CHAPTER VI

BIOTECHNOLOGY AND THE THIRD WORLD

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This paper seeks to present briefly major developments in biotechnology. It outlines areas in new and traditional or conventional biotechnology which appear to be of greatest relevance and feasibility or are likely to have much impact on developing countries, and focuses on some aspects which should receive the attention of these countries.

Definitions and Developments

Biotechnology is multidisciplinary in nature and its full potential is yet to be realised. There is no universally accepted definition of the subject and at this stage of its development this is not surprising. As a result of rapid developments in this expanding field and the interest they have created, governments, organisations and individuals have given diverse definitions of biotechnology (Appendix I,page 400). Some definitions exclude medical technology, agriculture and traditional crop breeding, but the two most commonly used are of wider scope, viz: (i) "the application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services" (OECD study by Bull *et al*, 1982); and (ii) "Biotechnology, broadly defined, includes any technique that uses living organisms (or parts of organisms) to develop micro-organisms for specific uses" (OTA report, anon., 1984).

As the focus of this paper is on the relevance of biotechnology to the Third World, and because some aspects of traditional or conventional biotechnology will continue to be of great importance for the economic and social development of these countries, this type of biotechnology is included in a working definition of the term, although it is separated from the 'new' biotechnology which the author calls 'high-tech biotechnology'.

Traditional or conventional biotechnology includes those technologies involved in the development of: fermentation for alcoholic drinks and for foods (numerous examples exist of commonly used and sometimes highly nutritious foods, in both industrial and developing countries); plant and animal breeding (since the classic work of Mendel at the end of the 19th century); sera and vaccines; pasteurisation and sterilization of foods (including the more recent long shelf-life foods and irradiated foods yet to be cleared for human consumption) since the discoveries of Louis Pasteur in the later half of the 19th century; artificial insemination of cattle; artificial propagation of fish by induced spawning through stripping, hormone injection (hypophysation) of pituitary extracts derived from fish, mammalian and synthetic sources (developed in India and China in the late 1950s for carp but now used for tilapia, catfish, trout, mullet, shrimps etc); inoculation with Rhizobium cultures to enhance legume yields (first applied in 1895 in Germany and in 1924 in UK); biological control of crop pests; use of algae as fertiliser; antibiotics (since Fleming's work of 1929 on penicillin); biogas, etc.

The 'new' or high-tech biotechnology is a term usually restricted to practical applications of recent advances in protein and nucleic acid chemistry, molecular genetics and recombinant DNA technology. It is, in fact, the most recent phase in a historical continuum of the use of biological organisms for practical purposes. Developments arising from these new technologies are spawning others which can make even the potentially most useful current technology obsolete in a short time. The OTA report has thus emphasised that any definition of biotechnology will involve an assessment of developments at a particular point in time.

The preceeding paragraphs have given some milestones in the development of traditional biotechnology. The series of dynamic recent advances, of far reaching consequences, in high-tech biotechnology can be ascribed to the discovery of the chemical structure of DNA by Watson and Crick in 1953. The most important developments in the commercialisation of biotechnology which have taken place in the last decade are given in Table 1 (page 371). Rapid advances are continuing: the fact that the 1984 Nobel Prize for Science was awarded to Neils Jerne, Georges Koehler and Cesar Millstein for their work on monoclonal antibodies illustrates this point.

Areas of Potential Application

Bull *et al* (1982) have summarised present applications of biotechnology in various sectors (Appendix II, page 402) and given examples of applications of genetic manipulation (Appendix III, page 403). Notes on major applications are given below (source: Commonwealth Mycological Institute *et al*), though what follows is not an exhaustive list.

(a) Food and agriculture

A wide area, encompassing traditional and modern fermentation technology, viz., brewing, fermented solid and liquid foods, new products such as polysaccharides and protein-enhanced foods, and enzyme engineering used for the catalysis of specific chemical reactions to produce a range of products including amino-acids and high fructose syrups. Both fermentation and enzyme engineering processes have much wider applications than foods, such as the production of antibiotics and drugs. The creation of single cell proteins using widely available substrates (usually petrochemicals such as gas oil and methane) and micro-organisms (especially *Fusarium*) has aroused much interest for the production of both human food and animal feed, although the immediate

