02

Appropriate Innovation

Researchers at the Kenya Medical Research Institute (KEMRI) © Rebecca Nduku – Commonwealth Secretariat

Science for development is undergoing rapid change. Traditional perspectives about the source of science ideas for development and how research should be done are being replaced by a new, broader perspective. This embraces ideas as diverse as traditional local practices and the most recent cutting-edge international science, and engages players ranging from farmer-innovators to multinational corporations. The result will be a science innovation system with enormous new potential to address international development challenges.

1. Where does science and innovation for development come from?

In the 20th century, there was a widespread view that most of the technological needs of the developing world could be addressed by extending to it technologies from developed, industrialised countries, most of which have been produced over the past 150 years through application of modern physical, chemical and biological knowledge. These "conventional technologies" typically deliver desired products in a ready-to-use 'packaged' form, e.g. a seed of a new crop variety, a bag of fertiliser, a medicine, computer or tractor. Such packages are often global or at least regional in their appropriateness and are easy to market.

While it is true that conventional technologies have provided a crucial stimulus to national growth in emerging economies, their benefit to the poorest communities has often been limited. In some cases, these products are of direct value to the poor, but unaffordable, or requiring delivery systems, maintenance or training to which they do not have adequate access. The technologies may also have environmental side effects which are more severe or less manageable in developing countries than in the industrialised communities for which they were developed.

In other cases, conventional technologies may be valuable to potentially poor people, but most existing products do not address their specific needs. For instance, a number of crop and livestock varieties, important to the poor, have not benefited from conventional breeding technology. Similarly, many diseases common in developing countries have not benefited from conventional pharmaceutical technologies, earning them the title of "neglected diseases". Market failure has been largely responsible for this, and in Chapter 3 we will see how the problem can be addressed through partnerships in science innovation.

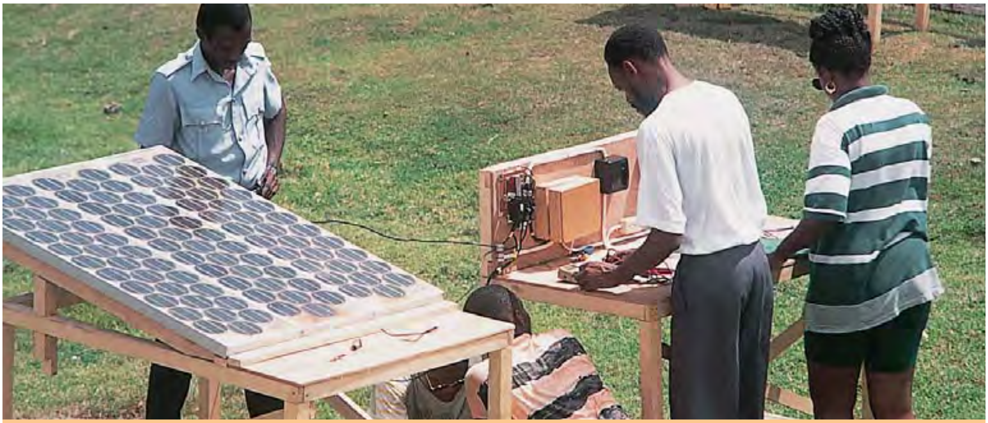


Figure 2.1 – Learning how to construct solar electric systems in Africa

Efforts to apply products from conventional technologies in developing countries have sometimes proven highly unsuccessful. Projects delivering machinery without training or maintenance, or crop or animal varieties unsuitable to the local conditions of poor communities, highlighted the need for appropriate application of science and technology. These errors have also stimulated greater interest in the "traditional technologies" of local communities, the understanding and support of which has often been overlooked in the rush to apply imported technologies from industrialised countries. In some cases, as we shall see, these traditional technologies can be integrated with conventional technologies to make "intermediate technologies" whose products are both appropriate and superior to those presently available.

Whatever the source and wherever the application, the important feature of technologies is that they are locally appropriate. For a technology to be appropriate in a developing country, as anywhere, it has to:

- Be readily accessible and affordable;
- Be easy-to-use and maintain;
- Serve a real need;
- Be effective.

In this chapter we will first discuss innovation in the more selective and appropriate use of conventional technologies and then look at the role of local traditional technologies, as well as how these have been combined with conventional ideas to produce intermediate technologies. We will conclude with a discussion of the promise for emerging new platform technologies and the way in which these, if developed in an appropriate manner, can be of critical value to international development. We will base our discussion on the following definitions:

Box 2.1 Sources of technology

Conventional: Technologies from industrialised countries developed through the application of modern physical, chemical and biological knowledge, and delivered as products in a packaged form for a regional or global market. *e.g. Fertilisers, conventional water treatment plants.*

Traditional: Technologies which have been developed, usually over an extended period of time, by communities in developing countries to meet local needs. *e.g. Natural medicines, rainwater harvesting techniques.*

Intermediate: Traditional technologies which have been improved in appropriate respects by their integration with modern conventional technologies. e.g. *Traditional treadle pump improved by engineers, soil bricks used for housing improved by incorporating new materials.*[1]

New Platform: New scientific "platforms" for innovation, based on advanced sciences which have the potential to be developed simultaneously for the needs of the industrialised and the developing world. *e.g. New forms of water treatment developed using nanotechnology; genetically modified, drought or pest resistant crop varieties.*

2. Selective use of conventional technologies

Most conventional technologies were developed in the 19th and 20th centuries, as products of large scale industrial processes often reliant on petrochemicals. The development of cement and concrete in the 19th century made large scale dams and irrigation systems possible. Widespread use of synthetic fertilisers was the result of the innovative production of ammonia from atmospheric nitrogen by Fritz Haber and Carl Bosch at the beginning of the 20th century. Both synthetic pesticides and modern antibiotics had their origins in the large scale chemical processes developed during the Second World War.

Such technologies continue to be highly effective and relatively inexpensive in developed countries where they are widely used. However, as we argued earlier, they may not result in products appropriate to developing countries. For instance, products are often costly in terms of energy and petrochemical inputs. Even where they can be produced cheaply on a large scale, transport costs make them expensive in developing countries, particularly in inland sub-Saharan Africa (Box 2.2).

Box 2.2 The high cost of fertilisers in inland Sub-Saharan Africa (2002 figures)[2]

Cost of a tonne of urea – FOB (free on board)

Europe	$90
The coastal cities of Mombasa, Kenya or Beira, Mozambique	$400
Western Kenya	$500
Landlocked Malawi	$770

They may also have deleterious local environmental effects. Large scale dam construction and impoundment can displace communities and destroy biodiversity, while synthetic fertilisers, if used to excess, can pollute water sources. Synthetic pesticides can be very destructive to wildlife and harmful to humans if they are not applied correctly. In each instance, the poor tend to suffer disproportionately from these unintended effects. Protective regulations are often lacking in poor areas and, if present, are rarely effectively enforced. The rich and powerful usually have the means, often corrupt, of avoiding compliance. The poor, by contrast, are usually the major victims and have little recourse to redress.

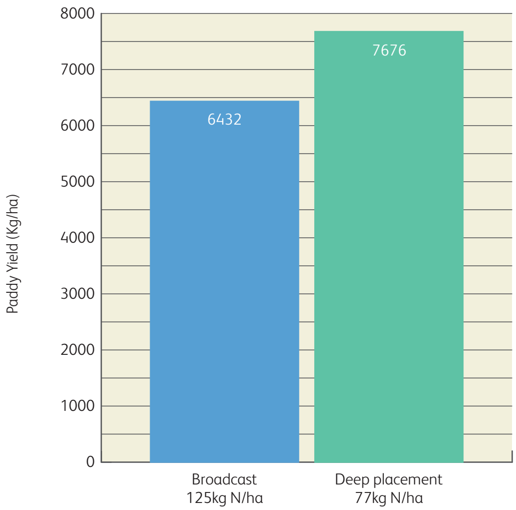
Unintentional poisoning by pesticides kills thousands per year in developing countries, where safe equipment, expert advice and training are often lacking.[3] Many farmers overuse pesticides and do not take proper precautions. Pesticides banned or restricted in industrialised countries are widely available in the developing countries.[4]

Both pesticides and modern pharmaceuticals are also prone to the evolution of resistance. In the case of drug resistance the poor have very limited access to the intensive health care systems that can provide appropriate treatment and monitoring.

