Appendix 4

Biotechnology

I. DEVELOPMENT OF TRADITIONAL AND NEW BIOTECHNOLOGY

4.1 Biotechnology is a term capable of various interpretations, and covering a wide variety of techniques. But broadly it can be said to involve the use of the principles of microbiology, biochemistry, genetics and biochemical engineering to process materials by employing catalysts, such as enzymes, and micro-orgnisms, and animal and plant cells. By such means it is possible to produce and process food and beverages, produce pharmaceuticals and biochemicals, recover minerals and metals, purify water, and manage industrial and domestic wastes.[1] A crude but useful differentiation can be made between 'traditional' biotechnology and 'new' or 'high-tech' biotechnology.

4.2 'Traditional' biotechnology stretches back thousands of years. It includes the use of organisms in fermentation for making alcoholic drinks or foodstuffs such as cheese; developments in animal and plant breeding, such as artificial insemination of cattle and artificial propagation of fish; developments in the production of serum and vaccines; pasteurisation and sterilisation of foods; innoculation of seeds with rhizobium cultures to enhance legume yields; biological control of crop pests; and developments in antibiotics. Its fruits can be seen in the 'green revolution' which has occurred in parts of the Third World, particularly in Asia.

4.3 'New' biotechnology is usually restricted to practical applications of some of the most recent advances in chemistry, biology and genetics. It includes genetic and cellular manipulation; fermentation related to the large-scale growth of living organisms and the removal or extraction of resultant substances (for example microbes for producing fuel or feedstock); and enzyme production and reaction. But new biotechnology is more than the latest phase in a historical continuum. It is evolving so rapidly that discoveries often overwhelm even recent advances. It also has implications for a far wider range of economic and social activities than did past biotechnology innovation. For all countries, but especially developing countries, it provides new opportunities to alleviate food shortages, treat human and animal diseases, generate renewable sources of energy, and generally achieve higher rates of economic growth and improve the quality of life.

4.4 Modern biotechnology may be said to have originated from experiments in industrial and pharmaceutical fermentation extending from 1910 to 1940. These led to the large-scale production of basic chemicals (for example acetone, butanol and ethanol) and, during the Second World War, to penicillin. They were followed by other antibiotics, and later by the production of what had been rare substances such as steroids, enzymes and certain vitamins.[2]

4.5 Knowledge of genetics has expanded similarly. Efforts to improve the genetic characteristics of plants and animals, through screening and crossing different varieties, have become increasingly refined since Mendel's seminal work, but advances in scientific research over the past thirty years have revolutionised genetics. Since the discovery of the chemical structure of deoxyribonucleic acid (DNA)[3] in 1953, scientists have advanced their understanding of the molecule and have defined its relation to protein synthesis. In the 1970s further research into molecular biology resulted in the recognition that the living cell is a collection of hundreds of thousands of controlled chemical reactions. It also led to the development of major techniques in genetic engineering relating to recombinant DNA (rDNA) and cell-fusion technology. rDNA technology advanced significantly in 1973 when a DNA sequence (containing several genes) was transferred from a donor organism to a host organism where it was chemically spliced, or recombined, in the host's genetic structure. Such techniques enable scientists to engineer genes or introduce them from one organism to another in order to give the recipient its desired characteristics. In this way, it is possible to insert the genes for producing human growth hormones, insulin, or antiviral interferon into fast-growing bacteria for biological production.

4.6 Similar advances followed in cell fusion after 1975 when a cell which produced an antibody (but would not reproduce in tissue culture) was fused with another which grew well in the laboratory. The resultant hybrid cell (hybridoma) was able to multiply and give rise to identical cells (clones) which produced the required antibody (the monoclonal antibody or MCA). MCAs can be used to detect minute quantities of almost any substance, but so far their main use has been to detect antibodies which indicate the presence of disease, thereby enabling doctors to diagnose diseases much earlier than previously. In future, MCAs are likely also be used to detect pollutants in water and air, to transport anti-cancer medications to specific cancer sites and, in industry, to separate valuable substances from large quantities of reaction mixture in order to purify them.[4] Cell fusion is currently used in most plant bioengineering because of the lack of knowledge of the molecular base for gene expression in plants, but in the longer term gene transference is expected to become more important.