Table 1

MAJOR EVENTS IN THE COMMERCIALIZATION 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	U.S. 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 (U.K.) started in the United Kingdom.
1980	Diamond v. Chakrabarty - U.S. Supreme Court rules that micro-organisms can be patented under existing law. Cohen/Boyer patent issued on the technique for the construction of rDNA. United Kingdom targets biotechnology (Spinks' report). Federal Republic of Germany targets biotechnology (Leistungsplan). Initial public offering by Genentech sets Wall Street record for fastest price per share increase ($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 targets biotechnology (Ministry of International Trade and Technology declares 1981 "The Year of Biotechnology"). France targets biotechnology (Pelissolo report). Hoescht/Massachusetts General Hospital agreement. Initial public offering by Cetus sets Wall Street record for the largest amount of money raised in an initial public offering ($125 million). Industrial Biotechnology Association founded. DuPont commits $120 million for life sciences R&D. Over 80 NBFs had been formed by the end of the 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. First R&D limited partnership formed for the funding of clinical trials.
1983	First plant gene expressed in a plant of a different species. £500 million raised in U.S. Public markets by NBFs.

Source: Office of Technology Assessment, U.S.A.

economic viability of such processes is open to question and may depend on future waste treatment legislation.

Biotechnology has a direct involvement in crop production. The energy crisis stimulated the development of nitrogen-fixing organisms, especially Rhizobium strains, to increase soil fertility and lessen the need for chemical fertilisers. It also opened the possibility of using genetic engineering to develop crop plants which produce their own nitrogen.

Another area of development concerns the control of crop pests using biological agents, mainly the use of micro-organisms and predatory insects against insect pests. Suitable organisms, perhaps in future genetically engineered and produced in commercial quantities, will give a more efficient and selective alternative to pesticides. High-yielding or disease resistant qualities may also be built into crops by genetic engineering techniques.

Technology for producing animal feed differs from that for human food, in that the degree of conversion of the starting materials need not be so great, and the legislation regarding safety, testing and preservation tends to be less stringent. Many low-tech processes have significance here. One example is the solid state fermentation of straw (composting) under non sterile conditions using selected fungi to produce an up-graded feed equivalent to hay. This has been used in a pilot factory in Canada but the economics of using the process on a large-scale is still uncertain. The substrate used in such conversions is often considered as waste.

(b) Waste recycling and pollution control

This has a long history, which is now taking on greater significance as the need to conserve resources grows. The range of potential substrates is wide, as they can come from:

agriculture - plant stems (straw), bagasse, maize cobs, bean and nut hulls, fruit peelings, oilseed pressing wastes, bran, fruit pulp, animal feedlot wastes;

forestry - wood waste, sulphite pulp liquor, bark, sawdust, paper and fibre waste;

industry - food wastes (olive, potato, citrus fruits, cassava, palm oil,waste waters (dairies, canneries), meat and fish effluents and wastes, whey), distillery wastes, molasses and other wastes from sugar refineries; and

sewage and municipal garbage - some of which pose serious pollution and health problems, giving an extra incentive to usefully process them.

The detoxification of chemical wastes and spills is another area which has aroused interest, although applications are not well developed. Much interest has centred upon the use of micro-organisms in cleaning oil spills, both in marine and terrestrial environments.

There are various approaches for the utilisation of such wastes:

selective direct use, e.g. for fuel, building materials, extraction of further useful chemicals;

biogas (methane) - production for use as fuel now extensive in many parts of India and China;

feeding - to animals, especially ruminants, whose multiple stomachs can deal with very high fibre contents. Processing the waste may render it suitable for use by animals such as fish, pigs or poultry; and

<u>upgrading</u> - for use as human food.

(c) Alternative energy sources

The production of cheap liquid and gaseous fuels is a goal which has already stimulated the development of a wide range of methods. Ethanol production as an alternative to petroleum spirit (e.g. from sugar cane in Brazil, oil palm in Malaysia, and molasses in India), and methane (biogas) production from animal wastes are examples. Other chemical fuels are possible using substrates such as milk solids, sugars and cellulose from food processing and agriculture, using specially developed organisms.

(d) Chemicals

Some products are traditional and supplies may be enhanced by consideration of locally available alternative products, e.g. industrial ethanol from molasses (used on a large scale in India for synthetic rubber production), acetic acid, butanol and acetone (especially in countries short of petroleum); alternatively they may be protected by consumer safety or legislative considerations, e.g. beers, wines, vinegar and citric acid.