Precision in application

For these various reasons there has been a move, since the 1960s, to find ways of using such technologies in a more sparing and selective manner. The high cost of fertilisers has resulted in a move to more precise applications in the developed countries, using controlled-release fertilisers, fine grained soil analyses and variable application on individual fields employing tractors fitted with Geographic Information Systems (GIS) devices.[5,6] This is not likely to be appropriate for smaller-scale farmers in developing countries until the prices come down, but farmers can substitute more selective placement of fertilisers instead of the widespread practice of broadcasting them. For example, urea super granules (USG) inserted in the middle of every four rice plants in Bangladeshi paddy fields (Figures 2.2 and 2.3), results in an extra tonne of paddy with a reduction of fertiliser by over a third.[7]

Figure 2.2 – Improvement in yield with reduction in fertiliser due to deep placement technique[7]



Countering resistance

Pesticides can also be applied more selectively, partly to reduce cost, partly to encourage natural enemies to control the pests and partly to counter resistance (see examples in Chapter 5). A notorious example of rapidly evolving resistance is of *Anopheline* mosquitoes to insecticides of all kinds. DDT became largely ineffective in the 1960s because of this. The new insecticides such as the pyrethroids worked well for a while but resistance is now spreading very rapidly in Africa (Box 2.3).

Box 2.3 Mitigating the risk of mosquito resistance to insecticides

Insecticide resistance in mosquitoes is a classic example of natural selection. Resistance occurs as a result of natural mutation or genetic recombination in the absence of the insecticide, but usually at a very low level because it is generally disadvantageous in other respects. However, it rapidly spreads through the mosquito population from generation to generation in response to the pressure of insecticide use. Survivors tend to be resistant and pass on the resistance through their genes to their offspring.

It is almost impossible to prevent this from occurring but the risk can be minimised in a number of ways:

- Using insecticides which are slow to elicit a resistance response;
- Using different insecticides in rotation from year to year or as mosaics (i.e. different compounds for different houses in a village);
- Avoiding opportunities for cross-resistance by knowing the resistance status of local mosquito populations to different pesticides (e.g. mosquitoes resistant to DDT may also be resistant to pyrethroids);
- Reducing agricultural use of the same pesticides (against crop pests) which are used locally against mosquitoes.

Malaria control is also affected by evolving resistance by the parasite *Plasmodium* to the various therapeutic drugs that have been developed over the years. Part of the answer here lies in using drugs in combination (see Chapter 6). Combination therapy has also long been used in the treatment of tuberculosis (TB) (Box 2.4).

Thus there are a number of ways to make conventional technologies and their products more appropriate to developing countries, by limiting or integrating their use so as to reduce their cost and maintain their value. Still, many conventional technologies remain inappropriate for a range of reasons. In some cases it makes more sense to make use of traditional technologies which are adapted to the local environment from the outset.

Figure 2.3 – A farmer in Bangladesh places USG granules in the centre of each of four rice plants

Box 2.4 Strategies to reduce drug resistance in TB[8]

The available conventional drugs to cure patients of TB require relatively long periods of treatment to be effective. Missed doses rapidly result in the build-up of resistance. Part of the answer lies in using a combination of compounds.

The World Health Organisation (WHO) recommends a drug regime consisting of two phases:

1. An initial intensive phase of four drugs – rifampicin, isoniazid, pyrazinamide and ethambutol – administered for two months;
2. A continuation phase of two drugs – rifampicin and isoniazid – for four months.

The drugs have to be administered daily in the initial phase and daily or at least three times a week in the continuation phase. But success depends on ensuring this regime is strictly adhered to and directly observed. The person ensuring the drugs are taken need not be a health worker; a community worker, neighbour or family member can be effective in this role.

When done according to these guidelines the treatment can be over 95 % effective. But when lack of supervision or drug availability results in missed doses it is not only ineffective but stimulates the spread of multiple drug resistance.

One answer to the problem is to develop new chemotherapy regimens which can be effective in a matter of a few weeks or even a few days so minimising the likelihood of missed doses.

3. The use of traditional technologies

One aspect of science and technology for development which is often overlooked is the important contribution that the knowledge and experience of communities in developing countries can make to technology development and adaptation. There is, however, a long history of appropriate technology for development having a strong element of local input, often referred to as Indigenous Technical Knowledge.

Traditional technologies are approaches to problems that have been used by people for hundreds, if not thousands, of years. They can be thought of as having 'stood the test of time.' Some have clearly worked and still work today; for others there is no scientific evidence that they are effective.

Herbal medicines

The use of plants for healing purposes pre-dates human history and forms the origin of much modern medicine. Many conventional drugs originate from plant sources: aspirin (from willow bark), digoxin (from foxglove), quinine (from cinchona bark) and morphine (from the opium poppy).[9]

Traditional healers who rely on herbal medicines are an important source of health care in developing countries. WHO estimates that 80 % of the African population makes use of traditional medicine.[10] In Uganda the ratio of traditional medicine practitioners to the population is between 1:200 and 1:400 while that of allopathic ('western') practitioners is typically 1:20,000.[11] For many rural people, traditional healers are the only source of health care within reach.

Box 2.5 What is traditional medicine?

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Figure 2.4 – Traditional healer, Uganda

WHO defines traditional medicine as *'diverse health practices, approaches, knowledge and beliefs incorporating plant, animal, and/or mineral based medicines, spiritual therapies, manual techniques and exercises applied singularly or in combination to maintain well-being, as well as to treat, diagnose or prevent illness.'*[11]

While many false claims have been made for the treatment of HIV/AIDS, there is evidence that herbal medicines can successfully treat some of the opportunistic infections that accompany AIDS such as *Herpes zoster*.[12]

The most important herbal-derived medicine in use today is artemisinin (Box 2.6). In combination with other drugs it is now recommended by WHO as the first line of attack against malaria where there is resistance to other drugs.

Box 2.6 Artemisinin – a frontline drug against malaria

Artemisinin is derived from *Artemisia annua*, known as sweet wormwood or qíngháo by the Chinese. It has fern-like leaves and bright yellow flowers. For over 2,000 years it has been used as an anti-malarial by the Chinese in the form of tea. In the 1970s Chinese scientists isolated the active ingredient artemisinin.

Artemisinin or its derivatives, such as artesunate and artemether, are now commonly used in combination with other anti-malarial drugs as Artemisinin-based Combination Therapies (ACT) (see also Chapter 6).

Figure 2.5 – Sweet Wormwood, *Artemisia annua*

In several settings there are current attempts to integrate, semi-formally, the traditional healer network with the allopathic system. The ubiquity of traditional healers means they can be a valuable resource in the frontline against various diseases, not least HIV/AIDS. Organisations such as Traditional and Modern Health Practitioners Together against AIDS (THETA) in Uganda, have shown that with appropriate training, traditional healers have performed as well as, if not better than, community health workers in educating communities, promoting and distributing condoms, and counselling, treating and referring the sick.[13]

Agricultural systems

Traditional systems of small-scale agriculture and gardening such as shifting cultivation and home gardens are examples of fundamental organic systems that, until recently, have relied exclusively on recycling of nutrients, biological forms of pest and disease control and household labour. Modern organic agriculture makes use of similar principles. In developing countries if there is sufficient organic matter and enough labour, organic cultivation can also provide profitable niche exports of vegetables, fruits and commodities such as coffee and tea to developed countries.

The home garden is a traditional agricultural system that has provided rural households with food and fibre on a sustainable basis for several thousand years (Box 2.7).

Box 2.7 Home gardens as a valuable resource[14]

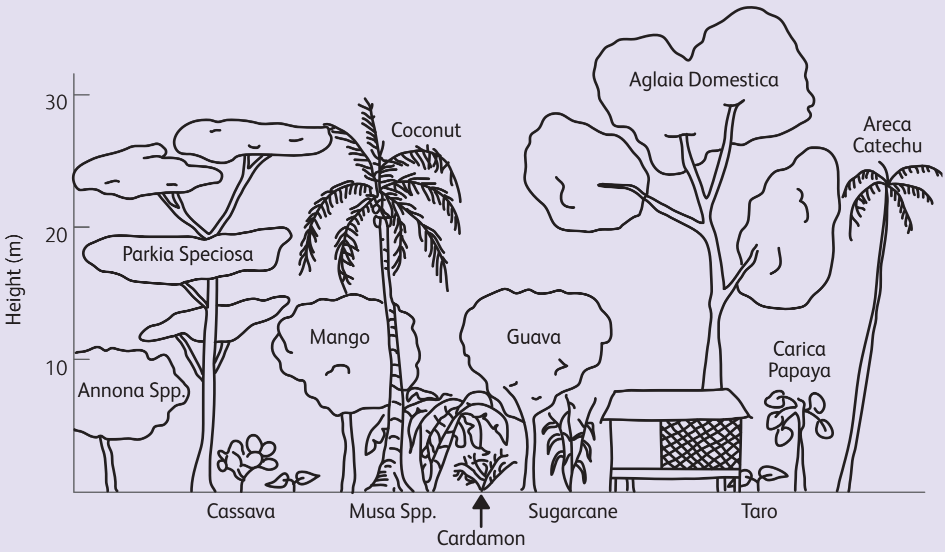

Figure 2.6 – The diversity in a Javanese home garden[15]

Home gardens are one of the oldest forms of farming system and may have been the first agricultural system to emerge in hunter gatherer societies. Today, home or kitchen gardens are particularly well developed on the island of Java in Indonesia, where they are called *pekarangan*.