4.7 Developments in genetic engineering, particularly protein engineering (where genes are artificially cultured before insertion in the host), are leading to improvements in the production of enzymes for a wide range of uses as catalysts in industry or in pharmaceutical production. This has been made possible by the ability of the enzyme-producing bacteria to reorganise themselves in many ways and reproduce on a large scale through fermentation techniques.

4.8 Table 4.1 overleaf summarises some of the more important developments in the commercialisation of new biotechnology over the past decade. It should, however, be stressed that full-scale commercial application of many of the latest innovations is a long way off, and the continued importance of advances in traditional biotechnology should not be underestimated.

II. BIOTECHNOLOGY APPLICATIONS

4.9 The areas of application of biotechnology are wide: not only can new and improved species and hybrids of plants and animals be developed, but substances which are valuable, rare, or do not occur in nature, can be synthesized on a large scale. Moreover, some of the products of genetic engineering (for example enzymes and bacteria with special properties) can, in turn, lead to more efficient techniques in processing food, pharmaceuticals, chemicals, etc. These may require less energy, fewer production stages or lower priority in material inputs. Tables 4.2 to 4.4 (pages 53–56) summarise existing and potential applications, worldwide.

4.10 From the viewpoint of developing countries, biotechnology may make one of its most vital contributions in food and agriculture. According to the FAO, 55 developing countries, with more than a billion people, are no longer able to feed themselves at acceptable levels of nutrition: in Africa alone some 225 million people are undernourished and a score of countries are facing acute food shortages;

Table 4.1

Major Recent Events in the Commercialisation of Biotechnology

1973	First gene cloned.
1974	First expression of a gene cloned from a different species in bacteria. Recombinant DNA (rDNA) experiments first discussed in a public forum (Gordon Conference).
1975	US guidelines for rDNA research outlined (Asilomar Conference). First hybridoma created.
1976	First firm to exploit rDNA technology founded in the United States (Genentech). Genetic Manipulation Advisory Group started in the United Kingdom.
1980	Diamond vs. Chakrabarty: US Supreme Court rules that micro-organisms can be patented under existing law. Cohen/Boyer patent issued on the technique for constructing rDNA.
	United Kingdom sets targets for biotechnology (Spinks' report). Federal Republic of Germany does likewise (Leistungsplan). Initial public offering by Genentech sets Wall Street record for fastest price increase per share ($35 to $89 in 20 minutes).
1981	First monoclonal antibody diagnostic kits approved for use in the United States. First automated gene synthesizer marketed. Japan and France set targets for biotechnology. Industrial Biotechnology Association founded. Over 80 new biotechnology firms established by end of year.
1982	First rDNA animal vaccine (for colibacillosis) approved for use in Europe. First rDNA pharmaceutical product (human insulin) approved for use in the United States and the United Kingdom.
1983	First plant gene expressed in a plant of a different species. $600 million raised in US public markets by new biotechnology firms.

Source: US Congress (1984).

Table 4.2

Implementation of Genetic Engineering Procedures: Some Market Predictions

Product category	*Number of compounds*	*Current market value ($ million)*	*Selected compound or use*	*Time needed to implement genetic production (years)*
Amino acids	9	1,703	Glutamate	5
			Tryptophan	5
Vitamins	6	667.7	Vitamin C	10
			Vitamin E	15
Enzymes	11	217.7	Pepsin	5
Steroid hormones	6	367.8	Cortisone	10
Peptide hormones	9	268.7	Human growth hormone	5
			Insulin	5
Viral antigens	9	n.a.	Foot-and-mouth disease virus	5
			Influenza viruses	10
Short peptides	2	4.4	Aspartame	5
Miscellaneous proteins	2	300	Interferon	5
Antibiotics	4*	4,240	Penicillins	10
			Erythromycins	10
Pesticides	2*	100	Microbial	5
			Aromatics	10
Methane	1	12,732	Methane	10
Aliphatics (other than methane)	24	2,737.5	Ethanol	5
			Ethylene glycol	5
			Propylene glycol	10
			Isobutylene	10
Aromatics	10	1,250.9	Aspirin	5
			Phenol	10
Inorganics	2	2,681	Hydrogen	15
			Ammonia	15
Mineral leaching	5	n.a.	Uranium	
			Cobalt	
			Iron	
Biodegradation	n.a.	n.a.	Removal of organic phosphates	

