without basic telecommunications infrastructure. Many high-tech firms, such as those in the semiconductor industry, require reliable electric power and efficient logistical networks. In the manufacturing and retail sectors, efficient transportation and logistical networks allow firms to adopt process and organizational innovations, such as the just-in-time approach to supply chain management.

The concepts of innovation systems and interactive relationships stress the links between firms, educational and research institutes, and governments. These concepts cannot be implemented without the infrastructure that supports and facilitates the connections. Particularly in the era of globalization and knowledge-based economies, the quality and functionality of ICT infrastructure, as well as logistical infrastructure, is essential for the development of academic and research institutions (box 5.1).

While efforts to expand the use of technology in development depend on the existence of infrastructure, the development of new innovations and technology also contribute to infrastructure development. For example, the advancement in communications and data-processing technologies has fostered the development of intelligent transportation systems for more efficient traffic management. The use of geographic information systems and remote-sensing technologies enables engineers to identify groundwater resources in urban and rural areas. Infrastructure and technological innovation for development thus reinforce each other. For these reasons the construction and maintenance of infrastructure represents a technological and institutional investment. Infrastructure is a fundamental element of a comprehensive and effective science, technology, and innovation policy.

Infrastructure and technological learning processes

Infrastructure contributes to technological development by providing opportunities for technological learning associated with the acquisition of technology

Box 5.1

Malaysia's Multimedia Super-Corridor has helped attract high-tech businesses

Source: Ramasamy, Chakrabarty, and Cheah 2004.

As part of its efforts to enhance its technological base in the ICT sector, the Malaysian government initiated the Multimedia Super-Corridor Project in 1995. Located in the corridor between Kuala Lumpur and Putrajaya, the new administrative capital of Malaysia, the Multimedia Super-Corridor accommodated a cluster of firms in the information technology sector.

The key element of the project is the provision of high-quality infrastructure. To attract high-tech multinational corporations—from small and medium-size high-tech firms to large corporations, such as Microsoft and Oracle—the government invested heavily in developing physical and communications infrastructure in Cyberjaya and other "cybercities" in the Multimedia Super-Corridor. This infrastructure includes a fiber-optic backbone with an estimated 2.5–10 gigabits per second capacity that has links to international centers, open standards, high-speed switching, and multiple protocols.

The project is complemented by other large infrastructure projects, such as transportation routes that link it with Kuala Lumpur and the new international airport. Recognizing that human resources are key to technological development, the project provides other infrastructure services and amenities that aim to improve the quality of life. It is clear that the Malaysian government considers infrastructure development to be a key component of its science, technology, and innovation policy.

(Putranto, Stewart, and Moore 2003). Because of the fundamental role of infrastructure in the economy, the learning process in infrastructure development is a crucial element of a country's overall technological learning process (box 5.2). This dynamic aspect of infrastructure is often overlooked in the development and infrastructure literature.

Every stage of an infrastructure project, from planning and design through construction and operation, involves the application of a wide range of technologies and institutional and management arrangements. Because infrastructure facilities and services are complex physical, organizational, and institutional systems, deep understanding and adequate capabilities are required on the part of engineers, managers, government officials, and others involved in these projects.

Infrastructure plays another crucial role in science, technology, and innovation efforts in developing countries: it is one of the most important factors in attracting foreign direct investment, in addition to being itself an investment target whose future economic sustainability is expected to stabilize (Ramamurti and Doh 2004). Infrastructure is one of the key factors that multinational corporations consider in determining the location, scope, and scale of their investments.

Foreign direct investment in infrastructure increased substantially in the 1990s, for several reasons, including favorable foreign direct investment policies, the reduced risk of expropriation in developing countries, and the development of innovative financing strategies, such as nonrecourse project financing and securitization. Increased foreign participation in infrastructure projects,

Box 5.2

Learning from a foreign consortium helped the Republic of Korea build a high-speed train network

Source: Rouach and Saperstein 2004.

In 1993 the Korea High-Speed Rail Construction Authority announced that it had selected a French consortium to build a high-speed train network linking Seoul with Pusan and Mokpo. Its experience with the French consortium has already helped Korea develop its own bullet train system. The Korean experience shows that in many respects an infrastructure project is a technological and institutional investment. It shows that a government can structure an infrastructure project in a way that allows domestic industries to benefit from technology transfer and organizational and institutional arrangements.

Korea expects the industrial and technological effects of the project to be enormous, because high-speed rail spurs the development of advanced aerodynamics, civil engineering, and mechanical and electronics technologies. Such technologies can also be applied to materials, automation, information, aerodynamics, and other industries. The project enhanced Korea's overall design capability for mass transportation, and the automatic computer control and self-diagnosis technologies it mastered can be applied to the automation of industrial robots.

particularly in the form of foreign direct investment, means that there are now more opportunities for developing countries to use infrastructure development as part of their technological and institutional learning process.

Governments need to design and implement the rules and regulations that govern private networks that are no longer under public control. They also have the option of building up the infrastructure that replaces private networks. Given that the global economy relies increasingly on information and knowledge flows, governments are faced with strategic options that could have significant implications for their science, technology, and innovation policies.

Innovation in energy: the sustainability challenge

The linkages between infrastructure development and technological innovation are illustrated by global trends to adapt to changing energy needs and new environmental standards. The emergence of alternative energy technologies and the challenges they pose to conventional sources illustrate the degree to which improvements in energy technologies have become central to long-term energy security and environmental management (Holdren and others 1999).

After the 1970s fuel crisis, the Brazilian government initiated a large program to encourage the design and manufacture of ethanol-only cars, as well as to cultivate sugarcane and refine it into ethanol as a way to reduce country's dependence on imported oil. By the end of the 1980s, ethanol engines powered almost 80 percent of cars produced in Brazil. The industry faced occasional shortages of ethanol fuel, however, and during the 1990s the price advantage of ethanol declined as gasoline prices fell. As a consequence, by 2002 ethanol-only cars represented a mere 3.5 percent of new car sales in Brazil.

Some auto-parts producers came up with the idea of building flex-fuel engines as a way out of the difficulties faced by ethanol vehicles (box 5.3). Some multinational auto-parts producers that located their world research centers

Box 5.3

Sales of flex-fuel cars are booming in Brazil

Source: Viotti 2004.

Flex-fuel was introduced in the Brazilian market in September 2003. By the end of the year, about 50,000 flex-fuel cars had been sold. By September 2004 sales of flex-fuel cars reached 150,000 and represented nearly 20 percent of new car sales in Brazil.

Almost all the large multinational carmakers established in the Brazilian market are in a race to launch more flex-fuel models. By the end of August 2004, one of them introduced the first car in the world to that can run on gasoline, ethanol, or natural gas (a fuel that is available at the pumps in Brazilian largest cities). The fuel efficiency of the engine, however, is lower than regular models.

The flexibility of the new engines could help overcome one of the most serious obstacles to liberating the transportation system from its dependence on gasoline: the lack of a distribution infrastructure for alternative fuels. Since flex-fuel engines can run on alternative as well as conventional fuels, the risk of running out of fuel due to the lack of alternative fuel pump stations is not a problem. The lack of a large distribution infrastructure does not prevent the introduction of the new fuel; the network of pumps of alternative fuel could be built progressively.

Flex-fuel engines can be built very inexpensively, because they use regular internal combustion engines with some adaptations and new electronic sensors, devices, and software to automatically adjust the engine operation to different fuels and blends of fuels. The new technology has transformed the conventional gasoline engine into an “intelligent” engine.

One of the main difficulties in using ethanol is that it is more corrosive than gasoline. Consequently, fuel pumps, gaskets, and piston rings need to be made less vulnerable to corrosion. Overcoming this and some other hurdles are feasible for the Brazilian industry, because of the large technological experience it accumulated with ethanol engines.

A preferential tax system is facilitating the rapid introduction of the car into the marketplace. In addition to the domestic market, car manufacturers and auto-part producers have high expectations about exporting flex-fuel cars and technologies. Several delegations from around the world have already visited Brazil to gather information about flex-fuel technologies.

in Brazil on related technologies built on Brazil’s technological capabilities in ethanol engines to develop flex-fuel technologies. Flex-fuel technologies can give customers and nations the flexibility to respond to volatile changes of fuel prices. These technologies also reduce urban pollution and the production of greenhouse gases. Flex-fuel engines also increase agricultural employment and income generation in developing countries.

Research facilities as infrastructure

Defining infrastructure to include technological innovation requires rethinking the strategic importance of research facilities (Nightingale 2004). Indeed, infrastructure projects can serve as research facilities themselves while maintaining strong links with other research institutions (Conceição and others 2003). The management of geothermal energy facilities, for example, require continuous in situ research as well linkages with external research facilities.

Infrastructure should include direct links to human resource development, enterprise creation, and R&D

But much of the research associated with infrastructure projects in developing countries is usually implicit.

Support to strategic technology development should be considered part of the national infrastructure, in the same category as energy, transportation networks, and water and sanitation. A number of developing countries, such as South Africa, are starting to work toward creating networked research facilities that are accessed in a managed way. Other countries have consolidated research entities to create single research institutions designed to maximize synergies in human resources.

The best-known research facility of this kind is the Industrial Technology Research Institute (ITRI) in Taiwan (China). ITRI was created in 1973 by the Ministry of Economic Affairs as a nonprofit R&D organization focused on applied research and technical service. Its original aim was to address the technological needs of Taiwan's industrial development. By 2003 it had more than 6,000 people in 11 laboratories. It acts as a locus of technical support to industry and an unofficial arm of the government's industrial policies. ITRI operations have become global.

ITRI's main task has been identifying the latest technology available globally, adapting it to local needs, and then diffusing it into Taiwan's industrial sector. Most of the major semiconductor foundries in Taiwan (China) have their roots in the Institute. ITRI also undertakes contract research for the private sector, provides technical training, carries out long-term research projects for the state, and provides incubation facilities to help entrepreneurs establish high-tech firms.

Planning for infrastructure development

An essential aspect of economic planning in developing countries is fostering the development and maintenance of infrastructure in a way that is appropriate to local conditions and consistent with ecological and other principles. Planning for infrastructure development should be placed on par with other planning processes.

Infrastructure serves as a strategic foundation for the application of technology to development. As an essential element of a country's long-term development efforts, it should include direct links to human resource development, enterprise creation, and R&D.