New processes have grown up, e.g. amino acids and nucleotides (especially in Japan). Microbial polysaccharide production is another growth area.

As genetic engineering develops, the field of chemical production is expected to expand greatly.

(e) Medical and veterinary care

Many important therapeutic agents are produced by biotechnology. The best known are the antibiotics produced from fungi. New processes include the production of insulin and interferon, the latter having potential importance in the treatment of viral diseases and perhaps cancers. Vaccine production, now assisted by the use of monoclonal antibodies, is another example of the application of biotechnology to the medical and veterinary field.

Economic and Social Aspects of Biotechnology

As a result of the rapid technological advances and the actions being taken by governments, universities, research institutions and commercial companies, biotechnology is having increasingly significant economic, social and environmental impacts. As an indication of this trend, Elkington (1983) identified 830 organisations involved in biotechnology in the health field alone. Their geographical and institutional breakdown is given in Table 2 below.

Table 2

BIOTECHNOLOGY ORGANISATIONS IN HEALTH-CARE

(source: IMS World)

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

* Sample of 27 countries.

From: Elkington, J.,"Biotechnology and Employment: The Integration of Traditional Economic Activities"; Case Study prepared for the ILO, October, 1983.

Some aspects of these impacts and their implications for the Third World are briefly examined below.

Economic aspects

(a) Investment

On a national level in countries developing biotechnology, there is usually initial government help, both in funding and in coordination. The level and type of support varies, as is evident from the following (source: CMI and others):

Australia - interest on a wide front, including high-tech areas. A review for the CSIRO was prepared in 1981;
West Germany - has a central biotechnology institute and a high level of government support;
USA - has tended to attract a higher level of venture capital than other countries. The U.S. Department of Agriculture has a £2 million programme to develop plants for use as feedstock for ethanol production;
France - works via government agencies, particularly in the fields of energy and feedstuff production and waste treatment;
Japan - active support of research directly by government and also within major companies;
Brazil - has a large fuel alcohol production programme;
UK - increasing support in a variety of ways. £10 million governmental funding of projects via British Technology Group;
India - has set up National Biotechnology Board which oversees developments and sponsors and coordinates R & D in biotechnology. Research is also carried out by CSIR's Institute of Industrial Microbiology and in relevant national institutes (e.g. Indian Agricultural Research Institute, Central Food Technological Research Institute, Biotechnology Centres in National Dairy Research Institute and Indian Veterinary Research Institute, etc); and
Malaysia - had spent some M$10 million by mid-1983 on clonal oil

palm R & D and recently succeeded in producing motor spirit from oil palm.

Precise figures of investment in biotechnology are not available. According to Fishlock (1984), the US companies are spending some \$2 billion (about \$500 million by 'new biotechnology firms' and \$1,500 million by older established companies); Japan appears to be the next largest investor, though it was only in 1980 that it started to invest on a large scale in response to what was seen as a threat to its pharmaceutical industry; in Western Europe, Switzerland seems to be the leader.

The incentive to invest in biotechnology can be judged from the fact that a new chemical pesticide could cost £12 million to develop and would need a £30 million annual market to recoup that investment, whereas a bioagent might be developed for £400,000 and could make a profit from £600,000 annual sales. This is besides the technical superiority of bioagents over chemical pesticides, there being no known problems of environment or of pests developing resistance (Fishlock, 1984).

Even so, the levels of investment required for R & D in biotechnology are not at present within the means of most developing countries, although the more industrially advanced among them could take up selected products requiring comparatively small investment and for which they had the required 'raw material'. Table 3 (page 378) categorises biotechnology products according to technological and investment levels.

Table 3

BIOTECHNOLOGY: BASED ON TECHNOLOGICAL AND INVESTMENT LEVELS

Category	Products
High level: High capital investment; sophisticated plant and processes often requiring strict containment; high maintenance costs; high operator skills.	High value-added products and products destined for health care and human food and food additives. Large-scale continuous processes.
Intermediate level: Moderate capital investment and less complex operations	Fermented foods and beverages. Animal feedstuffs. Biofertilizers and pesticides. Crude enzymes. Waste management processes which entail sophisticated operation and control.
Low level: Small capital investment and scale of operation; simple and usually indigenous equipment; labour-intensive operations; open septic systems; village level technology.	Low level products frequently related to alleviation of pollution, sanitation, fuel and food provision. Extensive use of naturally adopted mixed fermentations. Biogas; microbial protein from agricultural and food wastes; traditional fermented foods and beverages; mushroom production.