n.a. Not available.
* Figure indicates classes of compounds rather than number of compounds.
Source: Bull et al (1982).

Table 4.3

Biotechnology Uses and Products and Some Market Forecasts

Sector		*Products*	*Estimated Market ($mn)*	*Time-scale*
Chemicals:	organic (bulk)	Ethanol, acetone, butanol, organic acids (citric, itaconic), amino acids	Bulk chemicals/synfuels; 3,600 by 1990 (amino acids only)	Outlook depends on long-term oil price prospects. Could become attractive by end of century
	organic (fine)	Enzymes	Uncertain: dependent on economics of alternative non-biotech methods of enzyme production	Long-term view necessary
		Perfumeries	Uncertain	
		Polymers (including polysaccharides)	Plastics, uncertain	Unlikely to become viable before end of century
	inorganic	Metal beneficiation, bioaccumulation and leaching (Cu, U)	Minerals and oil together estimated at 4,500 by end of century	Interesting but speculative area, dependent on economics of mineral and oil extraction
Pharmaceuticals		Antibiotics, enzyme inhibitors, steroids, vaccines	Drugs; 8,000 by early 1990s, increasing thereafter according to new developments	Only few products on market to date. Upfront costs and regulatory delays make this a long-term if vast field
		Diagnostic agents (enzymes, antibodies)	2,000 including non-radioactive kits and monoclonal RIA kits	Already on market. Could reach full potential by 1990. Best short-term return
Energy		Ethanol (gasohol), methane (biogas), biomass	Uncertain	Outlook depends on long-term oil price. Could become attractive by end of century

Food	Dairy, fish and meat products; beverages (alcohol, tea and coffee); bakers' yeast; food additives (antioxidants, colours, flavours, stabilisers); novel foods; mushroom production; starch products; glucose and high fructose syrups; functional modifications of protein; pectins; toxin removal; amino acids; vitamins	Food and drink; impossible to quantify	Human food likely to encounter consumer resistance. Fair medium-term potential for animal feedstuffs
Agriculture	Animal feedstuffs; ensilage and composting processes; microbial pesticides; rhizobium and other N-fixing bacterial innoculants; mycorrhizal innoculants; plant cell and tissue culture (vegetative propagation, embryo production, genetic improvement)	Impossible to quantify	Attractive medium-term area with worldwide potential once scientific problems overcome
	Veterinary vaccines and products	2,000 by 1990	Good short-term potential due to less stringent regulations. Market growth depends on farming economies
Service industries	Water purification; effluent treatment; waste management	Biotech applications could reach 2,000 by 1990. Increased environmental concern would help	Already in use in some areas. Medium/long-term view
	Analytical tools	Biotech equipment and supplies currently estimated at 200 per year; growth very rapid	Good short-term 'back door' method of gaining profits from biotechnology
	Oil recovery	(See inorganic chemicals above)	

Source: Bull et al (1982) and Elkington (1983).