Developing countries need to prioritize infrastructure investment according to the degree of needs and the potential impact of particular investments on the economy and the society as a whole. Doing so does not mean that they should focus only on basic infrastructure, however, and forgo investment in infrastructure that is of strategic importance. To the contrary, developing countries need to upgrade strategically important infrastructure in order to tap into the opportunities that may arise from rapid technological change and the increasingly integrated global economy.[2]

Infrastructure services may be provided through combinations of public and private enterprises, while taking into account the needs of the poor

Developing countries also need to enhance their own ability to develop, operate, and maintain infrastructure services. Foreign construction and engineering firms will continue to be the main sources of technological, organizational, and institutional knowledge for infrastructure development. But governments in developing countries should devise policies to encourage technology transfer and build local capabilities in infrastructure projects (box 5.4). Research and development activities for the development, operation, and maintenance of infrastructure should also be promoted, and linkages should be established with both domestic and overseas research networks.

Infrastructure services may be provided through combinations of public and private enterprises, while taking into account the needs of the poor. Governments may reduce their role as producers of infrastructure but retain their roles as regulators, financiers, suppliers, and even competitors of private providers. Whatever roles they play, governments need to recognize that different types of infrastructure require different policies and approaches.

Although infrastructure services have several common characteristics, they also have important differences. Telecommunications is less essential than water, energy, and transportation. Its pricing is therefore less politically sensitive and reflects its true financial, if not economic, costs. This could mean that the payback periods for investments in telecommunications are shorter than other types of infrastructure. Different types of infrastructure have different technologies and organizational arrangements. Governments may need to assume a direct role

Box 5.4
Learning-by-doing in Algerian infrastructure development

Since the 1970s Algerian policymakers have considered the construction industry one of the “industrializing industries” that generates a large share of employment and GDP. To spur the industry, the government encouraged the purchase of complex, advanced, and costly technologies from foreign firms. Sophisticated and highly integrated contracts, such as turnkey and product-in-hand contracts, were used to assemble and coordinate all project operations—from conception through implementation and installation—into one package. The aim was to transfer all responsibility to the foreign technology supplier.

These types of contracts did not lead to as much technology transfer as the Algerian government had hoped. The turnkey contracts required that the foreign supplier take full responsibility for the project, but they did not include the sourcing or training of local people. This meant continuous reliance on external assistance, the inefficient operation by local management due to a lack of understanding and skill, or both.

Having learned from its failures, the government later encouraged “decomposed” or “design and installation supervised” contracts, under which infrastructure projects are more fragmented and involve more local firms. Local firms now take charge of the preinstallation phases (exploration and planning). With the technical assistance and supervision of foreign suppliers, local managers carry out the projects. This new approach not only reduces uncertainty in implementation, it also facilitates the process of learning-by-doing in local firms, enhancing their technological capability. The approach has also contributed to the development of investment and managerial capabilities of local managers.

Successful development of infrastructure services to meet the Goals requires mobilizing the energies of the engineering profession

in certain infrastructure projects if they see strategic importance in fostering the transfer and building up of the local capability of the required technologies.

In-country studies need to be carried out to identify the essential infrastructure services necessary to support achievement of the Goals.[3] The location of the poor and their critical infrastructure service needs should be pinpointed, and the cost and cost-effectiveness of infrastructure interventions to meet these needs should be calculated. Another fundamental task will be to highlight and address problems of implementation.

Such calculations should take into account the implications of infrastructure projects for technological learning. For example, linkages between the projects and research institutions should be considered as an investment whose returns will be reflected in the overall enhancement of technological competence.

Mobilizing the engineering profession and young professionals

Successful development of infrastructure services to meet the Goals requires mobilizing the energies of the engineering profession. Most national institutions of engineers have worldwide memberships. Members in developing countries include both expatriate and local engineers. Their nonprofit organizations include Engineers Against Poverty and Registered Engineers for Disaster Relief in the United Kingdom and Engineers without Borders in the United States and Canada. Many young and women engineers are the movers and shakers in these organizations. Much more could be done to spread these voluntary service organizations worldwide. The United Nations and its

Box 5.5
Young professionals have much to offer developing countries

A number of programs tap into the energy of young professionals. The United Nations Educational, Scientific and Cultural Organization (UNESCO) formed the International Forum on Young Scientists during the World Conference on Science in Budapest in 1999. The UN Program on Space Applications formed the Space Generation Advisory Council (open to professionals between 20 and 35). The World Bank, the Organisation for Economic Co-operation and Development (OECD), the Food and Agriculture Organization (FAO), and the International Labour Organization (ILO) all have young professional programs, designed to both develop and learn from young professionals around the world. Regionally, groups from the Asian Coalition for Housing Rights and the London Business School have young professionals, and many of the main organizers of NGOs are young professionals.

There are also a large number of young professional networks around the world that can be engaged, such as the Waikato Young Professionals in New Zealand, the Thai American Young Professionals Network, and the International Young Professionals Foundation. While the main focus of many of these groups is networking, many also understand that professional development can be achieved through sustainable development. With the right assistance from the United Nations, international development agencies, governments, and corporations, and with young professionals driving their own networks and organizations, these young professionals will be the most potent force in achieving the Goals.

Without adequate infrastructure, developing countries will not be able to harness the power of science, technology, and innovation to meet the Goals

specialized agencies should consider how they might capitalize on and reinforce these networks, particularly through their global organization, the World Federation of Engineering Organisations. In planning and implementing any Goal project, including infrastructure projects, efforts should be made to harness the enthusiasm and drive of young professionals, many of whom are looking for an opportunity to serve the developing world (box 5.5).

In the current knowledge economy, a large number of young professionals in both the developed and developing world have become captains of cutting-edge industries in ICT and other emerging technologies. Solidarity has always been strong among young people: knowledgeable young people, in developed and developing countries alike can surely be mobilized in an orderly way to provide help for development, following the leading example of Médicins san Frontières. Such a group could become a major force harnessing science, technology, and innovation for development.

The International Development Initiative at the Massachusetts Institute of Technology (MIT) is responding to the needs of partners in developing countries by bringing the resources of MIT to the task of technology development, education, and capacity building in their communities. Design that Matters (DtM) provides MIT students with the opportunities and resources to work on projects for underserved communities in developing countries as independent projects (DelHagen, MIT, personal communication, 2004). Students have developed numerous innovative strategies for solving problems in health, water testing and treatment, and rural education, among others. One student group designed a novel IV clamp to make treatment of cholera and other diseases more accessible in areas with few trained health workers. Another project brought down the cost of testing water for bacterial contamination by two orders of magnitude and made it accessible in off-grid communities, where it is most needed. A basic principle of fluid dynamics was applied by a DtM team to create a water chlorination system that passively adapts to large changes in the water flow rate that occur throughout the changing seasons. A project to deploy student-designed low-cost microfilm projectors for rural education initiatives has recently received funding from USAID for a field test in Mali.

Establishing standards

The design, manufacture, supply, and delivery of infrastructure hardware, software, and systems are now global. This globalization would not have been possible without internationally agreed on standards. In order for infrastructure services in developing countries to become more effective and extensible, countries need to create and enforce national standards that conform to international benchmarks. Efforts should be made to facilitate the coordination, skills development, and use of standards to promote the interoperability of infrastructure systems from the early design stages (Andrew and Petkov 2003).

Box 5.6

Government policymakers have a catalyzing role to play in licensing the radio spectrum

Licensing the radio spectrum can spur technology transfer, entrepreneurship, and foreign investment. Aligning their spectra with those of Western countries would allow developing countries to take advantage of existing wireless device economies of scale and expertise. Unlicensed spectra lead to the innovation of wireless standards like WiFi and WiMax and could provide a friendly environment for entrepreneurship, reducing barriers to entry and the risk of regulatory failure and ultimately providing a low-cost solution in low-income countries with poor telecommunications infrastructures (A. Raghunathan, Harvard Business School, personal communication, 2004). Significant heterogeneity in the regulation of 2.4 and 5.7 GHz bands across Africa hinders growth of telecommunications and the Internet by reducing potential economies of scale. The associated confusion, uncertainty, and poor policy enforcement have negative impacts on new entrants and small players. Significant heterogeneity of policy in developing countries will deter foreign direct investment and inhibit economies of scale (Neto, Best, and Gillett 2004).

The interoperability challenges are often associated with heterogeneity in legislation, which can hamper technological innovation (box 5.6).

Conclusion

Without adequate infrastructure, developing countries will not be able to harness the power of science, technology, and innovation to meet the Goals. Because infrastructure uses a wide range of technologies and complex institutional arrangements, its development provides a foundation for technological learning. Infrastructure is also critical in attracting foreign direct investment. Developing countries need to strengthen their infrastructure and enhance their ability to develop, operate, and maintain infrastructure services.

Investing in education in science and technology

Investment in science, technology, and innovation education has been one of the most critical sources of economic transformation in the newly industrial countries. Such investment should be part of a larger framework to build capacities worldwide. The one common element of the East Asian success stories is the high level of commitment to education and economic integration within the countries. This strategy was a precursor to what have come to be known as *knowledge societies* (World Bank 2002).

The commitment of the Republic of Korea to higher education suggests that spectacular results can be achieved in a few decades. These experiences are not limited to this region. The impact of education on local economies is also being recorded in less developed countries. Policy approaches to education, however, continue to generate considerable controversy in international development circles.

Primary and secondary school education in science

The growth of higher education needs to be accompanied by an increase in opportunities for graduates to apply what they learn. Developing countries need to devote resources to allowing more young people to obtain higher education, paying special attention to the barriers that appear at the secondary-school level. To increase job opportunities for graduates, they need to give incentives to private enterprises, particularly small and medium-size firms, to hire young university graduates, a strategy that helps create a virtuous circle of technological upgrading.

It is becoming evident that science education should be strengthened at the earliest level in educational systems. This will require greater emphasis on science education in primary schools (box 6.1). The importance of introducing science education in early childhood is illustrated by the failure in many parts

Today's economic circumstances make higher education a more compelling need in developing countries than it has ever been

of the world, especially in Africa, to understand the scientific basis of disease. This failure not only makes it difficult to implement public health programs, it has been a major factor in the spread of infectious diseases, especially HIV/AIDS. Providing an early foundation in science education is therefore critical to human development.

Although the education Goal is limited to achieving universal primary education, science, technology, and innovation education at the secondary and tertiary levels are critical to creating an innovative society.

Developing countries should be encouraged to adopt curricula that ensure that all students completing secondary school in any field will have been exposed to at least one area of science. They should also be encouraged to invest in science education at the secondary and tertiary levels in order to increase the number of scientists, engineers, and technologists.

Changes are also needed at the high school level. High school curricula need to be modified to prepare students for the materials introduced at universities. Teaching methods should also be changed to reflect the spirit of scientific inquiry by encouraging independent projects, inviting experts to speak as guest lectures, and taking students on field trips.