From: Bull et al, Biotechnology: International Trends and Perspectives; OECD Paris, 1982.

(b) Production

Statistics of production of biotechnology-related industries in selected OECD countries as percentages of their GDP are given in Table 4 (page 379). Similar information for other countries was not available. But the importance of biotechnology in developing countries can be illustrated with an example from

Table 4

STATISTICS FOR BIOTECHNOLOGICALLY-RELATED INDUSTRIES

Some Comparative Production Statistics (1978)

Country	Food[a]	Chemical Products[b]	Drugs Medicines[c]
	Production value as % of GDP		
France	10.5	12.8	n.a.
Germany	7.4	15.1	1.1
Japan	8.9	14.9	1.4
New Zealand[d]	15.5	6.0	0.3
Norway	13.2	8.8	0.2
Sweden	7.9	7.1	0.5
United Kingdom	9.8	14.8	1.0
U.S.A.[d]	9.1	13.6	0.8

a) b) c) According to ISIC classifications 311/2, 3500 and 3522 respectively.

d) Data for 1977

Source: OECD

From: Bull et al, Biotechnology: International Trends and Perspectives, OECD, Paris, 1982.

Brazil, which by 1985 was expecting to produce 10.7 billion litres of alcohol (ethanol) and 250,000 cars with engines designed to use ethanol.

Far reaching changes in input:output ratios and in product quality can result from high-tech biotechnology. For example, ICI's single cell protein animal feed supplement, 'Pruteen', is produced from natural gas, via methanol, and exploits a resource which is often wastefully flared over the world's oilfields; ICI sees the technology's advantages as including its complete independence of the weather and the fact that it requires only 100 hectares to produce one million tonnes of 'Pruteen' compared with two million hectares to produce soya bean meal of the equivalent protein. By the end of 1982, about 50,000 tonnes of Pruteen had been sold to manufacturers of livestock feed in several countries and 120 million animals of various species had been successfully fed on 'Pruteen'-containing diets. ICI was extending its 'Pruteen' programme by entering into collaborative ventures in the USSR, OAPEC and other countries. One product similar to 'Pruteen' is Phillips Petroleum's 'Provesteen', which uses yeast and may be able to exploit a wider range of feedstock like ethanol, methanol, glucose, sucrose and agricultural and forestry wastes, which are important for poorly endowed countries (Elkington, 1983). Another example is clonal oil palm: Unifield produced 100,000 plants in 1983 and had a target of one million plants a year. In the early 1980s, clonal plantlets cost £2.50, compared with perhaps some 14p for oil palms grown from seed, but the rapid improvements in cloning technology and the considerably boosted yields from clonal palms suggest that the new technology should soon become competitive.

Biotechnology is also entering the human food sector. One category of products of high-tech biotechnology important in the food industry are enzymes. The world market for industrial enzymes, which includes those used in the food sector, was put in

1981 at around 65,000 tonnes valued at $400 million, with likely growth to 75,000 tonnes and $600 million by 1985. The most famous enzymes in the food sector are the sweeteners such as fructose (aspartame) which is chemically synthesised from the amino acid asparatric acid and phenylalamine and manufactured bio-synthetically via fermentation. It is 200 times sweeter than sugar and safer than the artificial sweeteners saccharine and cyclamates which were found to cause cancer in animals in laboratory tests. Nevertheless, aspartame still has some problems for people suffering from an inherited inability to metabolise the amino acid and is alleged to be capable of causing mental disorders (though the product has been cleared by the UK health authorities).

Another category are biotechnology products which are of direct use in human food. One example is mycoprotein, a microfungus of the mushroom and truffle genus, which has been grown by the British company RHM under vigorously controlled conditions in a continuous fermentation process upgrading carbohydrates into high quality protein; RHM is using glucose syrup made from starch feedstock, a variety of indigenous carbohydrates like corn, rice, cassava, molasses and many residue wastes of the food industry. Mycoprotein is a natural organism unmodified by genetic engineering - a step the food industry is reluctant to take; its thread-like shape confers valuable textural properties for making simulated foods, including some resembling meats such as chicken and veal; it is the equivalent of milk protein, low in fat and sodium, high in fibre and with no cholesterol - all the factors demanded by the modern nutritional establishment (Fishlock, 1984 and Elkington, 1983). RHM's Director of Research informed the author that mycoprotein was comparatively expensive and the immediate market would be in the more affluent societies. The product was formally cleared by the UK Government in 1980 as safe for human consumption. When production costs have been markedly reduced, one can see considerable potential uses for the product in some Third World countries facing acute malnutrition and protein deficiency and at the same time having abundant, even surplus, supplies of starch.