Table 4.4

Value of Applied Genetics and New Biotechnologies in Various Market Segments in the United States

Market segment	*1982 ($mn)*	*1985e ($mn)*	*1990f ($mn)*	*Average annual increase, 1981-90 (%)*
Diagnostics	6.0	45.0	2,525.0	95.6
Vaccines/antigens	0.0	25.0	1,000.0	259
Pharmaceuticals	20.0	380.0	7,180.0	92
Chemicals	1.0	10.0	270.0	86
Plant agriculture	0.1	0.5	2.5	43
Animal agriculture	8.0	59.0	433.0	5.8
Processed foods (incl. alcoholic drinks, sweeteners, bread, dairy, etc.)	22.5	199.5	1,847.5	63
Misc. applications (mining, waste treatment, etc.)	1.5	13.5	120.0	63
Total	59.1	732.5	13,378.0	82.6

e Estimates. *f* Forecast.
Source: Elkington (1983).

some are experiencing famine. Moreover, the population of developing countries is expected to increase some two-and-a-half times by the year 2025, with a tripling in Africa where resources are currently under greatest stress.

4.11 Traditional biotechnology plays an important role in food production in the developing countries—in conventional plant breeding and animal husbandry and in food processing using conventional fermentation processes (for example bread, beer, cheese). However, new fermentation products, such as polysaccharides (bio-engineered sugar substitutes) and mycro-protein (based on a micro-fungus which can upgrade most carbohydrates to protein), are unlikely to have early application in developing countries, although their production in the developed countries could adversely affect developing countries' exports.

4.12 On the other hand, genetic engineering and certain other new biotechnology processes are already beginning to be used, albeit to a limited extent, in agricultural practices in developing countries. Their potential impact on agricultural output in the longer term is vast. As indicated above, rDNA can change the genetic characteristics of plants to increase their productivity or enhance their nutritional or other values. And cell manipulation can vastly increase the number of uniform plants available, or widen the range of genetic material from which desirable genes may be extracted to enhance the hereditary characteristics of plants. A few examples of many recent developments include a high-protein rice which has been developed in China by introducing soya proteins into rice plants; the high-yielding CICA 8 rice developed in Latin America, which is more nitrogen efficient, requires less weeding and can be grown with reduced irrigation requirements; and a high-protein 'sunbean' developed in the United States by introducing the genes of sunflowers into french beans. In Malaysia, cell and tissue culture techniques have been used to clone oil palms and vastly increase yields of oil and kernels in a project estimated to have cost Unilever some £1.5 million and Malaysia about $M10 million. Field trials of clonal oil palms are now taking place in a number of other developing countries (Brazil, Cameroon, Colombia, Indonesia, Papua New Guinea and Zaire)[5].

4.13 Geneticists and biologists are striving to engineer other desirable characteristics in plants to increase yields. For example, by making plants more hardy to extend their growing season or geographical range; by reducing their growth cycle to permit more harvests per year; by increasing their density; by strengthening their resistance to disease and adverse weather; and by increasing the size of the product and the ratio of edible matter to waste.[6] In addition, since the two major increases in petroleum prices during the 1970s, there has been an increased need to develop nitrogen-fixing organisms to raise soil fertility and lessen the need for chemical fertilizers. Genetic engineering may assist in this respect by making it possible to develop more crops which, like certain legumes, can fix atmospheric nitrogen.

4.14 There are also applications of biotechnology for producing animal feed which differ from that for human food, in that the degree of conversion in the basic materials need not be so great, and safety and preservation legislation tend to be less stringent. The production of a single-cell protein as a feed additive has already been tried in Britain, but there are also several low-technology processes of significance to developing countries, for example solid-state fermentation of straw (composting) under non-sterile conditions using selected fungi to produce an enhanced protein feed equivalent to hay.

4.15 Genetic engineering is likely to make a considerable contribution to animal husbandry. It can do so through the development of animal vaccines and antibiotics to control disease; through the supply of growth promoters or hormones; and through the improvement of genetic composition in order to enhance size, vigour, resistance to disease and efficiency in converting animal feed to animal protein, and to control the sex of offspring.