The immediately noticeable characteristic is their great diversity relative to their size: they usually take up little more than half a hectare around the farmer's house. Yet, in one Javanese home garden 56 different species of useful plants were found, some for food, others for condiments and spices, some for medicine and others for feed for livestock. A cow, a goat, chickens and ducks were also present, as well as fish in the garden pond. Most of the garden products are used for household consumption, but some are bartered with neighbours or sold.

The plants are grown in intricate relationships with one another: close to the ground are vegetables, cassava, taro and spices; in the next layer are bananas, papayas and other fruits; a couple of metres above are soursop *Annona spp*, guava and mango, while emerging through the canopy are coconuts, timber trees and fruit trees. The planting is so dense that to a casual observer the garden seems like a miniature forest.

Figure 2.7 – Javanese home garden

4. The development of intermediate technologies

Intermediate technologies have been defined in a number of ways, but fundamentally they are traditional technologies that have been improved in appropriate respects by their integration with modern conventional technologies.

Treadle pumps

There are numerous examples of such intermediate technologies in action. Some are simple, others more sophisticated. A good example of a relatively simple technology is the development of an affordable and reliable treadle pump. For many years, engineers have been developing pumps which allow farmers to replace the arduous task of lifting irrigation water from shallow wells by bucket. Oil driven pumps are expensive to purchase and to run. The modern treadle pump is ideal in many respects – it is efficient and easy for farmers to use and maintain and is virtually fool-proof. It relies on human rather than oil or electric power. It is also relatively cheap, as a result of a combination of public subsidies with private manufacture and servicing, and community involvement (Box 2.8).

Box 2.8 Making irrigation possible with treadle pumps

First innovated by local people in Bangladesh in the early 1980s, the treadle pump is a simple machine which a farmer can stand on and pump with his or her feet to irrigate a field. The pump produces the suction or pressure needed to pump water from a natural source or dug well to be sprayed on the crops. The technology has been improved upon by a number of enterprising engineers, producing a variety of effective and easy-to-maintain designs which can be used to irrigate up to two acres of land without any motor or fuel.

International Development Enterprises (IDE) began in 1984 by refining the pump design they encountered in Bangladesh. After successfully creating a market and supply-chain for the product there, they have since expanded the approach to countries across Africa and Asia.[16]

The Non-Governmental Organisation (NGO) *KickStart* responded to farmers in Kenya who needed a device which would pump water uphill, useful when water sources are at the bottom of a hilly plot or for filling overhead tanks.

Figure 2.8 – Using an IDE treadle pump this Bangledeshi woman can now support her family and run a small shop

They developed the 'Super-Money Maker' pump in 1998, which as of 2009 has been sold to over 129,000 farmers in Kenya, Tanzania and Mali.[17]

Pumps like these help farmers by extending the traditional growing season and expanding the number of crops that they can cultivate.

For example, Nazrul Islam, a farmer in Bangladesh, applied for a micro-loan of about US$20 to cover the costs of digging a well and buying a treadle pump. He was able to repay the loan and buy additional land and livestock within the first year of use.[18]

Figure 2.9 – An IDE treadle pump dealer works on a pump in Zambia

Chinese technologies

The Loess Plateau project, discussed in Chapter 1, also provides examples of intermediate technologies (Box 2.9). In order to effectively and sustainably rehabilitate this very degraded area, project planners combined large-scale engineering technology in the use of bulldozers for shaping terraces and dams, with local knowledge of past efforts, in erosion control and of the needs and priorities of the communities, to formulate a set of appropriate solutions.

While traditional and intermediate technologies offer a great deal to science innovation, in practice they may require considerable skill and experience; they can be labour intensive and time consuming; and they are often difficult to transfer to other areas. It is for this reason that we urgently need new technologies, derived from cutting edge science, that from the outset are designed for developing country conditions.

Box 2.9 Intermediate technologies on the Loess Plateau, China

- Construction of **modern terraces** using local bulldozer operators with additional manual labour for shaping – creating terraces that are broader, horizontal and sloping inwards. These terraces have converted sloping land to level fields, virtually eliminating erosion and helping to maintain moisture in the soils, allowing higher crop yields and more diversified cropping patterns.[19]

Figure 2.10 – Terraces on the Loess Plateau

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Figure 2.11 – Wheat growing on the Loess plateau through plastic covering to retain soil and moisture

- Construction of **sediment traps and dams** in the uninhabited gully areas to intercept sediment at its source. By using a combination of key, warping and check dams, the project was able to reduce sediment loads to the river by around 50 %, provide a new water supply, and greatly increase the arable land available for farming. All dams were constructed with earthfill, and can be easily maintained and modified as required.[19]
- **Improved transplantation methods** for planting trees on the upper slopes. Previous methods had been disrupting the rhizosphere, the important region of soil near the roots of a tree. Chinese scientists devised a method of wrapping the root ball of the trees in grass mats, rope or removable plastic, thus keeping existing soil intact.[20]
- Use of **plastic** to conserve water and for livestock housing. Modern plastics provide a cheap and efficient way of both protecting the soil and reducing water loss. They can also be used to trap heat – especially in the winter – providing warm housing for livestock and the temperatures to raise cut flowers, tomatoes and other horticultural crops for local and distant markets. Chinese researchers are currently working on the production of biodegradable plastics.

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Figure 2.12 – Plastic covered 'greenhouses' raising cut flowers for market, Loess Plateau (note combination with traditional mud and straw construction)

5. The promise of new platform technologies

In the past, most application of scientific innovation from industrialised countries has involved a process of adaptation to developing country conditions, in the ways described above. This two-step process of innovation and adaptation inevitably slows science innovation for development, that is why we have argued in Chapter 1 for the involvement of developing country scientists and perspectives in global science innovation systems. In this way developing country needs can be included from the outset in the interaction of basic, translational and applied science.

The increasingly global nature of science innovation, the "internationalisation" of universities and the engagement of new players in development research, including government institutions, industry and civil society is making this ambition all the more feasible. In the next chapter we will examine how these different players may be engaged in accelerating science innovation for development. Here we highlight three key areas of scientific advance – new scientific "platforms" for innovation – that have the potential to be developed simultaneously for the needs of the industrialised and the developing world. These new platform technologies are:

- Information and communication technology for development;
- Nanotechnology;
- Biotechnology.

While these research platforms have, not surprisingly, begun in industrialised research institutions, considerable effort is now underway to bring development agendas into the innovation process. Further, there is now a growing convergence and integration of application between all these technologies.

Information and Communication Technology (ICT) for development

Traditionally, ICT in developing countries has been based on indigenous forms of storytelling, song and theatre, the print media and radio. Modern ICT, based on electronic communications and the internet, has enormous but still largely unrealised potential for improving the lives of poor people. The challenge for science innovation here is to improve and encourage the effective use of existing technologies by the poor, while at the same time creating collaborations between developed and developing country scientists and engineers that will result in new communication technologies that are more appropriate to the environment and users in developing countries.

Improved ICT can benefit international development in many diverse ways, not the least of which is the improvement of science innovation itself through the engagement of developing country scientists in global innovation systems that require a capacity for rapid communication and transfer of scientific data.

Mobile phones

ICT development has already had demonstrable development value in the widespread use of mobile phones. This is a good example of an imported technology that has been widely and successfully adopted by developing countries. It was not specifically designed for, or with the involvement of, poor people and in many cases its primary advantage to poor people is unrelated to the key purpose for which it was designed, namely, mobility.

Furthermore, its success has not depended on a specific policy initiative on the part of donors or developing country governments to promote uptake of the technology. Nevertheless, the use of mobile phones has exploded in recent years, across Asia and Latin America, and especially in Africa. In 1995 there were 650,000 mobile phone subscribers in Africa; by 2003 there were nearly 52 million. Over the past five years the continent's mobile phone usage has increased at an annual rate of 65 %, twice the rate of Asia, and by 2008 there were over 250 million subscribers.[21,22]

Not surprisingly, new users are putting mobile phones to use in all kinds of situations, making things like banking, disease surveillance and election monitoring faster and easier. (Box 2.10)

Box 2.10 Putting mobile phones to use

Mobile phones can be used by everyone, including those who are poor, remote and/or illiterate. They can be shared between individuals and households, and made public at booths as a pay-service. Their use has not only dramatically improved communication and the flow of information in developing countries, but it has spurred a variety of completely new ways of doing things, in the areas of business, health and even social advocacy.