Higher education in science, technology, and innovation

Higher education is increasingly being recognized as a critical aspect of the development process, especially with the growing awareness of the role of science, technology, and innovation in economic renewal. While primary and secondary education have been at the focus of donor-community attention for decades, higher education has been viewed as essential to development only in more recent years. Today's economic circumstances make higher education a more compelling need in developing countries than it has ever been. Key factors in this change include increased demand for higher education due to improved access to schooling, pressing local and national concerns that require advanced knowledge to address, and a global economy that favors participants with high-technological expertise.

Box 6.1

The La Main à la Pâte program is shaping young minds through primary science education

Source: www.inrp.fr/lamap.

The most widely adopted primary science education program being promoted by the InterAcademy Panel and the International Council for Science is the La Main à la Pâte (LAMAP) program of the French Academy of Sciences. Brazil, China, Colombia, Egypt, France, Hungary, Morocco, Senegal, Viet Nam, and soon Malaysia have adopted the program. The hands-on, discovery-based methodology makes imaginative use of ICT. Its well-designed Web site is the most popular resource used by French primary school teachers.

LAMAP is also an active teachers forum. Its Web site allows teachers to communicate directly with scientists and engineers. Scientists and university science students act as advisors to classroom teachers. In order not to undermine the authority of the teacher, they are not encouraged to interact directly with students.

The scientific, technological, and engineering community and the associated institutions are among the most critical resources for economic trans-formation

Universities have immense potential to promote technological development. But most universities in developing countries are ill equipped to meet the challenge. Outdated curricula, undermotivated faculty, poor management, and a continuous struggle for funds have undermined the capacity of universities to play their roles as engines of community or regional development.

Vocational and polytechnic institutes in developing countries are very important. Technologists, technicians, and craftspeople are the bedrock on which small and medium-size enterprises are founded, especially in operations and maintenance. Many developing countries have made the mistake of neglecting the training of technicians and technologists.

During the 1970s many engineering graduates left India to seek employment abroad. Others were underemployed as draftsmen. This underutilization of highly trained human resources took place at a time when India suffered from a critical shortage of skilled craftspeople, such as pattern makers and instrument technicians. This experience highlights both the importance of training technicians and technologists and the need to foster internal demand for engineers.

Science and engineering courses continue to be unattractive to women even though the role of women in economic development is being recognized (box 6.2). Equipping women with the necessary scientific knowledge and technical skills needed for full employment is a critical aspect of the ability of developing countries to participate in the global economy. Developing countries are starting to explore ways to expand higher education opportunities for women. This could be a critical starting point for receiving support to higher education from developing international development agencies, such as the World Bank.

The need for training and capability building of technicians and technologists in developing countries has become even more acute with the advent of computer-aided design and drafting in engineering and construction industries. The proliferation of sophisticated computer-controlled machineries and instruments for manufacturing has also increased demand for technicians and technologists. These people are also needed in healthcare and banking.

Developing countries should invest in and promote institutions that provide recognition and continuing professional development of technologists and technicians, institutions such as the Institution of Incorporated Engineers and the Institution of Technician Engineers in the United Kingdom.

Scientists and engineers in the global economy

The scientific, technological, and engineering community and the associated institutions (universities, technical institutes, professional associations) are among the most critical resources for economic transformation. They deserve special policy attention. A disturbing global trend is the decline in enrollment in engineering courses in universities and institutions of higher learning, especially in developed countries, where some engineering departments have closed.

Box 6.2
Improving gender equality will enhance development

Women are central to economic and social development, through their productive, reproductive, and community management responsibilities. They make a major contribution to the production of food and the provision of energy, water, health care, and family income in developing countries. In addition, in many communities in developing countries, women are the primary holders of indigenous knowledge and know-how on sustainable use and management of the environment. Development would benefit from greater involvement of women in the decisionmaking process for development policies. Girls and women should receive scientific and technical education, so that they can apply what they learn in the performance of these tasks and roles.

A good example of how women are contributing to economic growth and development is found in many developing countries' efforts to increase exports. Most developing countries, especially the least developed among them, are dependent on one to three commodities for export revenues. This dependency on commodities has kept countries poor, because the prices of most commodities have been falling for several decades. The outlook is not encouraging. As a result, most developing country governments are trying to diversify their economies away from commodities. Several countries are succeeding, with production of nontraditional exports in rural areas. A World Bank study (Dolan and Sorby 2003) on the production of cut flowers, poultry, fruit, and vegetables in several countries in Africa and South America shows that many of these successful industries employ mostly women. Despite the central role of women in these industries, men are given more access to training opportunities. Getting rid of these obstacles would open the way for further growth and development.

Many technologies could improve the lives of women. Simple technologies such as treatment of water with chlorine in homes can improve the safety of water and sanitation. Improved technologies can help women produce more food and manage natural resources. They can reduce the burden of their work and improve the well-being of communities. ICT can create educational, economic, and employment opportunities for women and enhance their participation in political decisionmaking.

To meet the shortage of engineers and scientists, developed countries recruit from developing countries. Ironically, developing countries are putting their scarce resources into education and training that benefits the developed world.

Developing countries' ability to absorb scientists and engineers is limited due to their early stage of development. But highly educated human resources can attract foreign firms interested in investing in science, technology, and innovation in the developing country. Expatriates have helped establish small and medium-size enterprises by investing in their country of origin, often using technology acquired abroad, and they are involved in establishing joint enterprises between their home countries and adopted countries.[1] Public policy and a dynamic business community facilitate these processes.

Nevertheless, "brain drain" remains one of the most hotly debated international issues. The home country's loss of skills—and educational investment—needs to be set against the experience gained abroad by scientists and professionals, which may be available for use upon their return if adequate measures toward that end are implemented (see chapter 8 for further discussion on the diaspora).

Arrangements like the Colombo Plan can effectively support low-income countries that lack sufficient institutions of higher learning in rapidly building technological and scientific expertise

The international mobility of skilled people is one of the key mechanisms for the transition of technological capability across countries. To use this mechanism effectively, countries need to design institutions that enable them to use the skills of their nationals wherever they live. Such institutional arrangements need to rely on a commitment to international cooperation and partnerships.

A new Colombo Plan for Sub-Saharan Africa

Since 1951 donor countries have offered scholarships and fellowships to developing countries in the Asia Pacific region under the Colombo Plan for Cooperative Economic Development in Asia and the Pacific. During its first three decades, the Colombo Plan played an important role in supporting the development of technological and scientific expertise in Indonesia, the Philippines, Malaysia, Singapore, and Thailand. The Colombo Plan also contributed significantly to the stable administrative transition from colonial rule in Southeast Asia. It had an important impact on donor countries, especially Australia, where the presence of Colombo Plan students from Asia triggered a flow of students from Southeast Asia.

The Colombo Plan Scholarship and Fellowship Program is a collection of bilateral programs between donor and recipient countries that is largely devoid of multilateral bureaucracy and politics. As a result, program implementation is very focused on the needs of the recipient and the capabilities of the donor.

Arrangements like the Colombo Plan can effectively support low-income countries that lack sufficient institutions of higher learning in rapidly building technological and scientific expertise. Donor countries should establish a second Colombo Plan for Sub-Saharan Africa. The program could build on the existing expertise and structures of the first Colombo Plan. Such an arrangement would permit the rapid scaling up of investments in professional manpower across Sub-Saharan Africa.

The beneficiaries of such a plan could help lay the foundations for stronger institutions of higher education across the continent as part of the emergence of systems of innovation (Muchie, Gammeltoft, and Lundvall 2003). Toward that end, provisions could be made in the scholarships and fellowships that ensure that recipients return to their home countries after completing their studies abroad.

Having knowledgeable people is not enough, however. If investments in science and technology are inadequate, scientists and engineers will have few opportunities to apply what they have learned. The acquisition of knowledge and opportunities to apply it creatively are two inseparable parts of the learning process.

Learning is an endless process. Lifelong learning is based on being able to participate in activities in which explicit and tacit knowledge is shared, exchanged, and created.

Learning societies can be defined as places where a sizable proportion of the population and of the social and economic organizations permanently perform

Universities can contribute to economic revival and high-tech growth in their surrounding regions

knowledge-demanding activities in which many actors need to, and are able to, systematically upgrade their individual and collective skills, as well as their awareness of scientific and technological changes. In other words, learning societies are "interactive learning spaces" (Arocena and Sutz 2003). Fostering the development of and strengthening interactive leaning spaces can be seen as a fundamental developmental task. If it is achieved, the use of new knowledge in a socially valuable way will follow, as will better possibilities to face the challenges posed by scientific and technological changes. In this respect, international development agencies and their African counterparts could launch a new Colombo Plan with a focus on the sciences. Such a program could also be launched as a partnership between African and Asian countries that have previously benefited from the Colombo Plan and are willing to their share experiences.

New roles for universities and technical institutes

A new view that places universities at the center for the development process is starting to emerge. This concept is also being applied at other levels of learning, such as colleges, research and technical institutes, and polytechnic schools. Universities and research institutes (including polytechnics) are now deeply integrated into the productive sector as well as society at large. Universities are starting to be viewed as a valuable resource for business and industry; universities can undertake entrepreneurial activities with the objective of improving regional or national economic and social performance.[2] Others are charged with explicit reconstruction mandates (box 6.3).

In facilitating the development of business and industrial firms, universities can contribute to economic revival and high-tech growth in their surrounding regions. There are many ways in which a university can get integrated into the productive sector and into society at large. It can conduct R&D for industry; it can create its own spin-off firms; it can be involved in capital formation projects, such as technology parks and business incubator facilities; it can introduce entrepreneurial training into its curricula and encourage students to take research from the university to firms. It can also ensure that students become acquainted with problems faced by firms—through internships, for example. Universities should also ensure that students also study the relationships between science, technology, innovation, and development, so that they are sensitive to societal needs. This approach is based on the strong interdependence of academia, industry, and government.[3]

Industry in the developed world has benefited from the activities of research universities, particularly from their state-of-the-art laboratories, which conduct cutting-edge research for them. Universities benefit from the research funds provided by industry.

Many universities in developing countries serve merely as degree- or certificate-awarding institutions, providing the necessary documentation for

Box 6.3

Rwanda is using knowledge to foster national reconstruction

Source: www.kist.ac.rw/.

Reconstruction efforts following the genocide in Rwanda have been associated with an emphasis on the role of science, technology, and engineering in economic transformation. This is illustrated by the decision by the Rwandan government to convert military barracks into a home for a new university, the Kigali Institute of Science, Technology and Management (KIST), the first public technological institute of higher learning in Rwanda.