4.16 Biotechnology for therapeutic uses in medical and veterinary care is likely to become increasingly important for developing countries over the medium term. Genetic engineering offers the opportunity for large-scale and economic manufacture of many drugs and vaccines, which because of their modest cost could be widely distributed among these countries and improve their inhabitants' general health. As already mentioned, rDNA techniques are already beginning to produce much needed proteins, such as human growth hormones, insulin and interferon, and they are expected to lead to the production of vaccines against other viral diseases in humans and animals (including herpes, influenza and certain tropical diseases). MCAs are being used to enhance the ability of doctors and veterinarians to diagnose disease and monitor biological functions (such as reproduction) more readily. In the longer term, it is hoped to treat genetic diseases by the manufacture of proteins (which because of defective chromosomes cannot be produced in the patients' cells) in recombinant clones which can be administered to patients, or by the insertion of functioning genes into the patients' genetic material to restore functions.

4.17 Another major area of application of biotechnology is in the production of alternative sources of energy. This is dealt with more fully in Appendix 6; here it is enough to point out that traditional and new biotechnology can assist in a number of energy-related areas of particular interest to developing countries. For example, biotechnology can contribute to the large-scale production of ethanol (from sugars and starches) or methane and methanol (from wood or ligno-cellulosic material) to provide alternative fuels or chemical feedstocks. It can also contribute to increasing supplies of biomass (for example through cloning plants from prolific and fast-growing varieties of tree species) and improving its conversion into energy, a vital matter in view of the large proportion of the populations of developing countries who continue to rely on biomass for domestic fuel. Improved petroleum recovery techniques using micro-organisms or microbial products, together with new methods of converting waste material into energy and energy-related products, can further contribute to the energy available to developing countries.

4.18 In the longer term, biotechnology is likely to make a positive impact on pollution control and waste recycling in general. Sewage and other municipal wastes already pose serious pollution and health problems in many developing countries, and the issue of recycling will increase in significance with the growing need to conserve natural resources and to tackle industrial pollution. There are a variety of approaches to the utilisation of wastes, and the range of potential substrates is wide: from agriculture (straw, bagasse, maize cobs, bean and nut hulls, oil-seed pressing wastes, bran, fruit skins and pulp, and animal manure); from forestry (wood wastes, liquor, bark, sawdust, paper and fibre waste); and from industry (sugar, meat and other food wastes from processing and canning, and distillery wastes). It is expected that microbial techniques will eventually assist in both water purification and waste reprocessing, where processed waste can be used as building materials, fertilizers or animal feedstuffs, as well as for the fuels and chemicals mentioned in the previous paragraph.

III. BIOTECHNOLOGY RESEARCH AND DEVELOPMENT

4.19 Government support for biotechnology R & D has been vital in the initial stages of this high-risk activity. In the developed countries it has taken the form of full or partial funding of the scientific research programmes of universities and specialised institutions such as agricultural research centres, as well as of industrial enterprises, for whom governments have on occasions also made available resources for the commercialisation of R & D results. Table 4.5 shows the public funding of biotechnology R & D in 1982.

Table 4.5

Public Funds for Biotechnology R & D, 1982

	Biotechnology R & D £mn	*Biotechnology-relevant R & D £mn*
Germany (FR)	21	75
France	18	48
United Kingdom	26	34
Italy	7	20
Netherlands	6	15
Belgium	5	8
United States	135	360
Japan	35	n.a.

Source: New Scientist, 9 February 1984.

4.20 Few developing countries are in a position to provide government funds for R & D in biotechnology although the more technologically advanced among them do so. For example, in India some Rs 250 million (around $25 million) is expected to be spent each year on biotechnology R & D, out of a total annual research budget of Rs 7,500 million ($750 million), during the current five year plan.[7]

4.21 In the developed countries, private enterprises and numerous foundations are also financing programmes for biotechnology innovation and commercialisation, and at a scale many times that provided by public sector support. The firms involved comprise both small-scale enterprises engaged in R & D and consultancy (examples include Genentech and Biogen in the USA and Celltech in the UK), which are largely financed by venture capital; and large-scale transnational corporations (TNCs) primarily engaged in pharmaceuticals, petroleum, food and beverages, which have developed strong links with university researchers and small-scale firms, as well as having their own biotechnology R & D, manufacturing and marketing units. The industry has been particularly dynamic in the United States, where over 100 biotechnology companies were established between 1976 and 1983 and R & D expenditure has been almost twice that of Western Europe and Japan combined.[8]