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Figure 2.13 – Mobile phone booth in a Nairobi slum

First and foremost, mobile phone use has given previously disconnected communities a means of communicating with family and friends, connecting with markets and facilitating the flow of remittances from abroad. Mobiles can serve to provide households with an increased sense of security, especially in health and other emergencies. The mobile market has also provided employment for countless individuals selling phones, cards and services.[23-25]

A huge number of innovators in developing countries have taken advantage of the flexibility and power of mobile phone technology, and used it to transform various aspects of local life. The examples below illustrate a few of these beneficial applications:

Mobiles for farming – Expanding mobile phone use has begun to remove many long-standing obstacles for farmers in developing countries. Mobiles can be used to find out the location and prices of inputs and crop market rates, with the cost of a phone call being a mere fraction of that previously spent on transport. New services such as *AppLab*, run by the Grameen Foundation in partnership with Google and the provider MTN Uganda, are allowing farmers to get tailored, speedy answers to their questions. The initiative includes platforms such as *Farmer's Friend*, a searchable database of agricultural information, *Google SMS*, a question and answer texting service and *Google Trader*, a SMS-based "marketplace" application that helps buyers and sellers find each other.[26-28]

M-Health – Mobile phones are increasingly being used in new ways to improve health systems, resulting in Mobile or M-Health, or 'telemedicine.' They can be used to improve communication between health officials and patients, for example, by sending SMS reminders of treatment or vaccination dates. Public health officials have also begun taking advantage of the technology for disease surveillance and response, by interfacing GIS and mobile technology on smart phones to provide real-time information on both diseases and medication supply.[29] The organisation Voxiva has designed integrated 'mobile-centric' programmes for such projects as, reducing maternal mortality in Peru, while the group Cell-Life has done so for HIV treatment in South Africa, using the phone as a tool for education, action and social networking.[30,31]

Figure 2.14 – Mobile phone use is spreading quickly in the developing world

M-Banking – Mobile banking systems are revolutionising the banking industry by allowing users to convert cash in and out of 'stored value' accounts linked to their mobile phone, use the stored value to pay for goods, and even transfer stored value between their own and other people's accounts. This gives customers a simple and secure service, and allows them to avoid the expense and time of travelling to and waiting in a bank, and the risk of theft. A variety of successful initiatives are now running in South Africa, Kenya and the Philippines.[32]

Mobiles for advocacy – Mobile phones can be used by citizens as a tool for fostering improved governance and equality, by aiding in monitoring and mobilisation. Organisations such as Tactical Technology in the UK have worked with local NGOs in developing countries to use mobile phone technology to report problems such as corruption, violence and environmental degradation, as well as monitor elections. They have also helped groups use mobiles to improve their social advocacy campaigns, by using SMS messages, ringtones and mobile news updates to mobilise, inform and even fundraise for causes such as workers' and women's rights.[33]

The internet

Internet access in the developing countries is growing fast – with usage increasing between 2000 and 2008 by over 1,000 % in Africa, 800 % in Latin America and 400 % in Asia,[34] and the use of computers for education, communication and information processing is steadily expanding. This will be further helped by improvements in infrastructure, such as the new 17,000km long underwater fibre optic cable installed by the African-owned company Seacom along the eastern coast of Africa. The cable, which went live in July 2009, creates a much needed digital link between Eastern Africa, South Asia and Europe, and will bring higher-speed, lower-cost broadband to millions of users.[35]

The internet is a powerful communication tool for connecting people and groups, accessing up-to-date information from around the world, and as a medium for posting news, business information and even campaign or advocacy messages. Use in internet cafés, schools and businesses has taken off, and there are many less traditional ways in which the internet is being used (Box 2.11).

Box 2.11 The internet as a development tool

Broadcasting information

In the town of Veerampattinam in India, the M.S. Swaminathan Research Foundation has put up loudspeakers to broadcast information such as weather and ocean-wave forecasts, agricultural and fishing techniques, market prices, government programmes, and local bus schedules. This allows citizens to access accurate information without even touching a computer or phone, thus adapting internet technology for the specific local context.[36]

© HiWEL

Figure 2.15 – Children crowding around a HiWEL learning station in India

Revamping education

In 1999 in New Delhi, India, local physicist Dr Sugata Mitra cemented a computer with a high-speed internet connection into a wall adjacent to a rubbish dump used by the poor – and just left it there. He monitored the use of the machine using a remote computer and a hidden camera. The results were surprising. Local children quickly began experimenting with the machine in groups, and within days had acquired basic computer literacy – able to use the mouse to point, drag, drop, copy, and to browse the internet. They came up with names for the objects such as *sui* (needle) for the mouse pointer and *damru* (Shiva's drum) for the hourglass.

This phenomenon has since been termed the "hole in the wall" project, and after a few more similar successes, the idea proved worth pursuing. In 2001 the Hole-in-the-Wall Education Ltd. (HiWEL) partnership was formed between Dr Mitra's computer software and training company NIIT and the International Finance Corporation. The group has since worked to expand the number of learning stations across India and other countries. By 2009 there were more than 400 in place across India, as well as some in Cambodia and seven African countries.[37] The HiWEL stations are cheap and easy to set-up and, due to their explorative nature, research has shown the programme benefits across gender as well as socio-economic groups equally.[38] Students who have had access to a HiWEL learning station are performing better in subjects such as mathematics and science, with the benefits multiplying as children form groups and share information.[39,40]

Improving NGO networking

The organisation *Rede de Informações para o Terceiro Setor* (RITS) in Brazil works to help local NGOs use the internet as a tool for accessing and communicating information, thus enabling them to better serve those they are trying to help. RITS hosts a virtual research centre on Brazilian civil society, publishes a weekly e-magazine of NGO news, and also provides web site hosting, email access, and Intranet services for hundreds of NGOs.[41]

Improving access

The key challenge now is to improve both mobile telephony and internet access in developing countries and particularly in rural areas. Access is frequently limited by policies and regulation which make the uptake of the technology more difficult for the poor. For example, in Ethiopia, where the government regulates the mobile phone industry very tightly, the average annual cost of using a mobile is one tenth of a person's average annual income, whereas it is only 1/150th in the freer South African market.[42]

On top of this, the way in which existing technologies are designed and applied can prevent expansion to the full-range of possible users. Current efforts are focusing on new and innovative solutions to bring the benefits of telephone and internet technology to more people, for less money.

For instance, standardised hardware and software designed for students and professionals in developed countries are often challenging for the partly illiterate, or those who are not comfortable in a main language available on the keyboard, computer programmes, or internet. Most common operating systems today are not always the easiest to learn, or indeed the cheapest to install.[42] In addition, standardised set-ups for phone and computer networks often require users to either purchase their own device, or pay an unaffordable fee for use.

A number of designers have been working to address these issues. The One Laptop per Child (OLPC) group has sparked innovation in laptop design for education in developing countries, while the non-profit Movirtu has devised a way for the poorest to have a telephone number without buying a phone, and computer rooms are being redesigned so that many users can work off a single processor (Box 2.12).

Box 2.12 ICT for all

Laptops for education

Released in 2005, the OLPC XO laptop is small, rugged and energy-efficient. It can withstand high heat and humidity and has a screen readable in bright sunlight. Even more novel, however, is the open-source Linux-based software created by the team, called 'Sugar.' It reinvents the traditional user interface allowing children to 'learn by doing,' with 'objects' and a 'daily journal' rather than a file and folder system, and has the ability to create easy working connections with other students and teachers.[43]

Figure 2.16 – The XO-1 Laptop

The XO laptop has been a hit with many students in countries where it has been piloted, however its integration into school systems and as a viable business model have been harder to achieve. More teacher training and more educational content have been highlighted as areas which could improve its usefulness in schools.[44]

Regardless, it has helped to spur a wave of innovations in laptop hardware and software technology for more diverse users including the rise of 'netbooks', or smaller, cheaper and simpler laptops. While the OLPC project had an original target price of US$100, researchers at the Indian Institute of Science and the Indian Institute of Technology are developing a cheaper machine, called '*Sakshat*' meaning 'before your eyes,' which can store learning materials for students.[45,46]

A phone number without a phone

Currently, those who cannot afford to buy a mobile handset must either share a phone with others or pay to use a public one. While making calls this way is workable, if a bit inconvenient, it does not allow the person to have a phone number, or 'identity' so that they can receive calls, voice and text messages, or remittances. The non-profit enterprise Movirtu has designed a platform called '*MXShare*', which can be installed in the core of a mobile network, and allows the operator to provide a service which they have named '*M-KADI*.' Through this service paper cards with individual fully functioning mobile numbers can be sold or given away, working much like a 'SIM-only' option but without the need to hold onto or transfer a SIM card between phones. This new model has the potential to allow millions of new users into the mobile network.[47,48]

Affordable computing

Another innovation involves changing the way in which computers are connected in internet cafés, school computer rooms or offices. 'Thin client' systems use very cheap 'dummy terminals' with only a keyboard, mouse, screen and remote desktop software. These are connected to a more powerful server which does all of the processing. This type of system is not only cheaper, but more energy efficient and less likely to break down.[42]

Combining technologies

Currently, user interfaces for communication such as radios, telephones and computers remain quite separate. The recent trend in integration of these technologies in developed countries has not, by and large, reached developing country markets.[41] However, as access expands and new technologies are created, a huge number of possibilities exist. Radio stations can use mobile phones and the internet to improve listener interaction and the quality of information available for broadcasts. Devices based on the technology used in *Blackberries*, or other smartphones, may be able to combine mobile phone, internet, radio and television interfaces to improve rural access to information. Some exciting new ideas have already emerged, such as software which allows users to surf the internet using voice commands on a mobile phone or another which enables messages to be sent via a mobile phone network on a computer without the use of the internet (Box 2.13).