KIST aims to contribute to Rwanda's economic renewal through the creation of highly skilled manpower. It seeks to become a regional center offering courses in science, technology, and management; carrying out extensive research activities and knowledge dissemination; and providing technical assistance and services to all sections of the community.

KIST was created as a project of UNDP in 1997. It was established with the help of the government of Rwanda as the main stakeholder, UNDP (Rwanda) as the executor of the project, and the German Agency for Technical Cooperation (GTZ) as the implementing agency. Initial funding came from UNDP core funding and a UNDP Trust Fund obtained from generous contributions by the governments of Japan and the Netherlands.

KIST was officially inaugurated in April 1998. In July 2002 it held its first graduation, awarding 403 diplomas and 62 degrees to its 465 proud pioneers in management and computer science disciplines.

Despite many challenges, KIST today boasts a highly motivated and trilingual student population of 3,247, enrolled in both regular and part-time undergraduate programs. Students choose from a wide variety of engineering and management courses. KIST recently introduced a postgraduate diploma in demography and statistics.

thousands of young people to apply for jobs. Marginalized in the development process, these universities seek only to churn out graduates. Universities need to be re-envisioned as potentially powerful partners in the development process.

This adjustment can be implemented in a top-down manner by changing existing norms and procedures. It can be done for all academic departments of the university or certain select ones deemed to be of more importance with regard to national development goals. Imposing new standards on only certain departments would imply widely different standards for students and faculty and would likely require a separate administrative setup for the departments with higher standards. Moreover, the university's location would have to be appropriate for the selected disciplines. A benefit of this approach would be working with an established institution. Such an institution already has libraries, staff, and very likely some links with other research institutes.

Technical institutes are created to serve industry. By nature they are disposed to work with firms. Without neglecting their essential and primary roles in capability building for technologists and technicians, some of these institutes could be upgraded to university status.

New universities may also be created, particularly if a new field of knowledge in which existing universities have inadequate capability has been made a national priority or if student demand has outstripped university capacity. These universities could be entirely new institutes or expansions of industry-based training institutes.

Universities that are expected to boost technology-based industry need to be located near high-tech firm clusters and research institutes

For universities to be able to contribute to science and technology–based regional development, appropriate supporting institutions will be necessary. These include both enabling policies and organizations that can increase the pathways of interaction between academia, government, and industry. Specific measures include tax breaks, venture capital funding, low-interest loans, changes in intellectual property rights, higher returns on inventions, heavy investment in ICT, business incubation, and technology parks and centers within or near universities.

Partnerships with other institutions, at the national or regional level, could be of great benefit. Many developing country academics are benefiting from institutional partnerships with universities and R&D institutes abroad. Research partnerships across academic, industry, and government institutions help reduce knowledge gaps, especially in small and medium-size enterprises, which often lack adequate R&D facilities.

Reshaping universities to perform development functions will include modifying their curricula, changing schemes of service, modifying pedagogy, shifting the location of universities, and creating a wider institutional ecology that includes other parts of the development process. To help universities adopt a key development role, national development plans will need to incorporate new links between universities, industry, and government (box 6.4). This is likely to affect the entire national innovation system, including firms, R&D institutes, and government organizations. Developing countries will not be able to exploit the might of new technologies unless they become seriously involved in high-technology fields.

For this reason, university curricula are vitally important. The science, technology, and innovation curricula in many developing country universities are outdated or lack a cross-disciplinary approach. In certain departments, the research emphasis needs to be shifted toward issues of local and national relevance.

University faculties in many developing countries are poorly rewarded and thus undermotivated. Faculty are not always conversant with the latest developments in their fields. Their teaching methods tend to be old-fashioned, with little use of audio-visual equipment during lectures or of advanced apparatus during laboratory sessions, for example. Some of these problems are caused by inadequate funds. Faculty need to be aware of developments at the frontiers of their research.

Research ability will need to be considered when assessing applications for graduate study. Incentives such as scholarships and low-interest loans should be made available for the most promising students.

Universities that are expected to boost technology-based industry need to be located near high-tech firm clusters and research institutes, most likely in urban areas. If firm formation is expected to take off after the university is established, the university needs to be located in an area that is conducive to further development.

Universities and technical institutes that are expected to play an important role with regard to community development are likely to be more effective in

Box 6.4

University research partnerships are being forged in Campinas, Brazil

Source: UNCTAD 2004.

Since the mid-1990s, research partnerships between universities and the private sector, including foreign investors, have been established in Brazil. The University of Campinas (UNICAMP), in the State of São Paulo, has been involved in several partnership projects. One of these is the CPqD–FITEC (Centro de Pesquisa e Desenvolvimento–Fundação para Inovações Tecnológicas), the main technological center in Brazil, where university experts connect a company's needs for research with the expertise of UNICAMP's institutes, professors, and researchers.

More than 250 partnership agreements with private companies and 60 agreements with public companies have been established at UNICAMP. The companies include major global corporations with significant foreign direct investment in Brazil, such as Aventis, Bayer, Bristol, Compaq, Ericsson, Glaxo, HP, IBM, Monsanto, Motorola, Novartis, Roche, Syngentha, and Tetra Pak.

The partnership contracts include the details of the project and spell out the conditions of intellectual property rights. Patent ownership is determined on the basis of the technology disclosure and the innovative contribution given to the invention. If the private company provides most of the knowledge, it holds the patent. If the discovery is linked mainly to the university's work, UNICAMP holds the patent. UNICAMP holds about 300 patents, 3 of which have been licensed. UNICAMP expects to obtain 3 percent over the net profit of the licensee.

The success of R&D partnerships has been such that UNICAMP is now launching a bolder initiative: the creation of the UNICAMP Innovation Agency and the development of a technological park. The park will occupy 7 million square meters and provide human and physical resources, as well as facilities and services for R&D. The initiative will require about $1.5 billion, to be provided by the Ministry of Science and Technology, the Secretary of Science and Technology of the State of São Paulo, and the Municipality of Campinas. Private investors will also be called to participate in development of the park.

rural areas. Institutions that are involved in research that is very site specific will need to locate themselves, or some of their laboratories, accordingly. (Universities interested in marine research, for example, should be located near the coast.)

Universities throughout the world are undergoing reform and seeking new models to address challenges of sustainable development (box 6.5). Latin American, African, and Asian countries are exploring new approaches that can guide the creation of new universities and reform existing ones. The search is focusing on identifying appropriate curricula and pedagogy and integrating these institutions into the communities in which they are located. The new models emphasize educating graduates who serve as agents of socioeconomic change rather than mere holders of degree certificates.

Broadly speaking, there are three possible categories of action: reforming existing universities, upgrading existing institutes, or starting new universities. In all cases, supportive policies and regulations will need to be made and links created between universities, industry, and government.

For universities and technical institutes to adopt their new role as development partners, a new set of management procedures will be required. The

Box 6.5

Costa Rica's EARTH University is creating agents of change

The potential for adapting universities to social needs is illustrated by the case of Costa Rica's EARTH University, a private, nonprofit, international university designed to contribute to the sustainable development of the humid tropics (J. Zaglul, EARTH University, personal communication, 2004).

Created in 1990, the university currently has about 400 undergraduate students from more than 20 countries. Most of the students come from Latin America. EARTH University is focused on training leaders who will help promote sustainable development in their countries of origin. To foster the creation of agents of change, EARTH University has developed a distinctive and novel curriculum that emphasizes agriculture as a human activity, holistic integration of many academic disciplines, understanding today's changing and globalizing world, and a philosophy of learning by doing. The curriculum is characterized by practical learning, entrepreneurial capabilities, ethics and values, teamwork, group problem-solving, communication skills, vertical and horizontal integration of the curriculum, and fostering of social sensitivity through the acquisition of community development skills (L. Aylward, Harvard University, personal communication, 2004).

Over a four-year period, the EARTH program includes work experience, community experience, entrepreneurial projects, and an internship. Work experience, taking place on EARTH's teaching farms, gives students the opportunity to understand what happens day to day on a farm. Students work with members of the community to plan, organize, and execute projects for the benefit of the community and local rural farmers. This program is designed to promote an understanding of everyday rural family life.

Arguably the most distinguishing aspect of EARTH University's curriculum is the entrepreneurial project program. Provided with a loan from the University, students design a project, carry out feasibility and market studies, and develop and run their own business during the first three years of study.

In their third trimester of their third year, students leave campus and take part in a 15-month internship program with a host organization, such as a business, nonprofit organization, or farm. Using knowledge and skills acquired in their first three years at EARTH University, students obtain real-world practical experience upon which they can reflect during their fourth academic year. Instead of writing a dissertation or thesis, they prepare the equivalent of a business plan, which they use to start their own business upon graduation.

recommended changes—in many cases requiring drastic revisions in student and faculty selection procedures, new incentives and transparency mechanisms, and revised curricula and teaching methods—are likely to cause upheaval and resentment in various circles of the university. These organizational transformations must be effected, taking into account of the different systems of governance of universities, which differ across countries.

In some cases strong management can be recommended to ensure that the new schemes are put and remain in place. In other cases this recommendation makes no sense. In Latin America public universities are autonomous bodies ruled by processes in which faculty and students go through democratic procedures to elect rectors, vice-chancellors, and deans. Systemic tuning is needed to help the three actors—universities, government and industry—interact in a productive and respectful manner.

Science, technology, and innovation education can be enriched through partnerships with NGOs

Universities and technical institutes will very likely work closely with industry as well as government in the pursuit of national objectives. Therefore, it is important that the university have mechanisms in place through which it can retain its autonomy.

Forging partnerships with nongovernmental organizations

Science, technology, and innovation education can be enriched through partnerships with NGOs. The case of the Foundation for the Application and Teaching of the Sciences (FUNDAEC) in Colombia illustrates the importance of creating such partnerships (G. Correa, FUNDAEC, personal communication, 2004). The organization was created 30 years ago in the Valle del Cauca region of Colombia by a small group of physicists, mathematicians, agronomists, and professors in the social sciences who saw the need to extend high-quality education beyond the walls of the traditional university. The founders developed a common perspective that the right of the masses to have access to information and to fully participate in the generation and application of knowledge are fundamental to social and economic development.

This fundamental principle led to the creation of the University for Integral Development. The university has brought together a large number of organizations from across the world, working together to learn about how to involve populations in the processes of knowledge generation in pursuit of greater well-being (C. Honeyman, FUNDAEC, personal communication, 2004).