4.22 In the United States, pharmaceuticals biotechnology R & D can be said to play a role broadly analogous to that of the military in the development of microelectronics. The sectoral distribution of US biotechnology R & D has been estimated as follows (percentages): pharmaceuticals 62; speciality chemicals and food 20; commodity chemicals and energy 15; environment 11; and electronics 0.3[9]. Comparable data are not available for other countries, but pharmaceuticals appear to have been dominant in many of them, and the number of companies in the healthcare sector has risen markedly (see Table 4.6). Some countries, however, have specialised in different areas, for example Japan in fermentation technology and the United Kingdom in plant science.

Table 4.6

Biotechnology Organisations in Healthcare*

Region	*Academic institutions*	*Corporations*	*Specialist companies*	*Total*
Europe & Israel	162	106	32	300
USA, Canada & Mexico	137	111	146	394
Japan, other Asia & Australia	51	83	2	136
Total	350	300	180	830

* 1982 data for 27 countries.
Source: Elkington (1983).

IV. BIOTECHNOLOGY AND DEVELOPING COUNTRIES: IMPACTS AND ISSUES

4.23 Although there are few indications as yet on how developments in biotechnology are likely to affect developing countries, there is little doubt that they will be extensive and far-reaching. There will be direct impacts on producers in agriculture and other industries, and indirect ones through international trade; in both cases there will be effects on employment and on the pattern of income distribution.

4.24 The effects on agriculture are likely to be crucial, although it is difficult to draw parallels with the experiences of the green revolution. In the first place, the expensive inputs of fertilizers, pesticides, fungicides and irrigation needed to support the production of high-yielding varieties (HYVs) are unlikely to be required on the same scale. The advantages of the gene revolution are expected to come from developing high-yielding plants which will have in-built resistance to drought, insects, disease, etc. Moreover, the HYVs developed during the green revolution concentrated on wheat and other cereals appropriate to parts of Asia and Latin America but not, in the main, to Africa. Grains such as sorghum and millet, and pulses and rootcrops, so important to Africa, were much less affected. However, the new biotechnology presents opportunities to develop a wider variety of crops. Whether those of interest, say, to subsistence farmers in Africa, will be markedly improved depends to some extent on who undertakes the R & D and hence who controls the technology. While the work of international institutes such as the International Maize and Wheat Improvement Centre (CIMMYT) in Mexico and the International Rice Research Institute (IRRI) in the Philippines, and of regional and national institutes will continue to be important, it is the TNCs who control most of the technological developments taking place at present.

4.25 The question of who controls the new biotechnology may be critical. The green revolution was mainly the product of public sector research, and the resultant products and processes were generally widely diffused. The control by TNCs of the 'gene revolution' has a number of implications for developing countries. Three are especially important—access to technology, the location of production and the development of substitutes—and could result in the displacement of agricultural exports from developing countries, with marked effects on their balance of payments, income and employment.

4.26 Since most of the new products will probably continue to originate from TNCs, the technology gap between developed and developing countries may widen. The problem of access to biotechnology is likely to be exacerbated by two elements: the existence of property rights; and the increasing cooperation between industry and academic institutions, which is resulting in secrecy to protect commercial interests and an absence of dissemination of R & D results.

4.27 Although publicly-funded international and regional research institutes are seeking to develop crops of importance to developing countries, their resources are comparatively small. According to one estimate[10], the top 50 companies in the United States have invested more than $1 billion in biotechnology R & D. By comparison, the annual research budget of the International Centre on Genetic Engineering and Biotechnology (ICGEB), on which many developing countries are pinning their hopes, is $9 million.