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Figure 2.17 – Women refugees from Ghana speaking at a local radio station in Cote D'Ivoire

Box 2.13 Creating ICT hybrids

'An entirely new kind of web'

Figure 2.18 – Men texting in Kenya

A team from the IBM India Research Laboratory in New Delhi is now testing a completely new way of connecting to the internet – using voice commands spoken into mobile phones. They have created new software called *VoiceGen*, which allows users to create *VoiceSites* rather than websites, where they can enter information about their business or organisation through a series of prompts in the local language.

For example, a seller of agricultural products could create a *VoiceSite* which is then assigned a phone number, which acts as its URL. It can be accessed by customers using a voice controlled browser, which allows them to go back, forward and even to bookmark pages for later use. To make this possible, IBM developed a new type of transfer protocol, called hyperspeech transfer protocol (HSTP), to replace the text-version HTTP. This type of service will allow business owners who do not have the money for a storefront or advertising to get their information out to customers, and enable anyone to access information without needing to read or have access to a computer.[49]

Texting power

While the expansion of the mobile network and greater access to computers have been helpful to NGOs in developing countries, the non-profit kiwanja.net has gone a step further and designed a software package which allows users to combine the benefits of both. After downloading the free software, called *Frontline SMS*, a user can plug any mobile phone, or phones into the computer and send, receive and store text messages using the mobile networks to and from individuals or large groups.

This gives users great flexibility, enabling them to send messages where there is no internet, even while on the road using a laptop. It also avoids the use of outside servers, useful in places with strict internet controls. The software can be used to set up automatic replies to messages with keywords, such as the time of a scheduled vaccination clinic. NGO managers, doctors and researchers around the world have enthusiastically picked up this technology and used it to solve their communication challenges – from election monitoring, to communicating health and agricultural updates, to conducting surveys, to fundraising – the list is endless.[50]

The potential of nanotechnology

Nanotechnology involves the manipulation of matter at atomic and molecular levels, i.e. at a scale of a billionth of a metre, to produce a great variety of materials and devices. At this scale materials often have unique characteristics.

While the US is currently leading the way in nanoscience research, many emerging countries have also established strong programmes.

China currently ranks second to the US in the number of articles published on the subject in international peer-reviewed journals. Indian scientists are also big contributors, with India recently launching a five year, US $220 million national strategy for advancing nanoscience.[51]

Applications of nanotechnology may include: energy storage, production and conversion, disease diagnosis, drug delivery systems, air and water pollution detection and remediation, and food processing and storage. Most of these applications are being developed for wealthy countries, but many of them have applications in developing countries as well.

Water purification

One of the most promising applications for nanoscience is in the use of nanomembranes, nanosensors, and magnetic nanoparticles for water purification – allowing for desalination, detoxification, remediation and detection of contaminants and pathogens. Research is in the early stages and many of the products thus far are still too expensive for developing country applications, but the ability to immediately treat even very contaminated water to a high quality, at the source, without the use of electricity, heavy chemical dosages or high pressure makes it an area worth pursuing.[52]

Figure 2.19 – Children using the Seldon WaterBox in Rwanda

Scientists at Seldon Laboratories in the US have used carbon nanotubes to create a patented nanomesh™ material. The material works by attracting contaminants to its surface, and can be used to remove bacteria, viruses and pathogens as well as reduce lead, arsenic and uranium to US drinking water quality standards.

They currently have two products using this technology. The WaterBox (US$5,000) (Figure 2.19) is a durable and portable treatment system which can be either plugged in or used with a foot-pump, and is able to produce clean water at an average of about two litres per minute. For smaller-scale, individual treatment, the WaterStick (US$95), (Figure 2.20) can filter contaminated water as the user drinks, at a flow rate of up to 200 mls per minute. These products have already been used by aid workers in Uganda and Rwanda.[53]

Also working with carbon nanotubes, scientists at Banaras Hindu University, India, in a partnership with the Rensselaer Nanotechnology Center (US), have discovered how to create strong, reusable and heat resistant carbon nanotube filters by *spraying* the nanotube structure directly onto the carbon cylinders. The filters can be used to remove contaminants such as polio viruses and *E.coli* from water.[52-54]

Figure 2.20 – The Seldon WaterStick

Disease diagnostics

The diagnosis of disease can be a time-consuming process, often involving analysis of samples in a laboratory and the culturing of micro-organisms suspected of causing the disease. Advances in nano-science are making possible diagnosis of diseases at the point of care, without the need for laboratory analysis, thereby speeding up the time it takes to make a diagnosis and reducing costs. Rapid, inexpensive, point of care diagnosis is particularly important for new and emerging human, animal and plant diseases that pose risks of epidemics, and for reaching poor communities remote from medical and agricultural services and associated laboratories.

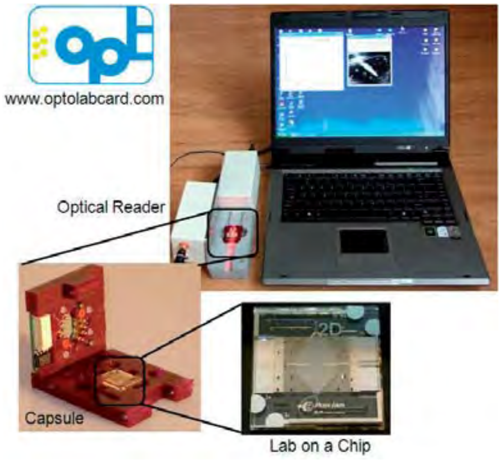

Figure 2.21 – The Optolab Card setup

Recent breakthroughs in diagnostics have been based on using biomarkers of disease-causing organisms. These may be characteristic chemicals produced by the pathogen, or its own DNA. Nano-surfaces are created with sensors that react with biomarker molecules and in so doing generate an electrical or visual signal that can be measured. These "labs on a chip" can be incorporated into handheld devices which can deliver a diagnosis in minutes after application of a sample such as saliva, blood or plant sap.[55,56]

For instance, the EU funded Optolab Card project is developing and mass producing a miniaturised optical laboratory on a card, allowing bacterially infectious diseases, such as *Salmonella*, to be diagnosed in just 15 minutes as opposed to the six to 48 hours for conventional tests.[57] And, the Central Scientific Instruments Organisation (CSIO) in Chandigarh, India is working to develop a nanotech based TB diagnostic kit which would measure only 1 cm^3 and can work more quickly, cost less (around rupees 30 per kit) and use less blood.[58]

Pharmaceutical efficiency

Nanotechnology can be used to improve the usability, effectiveness or efficiency of drugs. One example comes from the area of tuberculosis (TB) medication, where the current treatments are lengthy and difficult to remember – patients need to take their drugs every day for six to nine months. This is challenging even for those with good access to medical care, and failure to complete this full regimen can lead to complications and the emergence of drug-resistant strains (Box 2.4 and Chapter 6).

Dr Tumi Semete, a researcher at the Council for Scientific and Industrial Research (CSIR), in Cape Town, South Africa, has developed an idea which could greatly improve this situation. With funding from the Bill and Melinda Gates Foundation, she plans to use nano-size sticky 'balls' of conventional TB drugs, which have already been developed by scientists at CSIR, to improve the efficiency of treatment. Currently only about 20 % of the medicine taken gets to the infected tissue, while up to 80 % of it is excreted. With these nanoparticles, Dr Semete believes she can get the medicine to stick directly to infected cells, increasing efficiency to close to 100 %. The drug can also be released slowly, so that patients may not have to remember to take their pills daily.[59]

The utility of biotechnology

Biotechnology is defined as any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use.[60] Traditionally biotechnology has been associated with the centuries' old practice of fermentation, used in the making of bread, beer and spirits. Today's biotechnology is based on the revolution in cellular and molecular biology that occurred in the second half of the 20th century.[61] In particular, it exploits advances in understanding the DNA and RNA of an organism and their functions in order to identify and manipulate the genes that produce particular traits in animals and plants. Biotechnology has found applications across a range of fields (Box 2.14).