FUNDAEC has pursued a variety of lines of action toward this central goal, including systematic investigations with rural families in the area of agricultural and livestock production, helping to form cooperative community groups, developing appropriate agro-industrial technologies, developing the capacities of rural youth, and working with rural economies and small-scale businesses. As FUNDAEC has engaged in each of these areas, it has codified what it has learned in a series of educational materials written for secondary school and university levels. Some of these materials are available through FUNDAEC's University Center for Rural Well-Being, reaching more than 550 undergraduate and graduate students since its foundation. A further 75 interactive texts make up the curricular material for the Tutorial Learning System (*Sistema de Aprendizaje Tutorial* or SAT), an innovative secondary-school education and community development program. Some 70,000 students in Colombia have graduated from this program and another 30,000 are currently enrolled. The program has also been implemented on a small in several other countries in Latin America.

SAT was originally created to contribute to the process of development within a defined microregion near the city of Cali. Over the past few decades, however, as the reputation of the program has grown, it has become recognized as a formal secondary school system. More than 40 NGOs now offer its educational materials within an expanding number of regions, with FUNDAEC

It is more important than ever for developing countries to move ahead in scientific and technological development at an advanced level

continuing to provide training and curricular development. Often funded directly by local and municipal governments, the SAT program exemplifies a successful collaboration between the public and private sectors, carried out in pursuit of a common goal. Carrying forward FUNDAEC's central principle, SAT students are involved from the very beginning of their studies in the processes of generating knowledge, as they carry out investigations in their own communities and develop projects and initiatives to meet the particular needs they identify.

In its willingness to engage with others in such a far-reaching and ongoing process of learning, FUNDAEC provides an important example of the ways in which educational innovations can succeed in involving populations that have, for too long, been excluded from worldwide processes of knowledge generation and application.

Conclusion

It is more important than ever for developing countries to move ahead in scientific and technological development at an advanced level. Doing so will enable them to build local capacity that can help solve the many science and engineering–related problems they face. It will also position them to take an active part in the global knowledge economy.

Universities are vastly underutilized and potentially powerful vehicles for development in developing countries, particularly with respect to science and technology. If both universities and industry are encouraged to work actively together, universities will be able to assume new roles that could accelerate local and national development. Rendering these institutions more effective as key development partners will require changes at several levels of university administration. It will also require deep changes in enterprises, private as well as public, so that they can become strong demanders of the universities' capabilities, helping transform these capabilities into capacities. Government will need to act as a careful facilitator of interactions between these two actors. If this is achieved, the "loneliness syndrome" that for so long affected universities in developing countries will be redressed, allowing them to contribute to economic growth and social development.

Chapter 7

Promoting technology-based business activities

Policymakers in developing countries can do much to promote business activities in science, technology, and innovation. They can foster the creation and growth of small and medium-size enterprises, improve access to financial capital, establish industry extension services and help firms establish international partnerships and linkages, and use government procurement and selective industrial policies for technological development. Developing countries must also ensure that their enterprises comply with international agreements and meet international standards, including those governing intellectual property rights and phytosanitary and other standards.

Fostering the creation and growth of small and medium-size enterprises

Small to medium-size enterprises should be encouraged to take a leading role in exploiting new opportunities. There is a need to develop, apply, and emphasize the important role of engineering, technology, and small enterprise development in poverty reduction and in sustainable social and economic development. Initiatives are needed that build capacity, establish appropriate financial systems, increase public awareness, craft and implement policy, and ensure that engineering and technology are included in Poverty Reduction Strategy Papers (PRSPs). Governments, universities, NGOs, and international agencies all need to play roles in developing and implementing strategy.

In advanced industrial economies, small and medium-size enterprises have developed much of the innovative and cutting-edge technology (Andreassi 2003). In many developing economies these enterprises have been the foundation of industrialization. In Taiwan (China), for example, small and medium-size enterprises were the engines behind the postwar industrial upgrading of the economy. By serving as suppliers to multinational corporations and foreign

Incubators play major roles in the creation and facilitation of small and medium-size businesses

buyers, small and medium-size enterprises in Taiwan (China) gradually acquired both the process and product technologies that enabled the economy to upgrade its technology. Similar evidence on the role of small and medium-size enterprises is emerging from mainland China (Gibb and Li 2003; Jun 2003).

Despite the importance of small and medium-size enterprises, investments and incentives to grow them have been minimal or nonexistent in most developing countries. The focus of governments and foreign investment in developing countries has been on large infrastructure and industrial projects.

Supporting these enterprises is critical, but doing so is fraught with financial, administrative, legal, and market-related difficulties. Developing countries therefore can help foster the growth of small and medium-size enterprises by creating business and technology incubators, supporting clusters, and establishing export-processing zones. Each institution has benefits and drawbacks.

Business incubators

Incubators play major roles in the creation and facilitation of small and medium-size businesses (Scaramuzzi 2002; Vedovello and Godinho 2003).[1] Their role ranges from providing affordable space to providing core enterprise support functions, such as enterprise development, financing, marketing, and legal services. Governments in developing countries are encouraged to support business incubators (Lalkaka 2003).

Incubation comes in many forms, ranging from government-funded initiatives to public-private partnerships. Governments are encouraged to provide grants, low interest rate loans, and tax incentives to private companies that provide incubation resources for small and medium-size enterprises. They should also consider funding university-based incubators focused on a particular area of science, technology, or innovation area, as well as not-for-profit–based incubators.

Technology parks provide environments in which small and medium-size enterprises tend to flourish. Governments should designate areas throughout the country as technology zones and offer incentives to companies willing to relocate to these zones. Governments should also focus on making it simple for new businesses to obtain the necessary legal documents, facilities, and ICT.

Business incubation catalyzes the process of starting and growing companies, providing entrepreneurs with the expertise, networks, and tools they need to make their ventures successful (Grimaldi and Grandi 2003). Incubation programs diversify economies, commercialize technologies, create jobs, and build wealth. They promote the development of new and qualified small and medium-size enterprises by providing them with the resources (premises, infrastructure, and services) they need to improve their chances of success.

Many business incubators have strong links with real estate business development. Many receive significant public funding and are located near research institutes and technical universities.

The best results occur when start-up and existing companies are mixed, to encourage mutual learning and stimulation

The past 20 years of experience with business incubators has revealed three critical factors that are important to their success. The first is the creation of the incubator itself and its management. The second is the incubation process. The third is performance assessment.

Successful business incubator creation depends on careful planning and preparation based on thorough and objective analysis. The preparation and implementation of a business incubator may take one to two years. During this period a management team of up to 10 people defines the objectives of its activities and establishes selection criteria. It also gathers information about local or regional conditions to assess the feasibility of the incubator (von Zedtwitz 2003). Four aspects are important for assessing feasibility: profiles of local entrepreneurs and their needs, identification of the potential for mobilizing support, identification of suitable locations, and projection of investment requirements.

Designing the incubator organization and management structure, selecting staff members (especially experienced entrepreneurial managers and board members), and defining resources are also critical during this period.

Initial funds of $500,000–$1.5 million may be required to launch a business incubator. Securing these funds is a major obstacle in this early phase. Business incubators often require three to five years to become self-sustaining. The best results occur when start-up and existing companies are mixed, to encourage mutual learning and stimulation.

A successful incubation process consists of three steps. The first is entrance of entrepreneurs into the incubator based on clear admission criteria and procedures. Survival rates of the graduates from incubators strongly depend on admission policies.

The second—development of enterprises in the incubator—is done by creating a nurturing environment and providing various services, including physical infrastructure; business planning, assistance, and counseling services; advertising and marketing services; financial advisory services; management training services; know-how services; management advisory services; networking services; industrial infrastructure (roads, water, electricity, ICT, buildings, and industrial machines); secretarial services; security services (especially for intellectual property protection); and postincubation support. The objectives of the incubator define the services offered.

The third step, graduation of businesses from the incubator, needs to be based on policies that determine clear time frames and an agreement on the type, amount, and value of services provided during the incubation process. The success of the incubation process depends on the effective policies and management of the incubator itself.

Performance assessment needs to be carried out to evaluate the outcome of incubation, management policies and their effectiveness, and services and their value-added. Two types of information are needed. One is measurement based on incubator effectiveness versus alternative policy approaches. The other is

Technology incubators are a special type of business incubator that focuses on new ventures that employ advanced technologies

the measurement of the enabling factors for private sector development and the main institutional and structural gaps at the country level.

Business incubators increase the likelihood that small and medium-size enterprises survive, encourage information exchange and mutual benefits, overcome small business isolation and powerlessness by clustering small and medium-size enterprises, and become role models. In OECD countries survival rates of new ventures nurtured in business incubators are about 80–85 percent—much higher than the 30–50 percent rate of success of other firms. Survival rates among new ventures that emerge from incubators are as high as 85 percent in some developing countries, such as Brazil and China, where strong support from government and tight links with the university system are available.

Business incubators do have some downsides, including limited scope for job creation and short-run benefits, limited outreach and "picking winners" problems, the possibility of creating dependency on government support, the need to provide focused assistance and subsidies until incubators become self-sustainable. They also depend on having good business infrastructure in a good location. Business incubators are not a development panacea. They can address some important development issues but not all of them.

Technology incubators

Technology incubators are a special type of business incubator that focuses on new ventures that employ advanced technologies (box 7.1). Although technology incubators share the same general goals as business incubators, they focus more on the commercialization and diffusion of technology by new firms, both of which are often impeded by market and institutional failures and the high level of uncertainty associated with technology development. Commercialization and diffusion of technology increases the return from public investment.

Technology incubators help create high-tech companies. Unlike basic business incubators, they have the mission of turning innovative ideas into successful business. They provide an environment for prototyping and test-marketing knowledge on how an idea can be turned into a business.

Most technology-focused incubators come in the form of private companies. They often consist of a combination of venture capital resources and business support functionality.

Commercialization of technology has been a main focus of business and technology incubation activities in both developed and developing countries. In newly industrial and transition economies, technology incubators emerged from central government schemes rather than from local public-private initiatives. They aim mainly to build bridges between academia and industry, promote innovation in small and medium-size enterprises, and encourage investment in technology-based start-up firms. One important feature of technology incubators is that they are usually not stand-alone ventures but have a strong tendency

Box 7.1

Good practices can help technology incubators succeed

Source: Nolan 2003.

Both technology incubators and general business incubators require clear definition of objectives at the outset and recruitment of experienced entrepreneurial managers. Sharing experiences on what works is also important for both types of incubators.

Some good practices are particularly important for technology incubators. One is the emphasis on particular cluster-focused technologies, which helps the incubator achieve a critical mass, focus on specific needs arising from technology incubation, and enhance synergies among firms.

Selection criteria of technology incubators are also different from those of general incubators: they should not depend entirely on business plans but focus on factors such as marketability of products, entrepreneur experience, and the overall fit with other incubator tenants (in order to foster synergies).