4.28 While developments in new biotechnology will offer many positive opportunities for developing countries, there are negative effects. Biotechnology makes it possible to grow in temperate climates—outdoors as well as in the laboratory—products which hitherto have been grown only in the tropics. For example, it has been estimated that increasing the temperature tolerance of a tomato plant by 1°C could lead to a trebling of outdoor production of tomatoes in Britain. Of even greater significance is the fact that improvements in plant tissue culture could provide viable alternative to plantations for producing rare or specially valuable substances (for example drugs, perfumes, spices) and at the same time enable the development of alternatives to certain existing plantation crops (for example cocoa and sugar-cane: one plant under investigation is reputedly 200 times sweeter than cane-sugar). The impact on developing countries' agricultural exports, income and employment could be significant, since their exports of medicinal plants alone were valued at $500 million in 1983.

4.29 The increasing shift to laboratory-farming, whether in developed or developing countries, will have considerable labour-displacing effects, since tissue culture factories will not depend on agricultural raw materials that are produced under labour-intensive conditions.

4.30 On the other hand, the potential for increases in multiple cropping is likely to lead to greater demand for labour in developing countries; it will also cause changes in demand for particular types of land, in ownership patterns and in income distribution. Although the last is largely a product of existing patterns of economic and social organisation (notably systems of land tenure, access to credit and marketing outlets), it is probable that the effects on agricultural employment of what might be called the second green revolution will be similar to that of the first, where, despite considerable local variations, there was evidence that larger land-owners benefited at the expense both of smaller ones and of tenant farmers, with an increase in the employment of hired labour and a decrease in that of family labour.

4.31 Whether the application of new biotechnology will have any significant effect on farm-size is difficult to judge. Although the technology itself is not scale-biased, its indirect effects may well have an impact on farm-size through such factors as ease of access to new biotechnology products and processes and initial price of the technology. According to the US Office of Technology Assesssment, new technologies (of all kinds) are accelerating the creation of large industrialised farm-production units at the expense of small family-farms in the United States mainly because the innovations are costly and complex to implement.

4.32 Besides these economic effects, some of the social and environmental effects of new biotechnology should be considered. They include the need to evaluate, control and conserve the resources of developing countries. Already commercial requirements are leading to the removal of 10 million hectares of forest a year in tropical Asia, Africa and Latin America. This has serious implications not only for the preservation of the environment and the eco-system, but also for genetic balance. Developing countries are estimated to possess at least 70 per cent of the world's genetic material (germ plasm) needed for selecting useful breeding characteristics through new biotechnology techniques. Adequate steps have not yet been taken to control the exploitation of these resources, and gene banks urgently need to be established to enable these countries to maintain their genetic variability. An International Board for Plant Genetic Resources (IBPGR) has been established in Rome,[11] but it might be useful for countries possessing similar environments, or growing common crops, to cooperate in collecting and evaluating particular germ plasm resources.

4.33 Biotechnology offers considerable potential for collaboration between developed and developing countries, although the latter will have to be vigilant in guarding not only against possible over-exploitation of their genetic resources but also against being used as a testing ground for new biotechnology products of uncertain safety. The OECD Report on Biotechnology[12] emphasized that all countries should have regulations concerned both with health and safety and with protection of the environment. Unification of standards for safe laboratory practice and procedures (an issue being examined by the Scientific Panel of Experts at the ICGEB in New Delhi) should be encouraged internationally.

4.34 Some advances in human genetics have raised ethical questions relating to the manipulation of the human embryo and the insertion of human genes into other species. These questions have to be reconciled with the religious and cultural views of individual countries. But there are other ethical questions related to commercial practices, such as the possibilities for companies to distort breeding programmes in order to satisfy commercial objectives. For example, since clonally-propagated crops are currently many times more susceptible to disease and pests than are their seed-bred counterparts, agro-chemical companies are in a good position to profit from the confluence of plant protection products and plant-breeding research. Some observers fear that private industry could use its ability to manipulate genes in order to sell more chemicals.[13]

V. CONCLUSION

4.35 Over the next decade or so, it is expected that developing countries will continue to benefit more from traditional than from new biotechnology, especially in the production of food and chemicals through conventional fermentation processes, and in plant breeding and animal husbandry.[14] But in the longer term, the potential applications of new biotechnology are such that it can make a very real contribution to Third World development. For it to do so, however, will require developing countries to understand better its techniques for solving specific problems and to become more aware of available sources for its applications. Both require expertise and other skills.