Biotechnology in agriculture

Modern plant breeding, derived from the discovery by Gregor Mendel of the particulate nature of inheritance, and developed over much of the last century, has transformed agricultural production. It was at the core of the Green Revolution (see Chapter 5). However, such plant breeding is often an uncertain and lengthy process: discovery of mutations with desirable properties is serendipitous, and incorporating only those traits into the crops we presently use involves many crop generations and hence years of careful breeding, often with limited success. A recent example of successful, conventional breeding is the development of "quality protein maize". A discovery in the 1960s of maize mutants with high levels of desirable amino acids started a breeding programme which, after several decades, has successfully incorporated these desirable traits into better maize varieties for developing countries.[63]

Biotechnology makes this process of incorporating beneficial traits more effective and rapid, through three practical techniques:

Box 2.14 Biotechnologies that can help developing countries meet the MDGs[62]

Hunger

- High yield crops
- Drought and disease resistant crops
- More nutritious crop and animal products

Health

- Microbicides against sexually transmitted diseases
- Recombinant vaccines
- Combinatorial chemistry for new medications
- Molecular diagnostics
- Pathogen genome sequencing
- Bioinformatics for identification of drug targets
- Improved drug delivery
- Vitamin enriched crops

Environment

- Bioremediation for organic waste and heavy metal treatment

- *Tissue culture* – which permits the growth of whole plants from a single cell or clump of cells in an artificial medium;
- *Marker-aided selection* – based on the ability to detect the presence of particular DNA sequences at specific locations in an organism and link these to the presence of genes responsible for particular traits;
- *Recombinant DNA* or genetic engineering technology – which enables the direct transfer of genes from one organism to another.

The first two technologies, in the hands of international and national agricultural research centres are already delivering improved staple crops to poor farmers.

Tissue culture

Tissue culture has produced new rices for Africa (discussed in Chapter 1) and has also produced new pest and disease free bananas in East Africa that can yield up to 50 tonnes/ha (Box 2.15). One of its desirable features is its ability to generate rapidly many copies of a plant with desirable traits, a kind of cloning. Another feature is the ability, through this process, of generating planting materials that are known to be free of disease.

Box 2.15 Healthy bananas through tissue culture

Bananas are a major source of food and income throughout the tropics, and especially in East Africa. Ugandans, for example, are the largest consumers of bananas in the world, eating on average nearly 1kg/person/day.[64] The banana tree is, however, very susceptible to disease, as new plants are grown directly from cuttings from a 'mother plant,' thus transferring any disease present, even if it is not visible.[65]

Figure 2.22 – Black Sigatoka disease on banana tree

The Black Sigatoka fungus, a leaf spot disease, has been particularly devastating to banana crops worldwide since its first outbreak in Fiji in 1963. It arrived in East Africa in the 1970s, delivering a major blow to farmers' yields, decreasing productivity by as much as 40%.The fungus can be controlled with fungicides. However the disease has developed increasing resistance over the years, making this option both expensive and damaging to the environment.

Farmers needed a way to break the chain of disease. Kenyan agricultural scientist Florence Wambugu, having studied plant pathology and biotechnology in both the US and the UK, made a move to bring the benefits of tissue culture to the problem. With tissue culture, a banana shoot is dissected into tiny pieces and placed in a sterile container, quickly generating healthy new plants which can be planted in the field.[66]

Figure 2.23 – Tissue cultured bananas in a village nursery, Uganda

After the end of apartheid in South Africa, Wambugu made a visit to the country to observe the previously closely guarded work on tissue culture bananas. She was enthused, and quickly pitched the idea to the Kenyan Agricultural Research Institute (KARI), where trials began on local varieties in the mid-1990s. The work was successful, and with funding from the Rockefeller Foundation, Wambugu moved to expand the programme, offering training and credit to farmers to get started.[67]

The results have been remarkable. Yields have increased from averages of ten tonnes/ha to 30-50 tonnes/ha, and the national banana production has more than doubled since 1995, from approximately 400,000 tonnes to over one million tonnes in 2004.[66]

Wambugu has since founded the group Africa Harvest to spread this technology and others to farmers in Kenya. They are now working on increasing the benefits to small-holder farmers through support and training in post-harvest handling, marketing and sales.[68]

Marker-aided selection

With marker-aided selection (MAS) it is possible to identify segments of the plant genome that are closely linked to the desired genes, so the presence of the trait can be determined at the seedling or even the seed stage. This makes it possible to achieve a new variety in four to six generations instead of ten (Box 2.16).

Box 2.16 Marker-aided selection delivers resistance to Maize Streak Virus

Maize streak virus (MSV) is the most serious disease of maize in Africa, affecting 60 % of the planted area and causing an estimated 37 % yield loss, or roughly 5.5 million tonnes/year losses in production.[69]

Excellent genetic resistance to MSV has been known for over 20 years, but it has not been widely deployed in local maize varieties because few national breeding programmes can afford to maintain the insect colonies and other infrastructure necessary to measure for resistance against insect-vectored viral diseases.

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Figure 2.24 – A plant with Maize streak virus

Now, using genetic markers on the molecular map of maize, it is possible to identify the precise location of the resistance gene, and using the DNA markers flanking the gene, to backcross it into numerous well-adapted local varieties without expensive disease screening.

MAS is being used to introduce quality-protein genes into maizes already grown in Africa. It is also particularly useful for breeding drought-tolerance, which typically occurs as the result of a number of different traits – deeper roots, early flowering, water diffusion properties – working together. Breeding for drought-tolerance is a difficult and slow process using conventional techniques, but markers are now permitting combinations of these traits to be accumulated in new varieties.

Recombinant DNA

Recombinant DNA crops, otherwise known as Genetically Modified (GM) crops are produced by first isolating and culturing a gene of potential usefulness. This is then inserted into the cell of a crop plant by a process of transformation (Box 2.17).

Box 2.17 Transforming a crop[65]

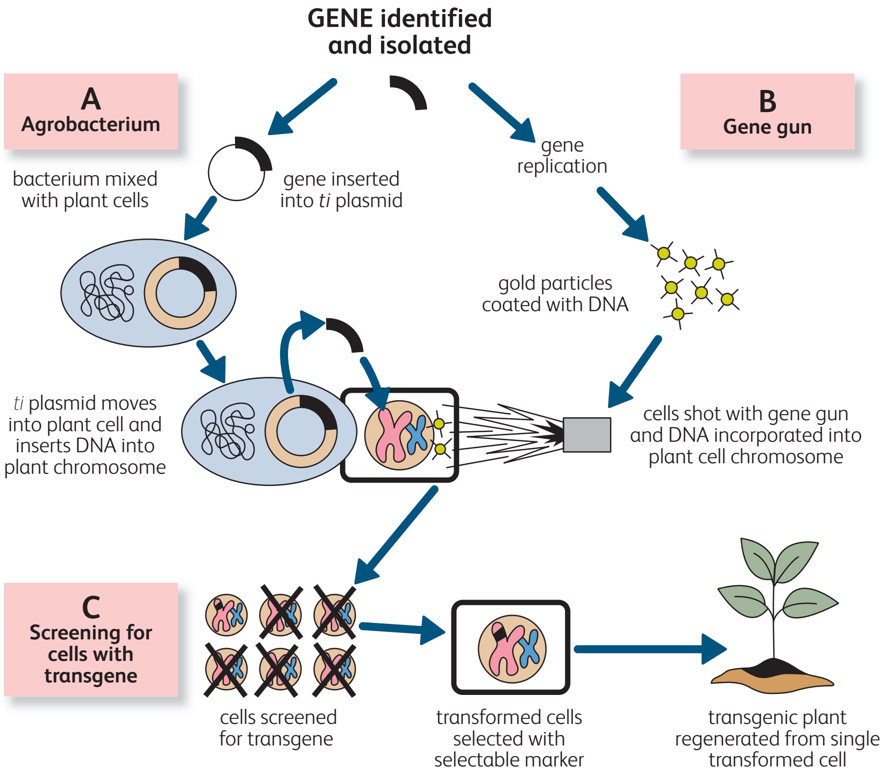


Figure 2.25 – Two processes of transformation in producing GM crops[70]