Another good practice for technology incubators is tailoring and leveraging existing services. Since technology incubators are often too small to provide the entire range of services, tailoring services to clients' needs and providing access to existing outside resources through brokering and networking can be helpful.

Diversification of financial sources for entrepreneurs is also important for technology incubators, because it helps match entrepreneurs to particular types of capital that support technology activities.

Another very important factor is the effort to integrate technology incubators with the surrounding infrastructure for innovation and the broader national innovation system. Many previous experiences show that real estate management should not be the primary goal for technology incubators.

Services provided by technology incubators are similar to those provided by general business incubators. But since their main objective is accelerating the transfer and diffusion of technological know-how and industrialization, several services hold particular importance. In OECD countries technology incubators tend to provide more assistance than general incubators in technology consulting and support services that connect enterprises with technology transfer programs providing access to external technical facilities and resources. These resources include university faculty and students; linked to manufacturing extension services; financing assistance for equity financing, including venture capital funds, mutually guaranteed loans and royalty financing; legal assistance for incorporation, drafting license agreements, and protecting intellectual property rights; and marketing (OECD 1997).

to affiliate with public and private sources of research knowledge, including universities, public research institutions, and large technology-based firms.

Technology parks have been the most popular kind of technology incubators. They have proliferated not only in developed economies but also more recently in Southeast Asia and Latin America. Technology parks have strong R&D components in their organizational structure. They are based on the possession of property and usually include university and research institutions, which ensure access to research facilities, simplify technology transfer operations, and allow the incubation of spin-off enterprises that can be launched by faculty or researchers from research institutions.

Silicon Valley is located near Stanford University and the Stanford Research Park; the industrial cluster along Route 128 is located near MIT. The

The clustering of university and research institutions and enterprises is expected to yield more efficient use of innovation resources

Hsinchu Science-Based Industrial Park is located near the National Tsing-Hua and the National Chiao Tung universities, in Taiwan (China). The Hsinchu Science-Based Industrial Park has helped reverse the brain drain in Taiwan (China), and it has exerted positive spillover effects on the surrounding area. The congregation of high-tech firms has enhanced competition between traditional and high-tech industry. These parks contribute to reindustrialization, regional development, and the creation of synergies. Within technology parks, there are numerous variations according to the services offered based on their objectives, which define types and levels of R&D and other technological capabilities required to create and sustain them.

Technology parks facilitate networking. By encouraging interactions, feedback, and awareness by bringing people from different institutions together physically, technology parks facilitate the transfer of technology from university and research institutions to enterprises. They also stimulate innovation through the cross-fertilization of ideas between researchers and entrepreneurs. In terms of stimulation of innovation activities, the clustering of university and research institutions and enterprises is expected to yield more efficient use of innovation resources and link basic research to commercialization through applied research (Link and Scott 2003).

Incubators without walls

Costs are an important determinant of services offered by incubators. Costs are especially high for technology incubators, which are usually facilities based. To avoid these costs, so-called "incubators without walls," or virtual incubators, are sometimes created. Most of them are technology incubators, often created by a university or research institution. These incubators are non–property-based ventures that require lower fixed investment. They serve small and medium-size enterprises in areas where a sufficient critical mass of tenants is lacking. The important characteristic of these incubators is their ability to operate both within and outside of walls, by linking them through computer and telecommunications networks.

Production networks and clusters

Networking is very important, because it allows small and medium-size enterprises to access skills, highly educated labor, and pooled business services. In the rapidly changing technological and global business environment, more attention is paid to groups of firms, teams, and interfirm networks than to individual firms (Chen, Liu, and Shih 2003). This makes networking more important than ever before.

Networking within the incubator is critical. Industrial clustering is effective tool for networking, because it brings actors into close proximity. This has been an important assumption behind property-based incubation activities. But effective networks do not occur just by bringing actors together. They are

Foreign direct investment can lead to an increase in productivity in the host country through technology diffusion to participating domestic firms

formed on the basis of mutual needs: cooperation happens when one entity has a need for goods or services that another can deliver. Connecting needs, rather than just bringing actors together in close proximity, is the most important role that incubators play.

Networking can also extend to existing and established firms outside the incubator facilities. Incubators can provide their services to outside firms (known as *affiliate clients*) and large or established firms (known as *anchor firms*). These firms can increase incubator revenue, help market products, and bring experience to tenant firms.

Export processing zones

Export processing zones (EPZs) are areas in developing countries that permit participating firms to acquire their imported inputs duty free as long as they export 100 percent of their products. This scheme works when selling manufactured goods at world prices is profitable given a country's low wages. The concept has been most widely used in Asia.

EPZs are an important mechanism for acquiring technology and diffusing it in the local economy. But strategies to promote the establishment of such zones must be designed with long-term technological development in mind.

EPZs can be used as business incubators, and they can be very useful for developing enterprises with export and foreign trade potential. But EPZs' linkages are generally with the international community; they have little potential to strengthen the local economy, due to their limited backward linkages or technological spillovers. This is because the focus of EPZs is attracting foreign direct investment by facilitating business services and providing access to infrastructure and tax incentives.

Foreign direct investment can lead to an increase in productivity in the host country through technology diffusion to participating domestic firms as well as backward and forward linkages. But forming such linkage formations is difficult, because most foreign direct investment to developing economies is vertical investment that has a much lower level of technology transfer than market-seeking horizontal investment. In vertical foreign direct investment, the investing firms fragment their production chain into stages, matching factor intensities of their activities with factor endorsements of host countries. EPZs can match demand and supply between foreign firms and local factories and help incubate new ventures within the zones.

The Republic of Korea and Taiwan (China) have been the most successful users of EPZs. Most of their rapid growth was the result of their export orientation. EPZs were the starting point of export-oriented performance standards. EPZs and exports by participating firms were tied to subsidies. In the Republic of Korea large exporters were given access to cheaper and longer term investment capital and tariff protection for their sales in the domestic market.

Taiwan (China) granted large exporters permission to sell products in several industries in the highly protected domestic market.

Improving access to financial capital

The main sources of finance for technological innovation are banks and financial institutions, individual private investors ("angels"), and public funds.

Banks and financial institutions

Banks and financial institutions can play an important role in fostering technological innovation. However, their record in this field in developing countries has been poor. There is a need to reform some of the banking and financial institutions in these countries so that they can play a role in promoting technological innovation. Such reforms should be part of a larger set of policies, incentives, and strategies aimed at funding innovation (box 7.2).

Box 7.2

Governments can take a variety of steps to increase access to financing for science, technology, and innovation

Governments can facilitate access to financing for science, technology, and innovation in many ways.

Create sound monetary and financial policies. Measures could include reducing cost inhibitors, allowing loans to be secured with intellectual property, and providing insurance and indemnity protection on loans to small and medium-size enterprises.

Provide additional capital incentives for specific technologies. This could be geared toward venture capitalists and lending institutions through specific policies that support small and medium-size enterprises engaged in developing technologies of particular interest. Incentives could include differential interest rates, access to domain experts, or preferential access to new R&D from local or foreign government or university research institutions.

Establish a government-funded venture type investment strategy. Capital markets do not automatically exist for all sectors or technologies. Indeed, part of the process of development is creating institutions to stimulate interest in a particular type of technology that the government or public deems a priority for development but for which private sector funding is not forthcoming.

Help capital to become professionally managed. In India the government funds R&D, but managers of these funds often find it difficult to assess new technologies, because they lack the expertise or for other reasons. The "graduation" of such traditional investors to more professional and technological management requires not only government support but ideally exposure to international learning as well.

Support microfinance. Microfinance schemes are emerging as a key way to help poor entrepreneurs help themselves. The technological components of such enterprises can be substantial, ranging from food processing to auto repair to solar energy and other initiatives. Microfinance also provides an opportunity for very small firms to build links and scale up, and it facilitates simple technology transfer and the consideration of export opportunities.

Many semi-industrial countries provide non-reimbursable loans to small and medium-size enterprises for technological innovation projects

Venture capitalists and angel investors

Attracting venture capital and encouraging the emergence of "angel" (private) investors can increase finance for technological innovation.[2] Small and medium-size enterprises have flourished in most developed countries because of the critical role that capital markets, especially venture capitalist markets, have played (Branscomb and Auerswald 2001; Bruton, Ahlstrom, and Yeh 2004). Venture capitalists do not just bring money to the table; they help groom start-ups into multinational institutions. Bringing venture capital markets into developing countries could help ensure the sustainability of the companies in which they invest (Chocce 2003). This realization is forcing developing countries to start reforming their venture capital systems (Dossani 2003).

Public sources of finance

In the absence of well-functioning capital markets and market-based mechanisms such as venture capital, most developing countries rely on publicly funded trust funds or specialized financial agencies to upgrade technology and promote innovation. These specialized technological financing agencies provide loans to firms or consortia of firms, particularly small and medium-size and research institutions, to undertake research and technological development, develop new products and production techniques, improve existing products and processes, and upgrade product quality and strengthen innovative capacity. In addition, many semi-industrial countries, such as Brazil and Mexico, provide nonreimbursable loans to small and medium-size enterprises for technological innovation projects.

The Inter-American Development Bank began financing science, technology, and innovation in 1962. It has made loans to Argentina, Chile, Mexico, Peru, and Venezuela. Brazil and Mexico have a number of special credit programs to encourage technological innovation by private enterprises.

In Brazil the Ministry of Science and Technology's Program to Support Scientific and Technological Development, funded by the World Bank, and the federal innovation-financing agency, FINEP, provide credit for innovation. The Bank-sponsored program includes two subprojects, a support program, which finances technological sector entities, such as QSTM (quality, standards, testing, and metrology) institutes, and a technology management and competitiveness program, which supports pilot partnerships between firms and research institutes. FINEP offers integral support credit for all stages of a technological innovation business plan, from design to licensing or purchase of technology, training, technical assistance, and initial working capital. It even offers pre-investment credit for engineering consultancy or quality management plans for environmental, technological, and product quality (IADB 2001). Provision of this support, especially to small and medium-size enterprises, has been instrumental in leveling the playing field for companies that lack the size and financial capability to venture into financially risky areas.

Establishing a virtual center is an exciting prospect that could bring knowledge to places that badly need it

This experience is of great interest and relevance for developing countries. It strongly suggests the need to develop differentiated institutions and facilities to support domestic technological development as one of the building blocks of genuine systemic gains in competitiveness. Microfinance is particularly important in the innovation and transfer of technology to small and microenterprises in developing countries. Many small loans are taken out for the purchase of technology, particularly by women. It is important to match microfinance models to local social and economic situations, as the transfer or innovation of inappropriate microfinance models frequently fail.