4.36 At present the major constraint faced in this respect by developing countries is a lack of trained personnel. It has been suggested[15] that these countries should try to establish, on a national or regional basis, core technical groups comprised of some 9 to 14 researchers and technicians specialising in organic chemistry, biochemistry, immunology, microbiology, engineering, and electronics. A lack of up-to-date laboratory facilities and equipment is a related constraint. On the other hand, the direct costs of biotechnology R & D are often not particularly high or constraining.

4.37 An immediate requirement for developing countries in the area of biotechnology is to analyse their national needs and establish priorities according to their own resource endowments. This would allow them to concentrate on those areas where new biotechnology applications could be most productive. In deciding priorities, the determining factors could be, for example, import substitution; optimal use of raw material and other feedstock for biotechnology products; alternative uses of raw materials for which export demand is diminishing; manufacture of biotechnology products which would solve pressing national problems (such as endemic diseases and pests, malnutrition, pollutants). Such exercises should assess not only the reliability of raw material supplies for biotechnology processes, but also the markets for the resultant products.

4.38 Many of the institutions in developing countries are capable of adapting to those areas of biotechnology (genetic engineering, enzyme engineering and fermentation technology) required to develop applications in particular sectors of agriculture and industry. But most of them have yet to develop a sufficiently close relationship with industry to ensure their R & D is based on real needs. In some cases a more adequate coordinating mechanism may be needed.

4.39 To ensure the effective future utilisation of biotechnology, developing countries will need not only to strengthen their national capability but also to enhance international institutions (ICGEB, IBPGR and other research centres). Finally, but crucially, they will need to increase their bargaining strength vis-a-vis TNCs. A detailed knowledge of the potentials of new biotechnology and an appreciation of their own genetic resources will be essential in this regard.

NOTES*

1. Based on Bull et al. (1982).
2. UNIDO, *The Promise of Biotechnology and Genetic Engineering for Africa;* UNIDO, IS. 513, p. 2.
3. For definition see Glossary (Volume I, Appendix 1). Laboratory techniques now exist for making synthetic DNA molecules, and scientists are able to cut and splice those molecules in order to introduce them into other cells to provide the genetic characteristics desired.
4. UNIDO, op. cit., p. 3.
5. Elkington (1983).
6. Narang (1981).
7. *Commerce* (India), 22 October 1983.
8. Annual expenditure on biotechnology R & D is estimated at around $2 billion in the United States and $1.25 billion in Western Europe and Japan.
9. U.S. Office of Technology Assessment (1984) p. 7. (The fact that the sum of the items exceeds 100 per cent presumably reflects some element of double counting.)

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* In those cases where only abbreviated references are given here to works cited, complete references will be found in Appendix 10, Selected Bibliography.

10. F. H. Buttel et al., 'From Green Revolution to Biorevolution: Some Observations on the Changing Technological Basis of Economic Transformation in the Third World'; *Cornell Rural Sociology Bulletin*, No. 2, August 1983.
11. Its aim is to promote the collection, documentation, evaluation, conservation and utilisation of genetic resources of important species, especially in those areas where the spread of new varieties may put traditional ones in danger of extinction, and to support training in aspects of genetic resource work.
12. Bull et al., op. cit.
13. Dembo et al. (1985).
14. Borlaug, for example, concluded that 'since it is doubtful that significant production benefits will soon be forthcoming from the use of genetic engineering techniques with higher plants, most research funds in crop improvement should continue to be allocated for conventional plant breeding'. (N. Borlaug, 'Contributions of Conventional Plant Breeding to Food Production'; *Science,* Vol. 219, No. 4585).
15. See *Exchange of Views with Experts on the Implications of Advances in Genetic Engineering for Developing Countries,* UNIDO IS. 259 (1981).