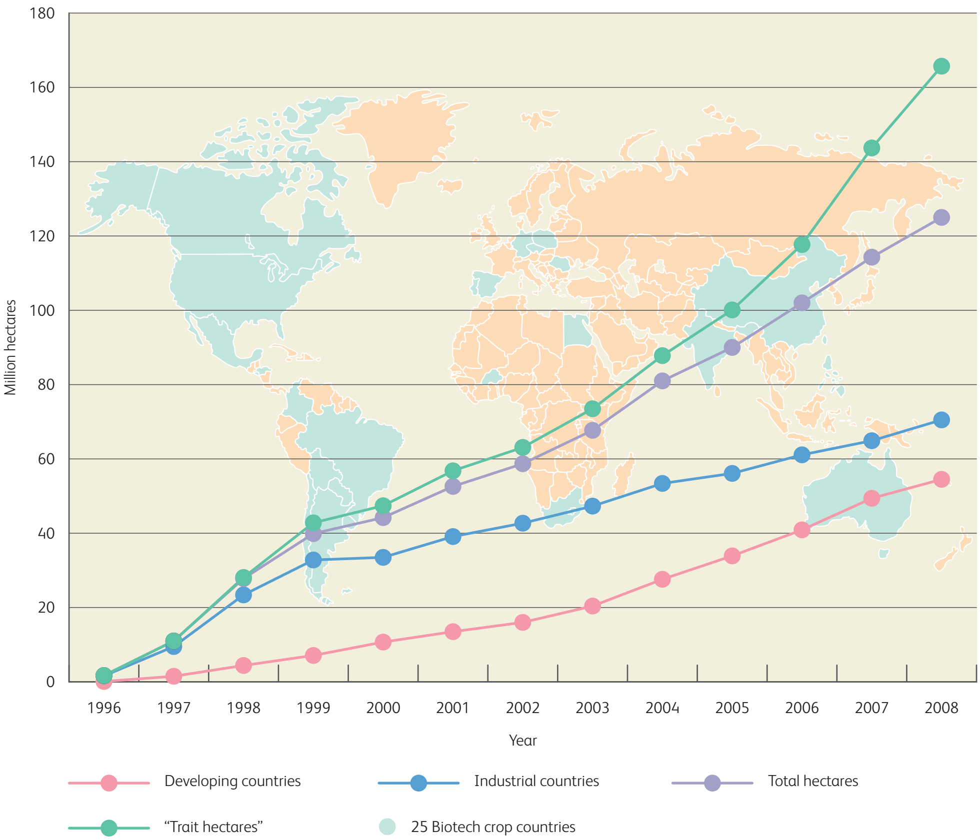
Once a crop cell has been produced by tissue culture it is transformed in one of two ways (Figure 2.25):

The first uses a naturally occurring bacterium *Agrobacterium tumefaciens* that infects some plants, causing Crown Gall disease for instance. It contains a small circular piece of DNA called a plasmid into which the cultured gene is inserted. The plasmid will then infect cells of certain plants transferring the gene to the DNA of the crop's cell.

The second involves coating gold particles with the gene of interest. The gold particles are then shot into single crop plant cells with a gene gun and in this way incorporated into the cell's DNA. It is not particularly efficient but can be used on crops that *Agrobacterium* cannot affect.

The transformed cells are then cultured and grown into whole plants which are tested in the greenhouse to ensure that the transferred gene, the transgene, functions properly. Not all transgenic plants will express the trait or gene product well. But once the trait is stable it can be bred using conventional plant breeding methods into cultivars with adaptation to the environmental conditions where the crop is produced.

Figure 2.26 – The Rapid Growth of GM crops *(note: a trait hectare is an area multiplied by the number of GM traits (stacked traits) present*[71]



An "apparent" increase of 9.4% or 10.7 million hectares (ha) between 2007 and 2008, equivalent to a "real" increase of 15% or 22 million "trait hectares"

GM crops are spreading rapidly in developing countries. About a third (some 34 million ha) of the total global GM hectarage is in developing countries, with some 7.7 million farmers putting the new technology to use (see Figure 2.26). China is a major investor in the science of GM. Several other countries, including some in Africa, are following suit.

The benefits of GM technology in developing countries so far have come principally from engineering several crops to express a bacterial gene which controls certain insect pests, thereby reducing the need for chemical pesticides, and from engineering herbicide-resistance into other crops to allow reduced, targeted use of safer herbicides. The total economic benefits for developing country farmers were estimated at US$22 billion between 1996 and 2007.[71] Bt cotton, in particular, has proved to be beneficial in a number of countries (Box 2.18).

What is now needed are crops that benefit a wider range of farmers, as well as consumers, in developing countries. We explore this topic further in Chapter 5.

Box 2.18 The benefits of Bt cotton for developing countries

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Figure 2.27 – Bt Cotton growing in a field

Cotton is a crop that suffers heavily from insect pest attack. Various species of bollworms, boll weevils, flies and mites cause significant damage to the crop, reducing yields and the quality of the cotton. As a consequence, cotton was until the early 1990s the target of 25 % of all the insecticides applied in the world.[72]

A gene contained in the naturally occurring bacterium *Bacillus thuringiensis* (Bt) codes for a toxin that is lethal to plant feeding bollworms (use of the bacterium is approved for organic farmers for pest control). It has proven very effective against such pests when transferred to a variety of crops through recombinant DNA engineering. Bt cotton was first developed in the US and introduced in 1996. It now accounts for 87 % of the crop there (28 % of world-wide production).[73]

It has been rapidly taken up in China, South Africa and most recently India and Burkina Faso. Over 12 million farmers, mostly in China and India, planted Bt cotton on 3.8 million and 7.6 million ha, respectively, in 2008.[71] China's adoption was driven by low seed cost, largely due to publicly developed Bt cotton varieties, and decentralised breeding that enabled the transfer of the Bt trait into locally adapted varieties. The dramatic take-off in India, from an initial 500,000 ha in 2004[71,74] has brought many farmers significant yield increases. Over 80 % of India's cotton is Bt and the country is now the world's second largest producer and exporter.

Although the benefits vary across years, institutional settings and agro-ecological zones, farm-level studies largely confirm higher profits from adoption of Bt cotton, and also document substantial environmental and health benefits through lower pesticide use,[75,76] with worldwide use of insecticides for cotton now down to about 18 %.[77] Table 2.1 below shows the benefits for a range of countries.

	Argentina	China	India	Mexico	South Africa
Added yield (%)	33	19	26	11	65
Added profit (%)	31	340	47	12	198
Reduced chemical sprays (number)	2.4	–	2.7	2.2	–
Reduced pest management costs (%)	47	67	73	77	58

Table 2.1 – The economic and environmental benefits of Bt cotton in developing countries[78]

Biotechnology in human and animal health

While much progress has been made in reducing the burden of disease through conventional technologies such as oral-rehydration therapy, improved water supply and traditional vaccines, there still remain many challenges. There are no conventional treatments that will cure AIDS patients, current TB regimens are lengthy and expensive, and resistance to malaria drugs is rising. The place to look for these new breakthroughs is biotechnology.[79]

Biotechnology for health, as for agriculture, takes a number of forms. For example, tissue culture has been instrumental in developing a vaccine against the cattle disease, Rinderpest, discussed in Chapter 5. Scientists can also use biotechnology to target critical molecular processes, thus making drug production more efficient and effective. The highly active anti-retroviral drugs used in treating HIV/AIDS are examples. Hundreds of new and improved medical diagnostic tests would not be possible without modern molecular biology.[80]

To date, however, the most striking successes in health biotechnology have been the development of pharmaceuticals through recombinant DNA (rDNA) technology. This technology allows scientists to isolate a gene of interest, incorporate it into a host cell such as *E.coli*, and replicate it to produce a large, reliable, pure source of new DNA. The first application of this technology was the production of recombinant insulin in 1982, which gave diabetic patients an alternative to insulin from animal sources (Box 2.19). Since then there has been a steady stream of products, and there are now over 200 in common use, and more than 400 in clinical trials.[80] The vaccines for hepatitis A and B are among the most important.

The industry has grown considerably over the last few decades, with US revenues alone rising from US$8 billion in 1992 to $58.8 billion in 2006.[80] But despite the enormous opportunity inherent in the technology for better, faster and cheaper drugs and vaccines, only a tiny proportion of the efforts in health biotechnology have focused on the specific diseases of the poor in the developing countries. This is slowly changing however, and as discussed further in Chapter 3, creative financing mechanisms, such as public-private partnerships like the Global Alliance for Vaccines and Immunization (GAVI), are drawing more resources to products for developing world diseases.

Current research is focused on new Highly Active Anti-Retroviral Therapies (HAARTs), microbicides and vaccines to combat HIV AIDS, as well as vaccines against malaria, TB and influenza, the details of which are explored further in Chapter 6.

Figure 2.28 – Biotechnology laboratory in Vietnam

Box 2.19 Making recombinant DNA insulin[81]

The production of rDNA insulin paved the way for recombinant DNA technology in the health arena, showing that genetically modified products could be made and used safely. It makes it possible to produce human insulin quickly and comparatively cheaply from bacteria in an industrial fermentation unit. The procedure is illustrated in figure 2.29.