Establishing industry extension services

"Food production in developing countries relies heavily on technical support through agricultural extension services. Such support, however, is not widely provided. The Japanese government is starting to incorporate such support in its development assistance to Indonesia as part of a joint effort to strengthen the country's industrial clusters (KRI International Corporation 2004).

Knowledge extension can be applied to help meet the Goals using science, engineering, and technology in many ways. ICT can be used to match people with knowledge with people who need that knowledge. However, it must not be forgotten that tacit knowledge is a fundamental part of the ability to solve problems, and this type of knowledge can be deployed only face to face. Industry extension services will need to ensure that people can interact both physically and virtually.

Establishing a virtual center—one that ties into the many existing extension and engineering centers around the world—is an exciting prospect that could bring knowledge to places that badly need it. Compiling knowledge of best practices into freely accessible databases would be another way to use ICT to diffuse technology and encourage its appropriate adoption in developing countries.

The loss of skills may come about through many different processes. These include allowing universities to languish, allowing lack of funds or a track record of innovation to erode the confidence of local individuals to participate in global innovation, introducing new technologies too rapidly, and letting the infrastructure necessary to sustain previously made gains erode and importing technologies that require foreign technicians to service them without creating a local technical capability.

Establishing international partnerships and linkages

International partnerships and linkages are an important aspect of technological development in developing countries. Incentives should be provided that encourage such partnerships. These include the diffusion of hardware technologies from centers such as Silicon Valley and Route 128 through diaspora channels to countries like Israel, India, and Ireland. In addition, the potential exists for establishing private-public partnerships to invest in new technolo-

Public technology procurement can be instrumental in developing technical specifications and improving standards in cooperation with manufacturers and buyers

gies. An often neglected development is the link between the private sector and the open source material from public sector institutes all over the world.

Building local, regional, and international linkages can provide relevant services, and it can integrate local infrastructure with national and international sources of technologies and markets. In Germany, for example, networks of technology and innovation centers connect not only throughout Germany but also with those in Central and Eastern Europe.

Using government procurement

Government technology procurement can be an important tool in low-income countries, which have weak productive sectors and a weak technological demand (box 7.3). There is a debate over the role of public support for procurement as a tool for technological development. But many countries have created and nurtured new industries or lagging old ones on this basis. Firms have gradually acquired technological capability in this way and become globally competitive over time. The question is not whether public procurement is a legitimate mechanism appropriate but when it should end and how it can help firms compete on their own.

Government technology procurement is currently used most in building public health infrastructure and increasing access to medicine. This experience can be used to develop government technology procurement with strict guidelines for selection of firms and evaluation of products and services delivered. The process must all ensure that participation is inclusive.

Public technology procurement can be instrumental in developing technical specifications and improving standards in cooperation with manufacturers

Box 7.3
Public procurement can spur the development of domestic firms

In the drive to make nationally owned firms globally competitive, the Chinese government promotes domestic computer hardware firms through both direct and indirect support, including favored treatment in government procurement of technologies developed in state R&D institutions. The Indian government gives similar support to the country's pharmaceutical industry to produce "essential" drugs. The Nordic countries have successfully used public procurement to promote industrial development, particularly in the telecommunications sector. The lessons these countries learned from these industrial development processes are now being extended to other fields, such as environmental management.

In Scandinavia government technology procurement has helped solve national problems while helping local firms grow and become international. Projects on a large scale (in Sweden) and a small scale (in Denmark) have fostered innovation and global competitiveness among domestic enterprises. Working on public projects (the civil use of nuclear technology, railroads, telecommunications) helped Swedish firms like ASEA and Ericsson become global players. Public technology procurement in areas related to health, such as electronic medical devices, and other areas, such as wind energy, were key to allowing small and medium-size Danish enterprises to become global players in niche markets.

Some of the new international trade rules limit the application of some policies previously critical to fostering domestic industrial development

and buyers and hence promoting higher efficiency and increased returns arising from the adoption of new technologies (Nelson, Peterhansl, and Sampat 2004). For example, by supporting the prototype development or issuing competitive bids for products that match or exceed certain technical specifications, public sector agencies can directly support learning and innovation in domestic firms.

Using selective industrial policies

International trade is one of the most important sources of impetus for rapid technological innovation. In the past, countries were able to use various trade and industrial policy instruments to build up domestic technological capabilities. Many of these instruments are now prohibited under the new trade rules, especially those of the WTO. Some of the new international trade rules limit the application of some policies previously critical to fostering domestic industrial development. These policies include infant industry protection, export subsidies and targeting, local content rules and other performance requirements on foreign investors, directed credit, copying and reverse engineering, and restrictions on foreign entry, ownership and treatment.

The theoretical underpinning of the new rules is the efficiency of free markets. The issue is not whether markets fail but the extent to which governments can improve upon them and promote faster industrial and technological development. History shows that it is possible for governments to do this, but it also shows that they can also go very wrong. Given the risk of government failures, the policy issue is then how to improve government capabilities, not to presume that governments can do no right.

The main forms of selective policies permitted under the new rules pertain to skill formation, technology support and financing of innovation, promotion and targeting of foreign direct investment, infrastructure development for information technology, and general subsidies that do not affect trade performance. The advanced industrial countries and most semi-industrial countries use all of these tools—and some that are not in conformance with the spirit of the rules. The least developed countries tend not to use them.[3]

It is imperative that all countries maximize their deployment of available instruments to build industrial capabilities. It clearly requires advanced administrative competence, information and flexibility—capabilities not found in many countries (Amsden 2001; Amsden and Chu 2003). The first challenge of new industrial policy must be to strengthen these capabilities.

Until recently, the trading system, dominated by the WTO, addressed development only in a piecemeal fashion. Debates on trade at the WTO were conducted with little reference to a broader vision of how trade fits into development. Concerns over the agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) have taken center stage. Patent law changes have occupied much of the WTO's time and created excessive pressures on developing countries to harmonize their systems with those of the advanced industrial countries.

It is imperative that all countries maximize their deployment of available instruments to build industrial capabilities

There has been relatively little appreciation of the amount of time institutional reform may take, even when developing countries learn from the histories of the industrial countries.

The 2000 WTO Ministerial Meeting recognized that the links between trade and technological development needed to be better understood. Decision-makers at the meeting agreed to set up a Working Group on Trade and Transfer of Technology to examine these links and make recommendations on how to accelerate technology flows to developing countries (WTO 2002). The WTO also agreed to put development at the heart of the WTO Work Program. This agreement, together with the establishment of the Working Group on Trade and Transfer of Technology, has opened a window of opportunity to make the multilateral trading system more technology oriented. Doing so will be very difficult. Subsequent WTO negotiations under the Doha Ministerial Declaration have shifted attention to other issues such as agriculture, and technology is no longer a major subject on the agenda.

Complying with intellectual property rights regulations

Protecting intellectual property rights is a critical aspect of technological innovation. But overly protective systems could have a negative impact on creativity. It is therefore important to design intellectual property protections systems that take the special needs of developing countries into account. Provisions in international intellectual property agreements that provide for technology cooperation with developing countries need to be identified and implemented immediately.

To encourage innovation and unlock local capital, individuals and corporations need to feel that their research is protected; where intellectual property rights have been violated, compensation must be provided. However, most countries developed without these protections being structured across the economy in any clear way. Indeed, institutional development of patent regimes usually occurred after a country's firms achieved a significant level of innovation capability and then desired to protect their investments. This line of thinking would lead to a global intellectual property regime that acknowledges the co-evolutionary nature of technological innovation and enforcement of intellectual property rights.

One way of adjusting intellectual property rights based on a country's level of development would be to create a three-tier system. Tier A countries would be required to comply with all provisions of TRIPS, including the legal framework and "effective enforcement," as required under Article 41. Developing countries with per capita GDP of, say, more than $5,000 would fall into this category (alternatively, an export criterion could be used). Tier B could apply to countries with per capita GDP of $1,000–$5,000. These countries would adopt the full legal framework required under TRIPS, perhaps with some minimal level of enforcement. Countries with per capita GDP of less than $1,000 (Tier C countries) would establish the legal framework required

Protecting intellectual property rights is a critical aspect of technological innovation

under TRIPS, perhaps with the exception of patent laws and protections for integrated circuits.

If one of the applicants or the assignee is from a developed country, the initial application would need to be made in a country with A-level protection. If all the applicants were from a least developed country, they could apply for protection in their own country, where the laws may provide C-level protection. If these applicants wanted to extend their rights to cover a developed country, they would be able to obtain only C-level protection for their invention, even in the country that has A-level protection.

The recent recognition by the TRIPS Council of the right of developing countries to obtain generic drugs to fill their domestic needs should be built upon to help countries develop the ability to manufacture pharmaceuticals for local (and perhaps ultimately export) consumption. Less developed countries could be permitted to use process patents to make drugs for their own markets and for markets in other countries that lack domestic manufacturing facilities or competence, but they would not be able to compete in markets with A-level protection. Compulsory licensing procedures for such uses could be simplified, at least for C-level countries.

Successful developing countries with C-level protection may become industrial and in time meet the GDP criteria to reach the intermediate level. They would then have to amend their laws to afford B-level protection. This might facilitate the eventual adoption of patent regimes desirable to both advanced industrial and developing countries, while still allowing developing countries to frame their own laws.

The TRIPS agreement represents an important step in establishing minimum standards for national laws governing intellectual property protection. Most of the key elements of the intellectual property systems of the United States, the European Union, and Japan were similar and could be harmonized. These regions are the largest sources of inventions. Areas of divergence between their systems include first-to-invent systems, the scope of patentable subject matter, the treatment of plants and animals, geographical indications, and the degree to which moral values should influence the granting of intellectual property rights.[4]

The need to strike a balance between enforcing intellectual property rights and meeting the technological needs of developing countries became a key theme in the Uruguay Round of negotiations. Article 8 of TRIPS states that countries "may, in formulating or amending their laws and regulations, adopt measures necessary to protect public health and nutrition, and to promote the public interest in sectors of vital importance to their socioeconomic and technological development, provided that such measures are consistent with the provisions of this Agreement." Article 8.2 provides countries with the freedom to adopt measures that "may be needed to prevent the abuse of intellectual property rights by rights holders or the resort to practices which unreasonably restrain trade

Developing countries are increasingly recognizing that traditional knowledge associated with biological diversity forms part of product development

or adversely affect the international transfer of technology." This prevention of abuse clause deals primarily with measures that undermine competition.