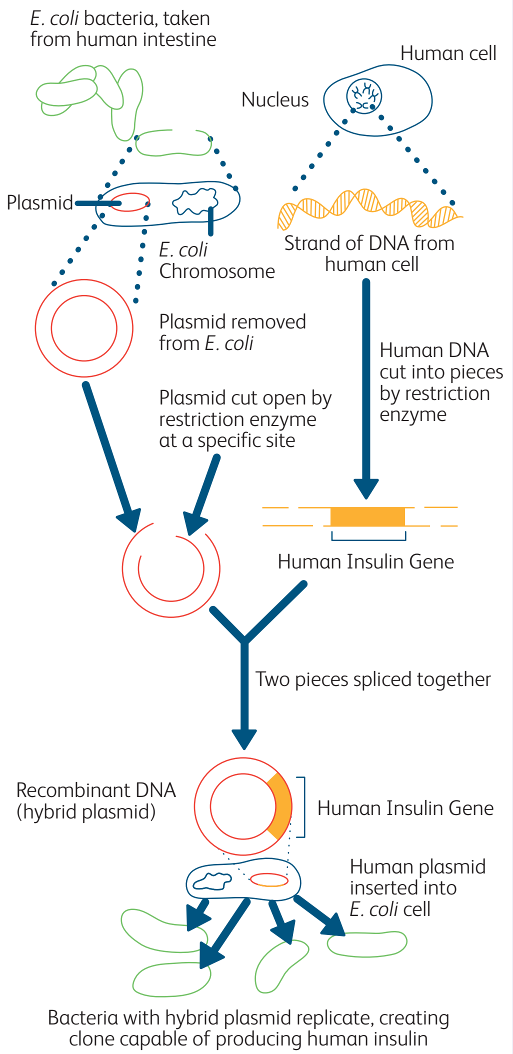

Figure 2.29 – Production of insulin by recombinant DNA[81]

Here we describe the basic process by which the human insulin gene is inserted into a bacterium. It is a relatively complicated process similar in some respects to the recombinant DNA process used in producing GM crops.

First, an insulin gene is identified and cultured. As in the GM process the piece of DNA (in this case human DNA) is cut out using a special bacterial enzyme known as a restriction endonuclease. Each restriction enzyme recognises and cuts at a different nucleotide sequence, so it is possible to be very precise about DNA cutting by selecting one of several hundred of these enzymes that cuts at the desired sequence.

Next, the human insulin gene is spliced into a plasmid, a circle of bacterial DNA in this case contained in an *E.coli* bacterium. This plasmid has been opened with another restriction enzyme. Attaching the cut ends together is done with a third enzyme (obtained from a virus), called DNA ligase. The result is a cut-and-pasted mixture of human and bacterial DNA.

The last step involves putting the new, hybrid plasmid containing the recombinant DNA back into the bacterium *E.coli*. Once cultured the bacterium is capable of expressing the human insulin gene and hence producing suitable insulin for the treatment of diabetes.

Risk and uncertainty with new platform technologies

By their very nature, the indirect effects of applying new platform technologies will often be unknown. Product registration and regulatory systems help to ensure that potential, unanticipated environmental and health risks associated with new technologies are identified and addressed before any technologies are licensed and deployed. However, countries may differ in their regulatory requirements and interpretation of risk, hence the difference between the US and European countries in regulation and decisions regarding the use of GM crops.

In developing countries, risks and uncertainties associated with new technologies will often be different than in industrialised countries where new platform technologies will probably be registered first. There may be a difference in the conditions under which the new technology may be deployed, for example, the efficacy and safety of a new medicine for a particular disease may be affected by local background levels of other diseases and treatments. There may also be differences in local capacity to address potential hazards. New technologies may require training or monitoring capacity which may not be locally available, and this could increase risks associated with the technology's use. This has been the case, for instance, in many parts of the developing world with the application of new chemical pesticides developed originally for industrialised countries, where lack of training in safe and appropriate use has, in some cases, led to local food contamination, poisonings and pesticide resistance.

National regulatory systems in developing countries are frequently under-resourced and challenged by the process of registering new platform technologies. Very often, they can make use of data from the registration of products in industrialised countries, but there always needs to be a capacity to relate this to local conditions, and this may require additional resources and expertise. Sometimes countries do not have the basic registration systems for new technologies. For instance, traditional pesticide regulatory systems in developing countries have had difficulty in evaluating and approving new, biological pesticides which have many local advantages. This is due to a lack of regulatory protocols for such products, in contrast to industrialised countries. As a result, in Africa, the donor agencies which funded the development of new biological pesticides to replace harmful chemicals for locust control, have also supported national regulatory programmes to develop new and regionally harmonised systems for biological pesticide registration.[82] Regional harmonisation of regulatory and registration systems may also help to accelerate registration and use of other new platform technologies, including new medicines.[83] Box 2.20 looks at the particular challenges in the nanotechnology field in gaining harmonised understanding of its risks and formulating regulation.

Box 2.20 Issues in regulating nanoparticles

Nanoparticles, or three dimensional materials in the range of one to 100 nanometres, occur naturally in the environment, yet it is only with recent technological advances that we have gained the ability to manipulate materials at this scale. With this has come a surge in research and development of new products, with applications ranging from improving solar panels to creating new types of antiperspirant.

However, as with any new technology, standardised safety testing and regulations are not yet in place, and policy makers are struggling to keep up with the pace of discovery.

While frameworks exist to evaluate novel materials, nano-materials are stretching these boundaries for a number of reasons. Particles at the nano-scale actually behave quite differently from those at a conventional or bulk scale, exhibiting properties that have not previously been observed in traditional chemistry or materials science.

One reason for this is that nanoparticles are more reactive due to their *higher surface area to volume ratio*. This leads to changes in surface reactivity and charge, making the quantum (atomic and subatomic) level behaviour of the particles significant, and many argue that new safety protocols are quite essential.

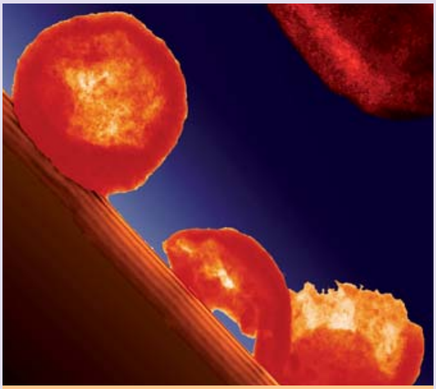

Figure 2.30 – Cadmium sulfide nanospheres during an experiment to test resistance to stress[84]

In addition, nanoparticles which exist in nature tend to clump together, and thus the behaviour of particles designed in the laboratory specifically to stay apart is largely unknown. And, while particles can be tested in the laboratory for safety, once released into the environment unpredictable, self-assembly of new structures could lead to unforeseen effects.

Therefore, while there is no evidence yet of harm, there is reason to be cautious. Studies have begun in both Europe and the US,[85-88] looking into the potential effects on human and animal health, and the environment. Many questions remain to be answered, including the persistence of particles in the environment, their behaviour when airborne or in the ground, or how they may behave inside the body.

Reports have called for greater coordination and a real need for vigilance, but most stress a flexible and adaptive governance regime which can be developed along with production, rather than halting innovation in this otherwise promising field.

Potential concerns regarding new platform technologies in development extend beyond technical issues of risk and the capacity to evaluate and regulate it. Inevitably, new technologies have the potential to create inequity and to disadvantage parts of society, particularly the poor. New information technologies may reduce or widen the digital divide, disadvantaging rural populations whose access to the internet may be less than city dwellers, and new agricultural and health nano- and bio-technologies will inevitably be more available and affordable to more wealthy parts of society. Therefore, use of these technologies in a development context must always consider how best to ensure that they benefit the poor and reduce, rather than increase, inequities.

In the future, development of new platform technologies should consider these developing country opportunities and issues from the outset, not as an afterthought. An example of such proactive effort has been the development in 2005 of a “Global Dialogue on Nanotechnology and the Poor: Opportunities and Risks” by the Meridian Institute, with support from DFID, the Rockefeller Foundation and IDRC. This has generated a rich dialogue in the international scientific community on the implications of nanotechnology for the poor and how these technologies can play an appropriate role in the development process.[89-91]

6. Conclusions

Science and technology for development today enjoys a broad range of sources of ideas, by virtue of the increasingly global nature of science innovation systems. But there remain enormous challenges in accessing these and integrating them into appropriate technologies. What unites the various examples in this chapter is that the source of a technology is not important as long as that technology is *appropriate*. Ultimately, the appropriateness of a technology in a developing country is demonstrated by how it is used, not by the intentions or the assertions of those who design and market it.

We also believe that in the rush to apply cutting edge science to development problems, we must avoid the tendency to ignore indigenous and local knowledge and innovation, and to use this to develop intermediate technologies. Secondly, in developing new platform technologies, we must move beyond the traditional model where initial applications are focused on wealthy countries and international development applications are a much-delayed afterthought. Developing country needs and opportunities must be incorporated from the outset in the development of new platform technologies, through involving developing country scientists and interests in global science innovation systems. Development agencies have played, and will continue to play, a crucial role in achieving this engagement.

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