This flexibility suggests that developing countries need to formulate their interests through national policy and legislation. The successful use of the flexibility granted in the TRIPS agreement will depend on the relationship between a country and its major trading partners in the industrial world, since most of the inventions that are likely to be affected by national laws belong to rights holders in the industrial world.[5] Trading partners are the primary focus for TRIPS protection issues, because only trading partners have the incentive to pursue trade remedies against a country for violating their intellectual property treaty obligations (D.S. Long, John Marshall Law School, personal communication, 2004).

Article 66.2 of the TRIPS agreement states that "developed country Members shall provide incentives to enterprises and institutions in their territories for the purpose of promoting and encouraging technology transfer to least-developed country Members in order to enable them to create a sound and viable technological base." This provision has received little attention, despite a 2003 decision of the TRIPS Council that called for annual reports on its implementation. The reports required by the decision will include information on the type of incentive and the government agency or other entity providing it, as well as information on the practical functioning of the incentives.

Developing countries are increasingly recognizing that traditional knowledge associated with biological diversity that is held by local and indigenous communities forms part of product development (box 7.4) (Dutfield 2004).

Box 7.4

Building on local knowledge

Source: www.nifindia.org.

The role of traditional knowledge in economic transformation is emerging as an important foundation for community development. For example, in 2000 the Indian Department of Science and Technology helped establish the National Innovation Foundation, which focuses on scouting, spawning, sustaining, and scaling up grassroots innovations of relevance to sustainable development. The foundation's work builds on long-standing efforts by the Honey Bee Network and the Society for Research and Initiatives for Sustainable Technologies and Institutions to document local innovations. They have more than 10,000 documented innovations (A.K. Gupta, Honey Bee Network, personal communication, 2004).

The National Innovation Foundation began its first national campaign in 2000 to scout innovations and outstanding traditional knowledge. It has since completed four national campaigns. By 2003 the foundation had documented more than 37,000 innovations in 350 districts of India. In addition, the National Innovation Foundation has access to another 6,000 traditional knowledge examples in the Honey Bee database managed by the Society for Research and Initiatives for Sustainable Technologies and Institutions. The main challenge facing the initiative is how to transform the innovations into products for wider commercial application. To make this possible the National Innovation Foundation is helping to obtain intellectual property protection for qualifying ideas. By 2004 more than 70 patent, trademark, and industrial design applications had been filed in India and abroad.

Open access to sequence data is an important tool for promoting innovation and should therefore be encouraged

They are seeking to enhance their capacity to use such knowledge as part of their efforts to implement the relevant provisions of the United Nations Convention on Biological Diversity, especially those provisions dealing with traditional knowledge and access to genetic resources. Developing countries are seeking intellectual property registration systems that identify and document the sources of genetic material and indigenous knowledge used in product development. Such a system would allow for the sharing of benefits arising from the use of such genetic material and knowledge in accordance with the Convention on Biological Diversity.

One of the most controversial areas of intellectual property protection relates to ownership of genetic information derived from the sequencing of the human genome and other organisms. The private sector would like to extend intellectual property protection to the data using a variety of means. While such a measure would provide the incentives needed by the private sector to invest in product development, there is concern that such measures could undermine long-term research. Open access to sequence data is an important tool for promoting innovation and should therefore be encouraged as part of the large pursuit to balance "open science" and proprietary incentives embodied in intellectual property rights (David 2004).

Meeting international standards and technical regulations

Standards and technical regulations are a set of technical specifications that describe the characteristics of a product, a service, a process, or a material (Lall and Pietrobelli 2003). The use of standards reduces transactions costs, information asymmetries, and uncertainty between buyers and sellers with respect to quality and technical characteristics. Standards and technical regulations provide many benefits to producers and consumers, not the least of which is their information value. In order to protect human health, for example, foodstuffs are required to meet sanitary and phytosanitary standards. Other benefits from standards and technical regulations include those that can be attributed to enhanced competition and economies of scale. When production can be standardized, components can be produced more efficiently around the world. These standards also accelerate the spread of best practice and innovation, especially to small and medium-size enterprises.

Products have to comply with a large number of standards and technical regulations in order to access importing markets. These standards and regulations can sometimes lead to discretional enforcement, effectively restricting market entry despite the absence of tariffs or quotas. Even when applied properly, they require significant technological infrastructure in the exporting country, as it is the seller who must demonstrate that its products satisfy applicable requirements. The Technical Barriers to Trade Agreement and the Agreement on the Application of Sanitary and Phyto-Sanitary Standards, negotiated

The use of standards reduces transactions costs, information asymmetries, and uncertainty between buyers and sellers with respect to quality and technical characteristics

during the Uruguay Round, were meant to ensure that standards and technical regulations do not create unnecessary obstacles to trade.

Metrology provides the measurement accuracy and compatibility without which standards cannot be applied; it is a necessary requisite for the advancement of scientific and technical knowledge. The application of standards and the certification of products necessarily imply testing and quality control services. Quality, standards, testing, and metrology (QSTM) are thus a critical component of the technological infrastructure.

Developing countries' ability to meet their international commitments and participate more meaningfully in global trade depends on having adequate physical, institutional, and technological infrastructure as well as scientific and technological skills and capabilities to comply with current and future standards (UNIDO 2003). Such capacities are often lacking in developing countries, particularly in the least developed countries. Enterprises in developing countries have very little knowledge of or information about the standards and technical regulations required to enter advanced country markets, and they are unable to rely on the domestic technological infrastructure to trace and prevent problems. In addition, for a large and growing number of products, importing countries require independent evidence that their manufacture complies with quality management (ISO 9000) and environmental management (ISO 14000) systems.

Asymmetric information on standards and technical regulations places developing countries at a disadvantage because of the higher costs associated with duplicative testing requirements performed by importers in order to assess conformity with sanitary and phytosanitary standards. This duplication of tests is often associated with lack of international credibility of developing countries' standard organizations, which is partly attributable to underinvestment in these areas. This lack of credibility prevents these countries from participating in what is considered to be an important instrument in liberalizing technical barriers to trade, namely, mutual recognition agreements.[6]

The investments required to meet standards and technical regulations often entail discrepancies between private and social costs and benefits, which therefore often warrant the supply of public goods.[7] Furthermore, while international technical assistance has been increasingly available to train trade negotiators in least developed countries, it has failed to put enough emphasis on the technical infrastructure needs of developing countries in the area of trade capacity building. Overall, the development challenge for the developing countries is not only negotiating better market access but ensuring that the productive capacities are in place to respond to demands and requirements.

While the WTO agreements require developing countries to develop national capacity to implement the agreements on standards and technical regulations, little technical assistance has been provided for them to do so. The

To ensure that international (and national) standards are set in a balanced manner, developing countries need to participate in their development

recent Doha Ministerial Declaration on Implementation Issues indicates serious problems for developing countries in implementing some of the standards.

For many developing countries, minimum levels of investments in technical and human infrastructure needed to comply with standards and technical regulations may exceed their annual health and development budgets (Finger and Schuler 2000). But underinvestment in these standards and regulations reduces the potential growth of exports and GDP, creating a vicious cycle. There is, therefore, a case for providing subsidies to these countries to enable them to create the infrastructure needed to meet the standards and technical regulations.

Meeting the proliferation of standards and technical regulations requires a scientific and technological base that is located largely in industrial countries. It is not surprising that these are the countries that report the highest number of new standard notifications to the WTO.[8]

Currently, although some developing countries have parts of the requirements to deal with international standards in place, in most cases, especially in the least developed countries, major parts are missing. Even if services exist, they are usually not recognized internationally and do not therefore fully assist potential exporters. Because of these missing domestic capabilities, developing countries are not able to technically analyze and challenge importing countries' claims about exported products or participate in international standard setting bodies in a meaningful way.

To ensure that international (and national) standards are set in a balanced manner, developing countries need to participate in their development. This requires establishing and strengthening national and regional standards bodies. These standardization institutions need to be equipped with the technical and human capacity to develop and adopt standards through subsectoral technical analysis. In addition, they can help establish national and regional databases of relevant standards and regulations, providing essential services to inform the private sector. Regional cooperation, especially among African countries, has the added benefit of harmonizing standards and achieving regional economies of scale in information gathering and dissemination.

Other supporting technological infrastructure is required to complement the work of standardization bodies. A national and regional system of metrology ensures that the measurements and tests required for all production, quality, and certification activities are consistent and correct. This includes operational laboratories for primary and secondary physical standards and certified reference materials for chemical and microbiological purposes, laboratory capacities for legal and industrial metrology, and a framework and system for calibration and materials testing.

Certifying that products, management, and production processes comply with applicable requirements and standards requires a certification and conformity assessment system, including internationally recognized testing facilities. Certification for ISO 9000 (evidence of a functional quality management

Creating links between knowledge generation and enterprise development is one of the most important challenges developing countries face

system), ISO 14000 (evidence of a functioning environmental management system), and Hazard Analysis of Critical Control Points (HACCP) are increasingly important prerequisites for international trade. Because sending samples abroad is not feasible, testing facilities must be established domestically.

In order for these facilities to be accepted by international markets, an accreditation system is necessary to evaluate the calibration and testing laboratories and other bodies involved in certification of products, systems, and processes. The regional and national accreditation bodies have to be recognized by the International Accreditation Forum and the International Laboratory Accreditation Cooperation.

Given the many and complex requirements and the quality demands on producers, technical support and information services are essential. Support services provide information on applicable standards and product requirements, including product specifications, quality standards, packaging, and labelling, and they help producers improve their process and product quality.

The production-oriented scientific and technical infrastructure is a source of important externalities, which justifies the provision of public goods. The international community has a responsibility to ensure that products exported from developing countries meet legitimate health, safety, and environmental concerns. But it must also ensure that the export development and economic prospects of developing countries, especially the least developed countries, are not unduly harmed by resource constraints and implementation problems in the standards area.

Building export-related technological capabilities creates further demand for technological learning and product/process upgrading, thus prompting further exports and growth. For this reason, the technological capability development needs of developing countries need to be assessed and addressed. Quantifying capability development is not easy. But it is still possible to undertake national needs assessments of technological capabilities, especially as they relate to trade capacity.

Conclusion

If a developing country is to unlock the potential to turn science, technology, and innovation into business opportunities, it needs to undertake a number of core activities. These include providing broader incentive structures to all firms while creating an institutional environment that encourages entrepreneurship, rewards innovation, fosters start-ups, and sustains existing firms with injections of capital.

Creating links between knowledge generation and enterprise development is one of the most important challenges developing countries face. A range of structures can be used to create and sustain enterprises, from taxation regimes and market-based instruments to consumption policies and sources of change within the innovation system.