A second example is of a product which has been developed by Bio-Isolates (of Swansea, Wales) from the whey effluent of creameries. This otherwise goes to waste and poses disposal problems (South Caernarvon Creameries typically produces some 20 - 22 million litres of whey a year). The process involves a hydrophilic ion exchange technique for isolating the protein in commercial quantities; the product, which is a powder, contains 97 per cent protein, 3 per cent minerals and mere traces of fats and lactose (Elkington, 1983).

(c) Employment

It is too early to assess the employment effects of high-tech biotechnology in developing countries; however, it can safely be asserted that its direct adoption or use of its products should not result in any significant loss of employment in developing countries. Indeed the experience of introducing the high yielding varieties (HYV) and the accompanying agricultural mechanisation which resulted in the 'green revolution' of the mid-sixties disproved earlier fears that it would cause unemployment. In the Indian Punjab, where the HYV programme has been a major success, the higher production has resulted in greater labour absorptive capacity in the primary, secondary and tertiary sectors: the Punjab is now importing manual labour from other states of India.

Watanabe (1984) and Elkington (1983) studied several aspects of biotechnology as it related to employment. Watanabe's study on the employment implications for Africa was almost entirely focused on the achievements of traditional biotechnology, mainly plant breeding. It cited two interesting examples: (i) the replacement of bananas by oil palms in Costa Rica,which caused unemployment till such time that the oil palm expansion had created sufficient new employment in the secondary and teritiary sectors; and (ii) the genetic improvements resulting in the shifting of native crops of Africa to other countries, e.g. oil palm (a native of West Africa) from Nigeria to Malaysia. Elkington studied the employment implications of traditional oil palm versus clonal oil palm, and found that Unilever employs 3,200 people in the plantations (13,000 hectares) and 40-50 people in the processing mills. More significant for employment has been the use of the weevil Elaeidobius Kamerunicus to replace manual pollination of oil palm. The workers thus freed were redeployed around the plantations and though the labour intake was affected, that should only be temporary as the 30 per cent increase in the oil yield per hectare of clonal plantation than of uncloned one should result in additional employment. Overall, there seems to be no cause to fear for employment as a result of the introduction of biotechnology in the Third World. In fact, when the present agricultural,forestry and industrial wastes are exploited to produce a variety of goods of higher value and multi-use, the use of biotechnology should create new employment.

The developing countries pursuing biotechnology will create a new demand for semi-skilled and highly professional people, qualified and trained in various disciplines such as biochemistry, chemistry, microbiology, engineering (chemical and other branches), genetics, immunology, human and animal nutrition, food technology, physiology etc. Therefore, the developing countries deciding to enter into high-tech biotechnology will first need to assess their human resources and, if they are to acquire self-sufficiency, take up well designed, pre-planned programmes of human resource development.

(d) Trade

Market forecasts for some biotechnology products, their value in various sectors, and their contribution to trade have been studied by Bull et al (1982) and Elkington (1983). Appendix IV (page 405) gives some biotechnology market forecasts, Appendix V (page 407) some market predictions for genetic engineering products, and Appendix VI (page 409) some estimates of the value of applied genetics and new biotechnologies in various sectors of the US market. Information on trade in biotechnology products is not available and even that on medicinal and pharmaceutical products is confined mostly to OECD countries.

It is thus impossible to assess the impact of biotechnology on the trade of Third World countries. However, the implications of some possible future developments can be foreseen. The proteins successfully developed for additives to cattle feed could in the long run affect the exports of concentrated cattle feed such as oil cakes, rice bran etc. from the developing countries. New sweeteners have already reduced, and might in the long run almost eliminate, the demand for sugar exported by developing countries. Likewise, synthetic rubber, which has already replaced natural rubber in many industries, might complete the process. There are doubtless other examples and there will be more, perhaps of products which are major sources of foreign exchange earnings. However, the countries concerned need not be adversely affected provided they foresee and plan for such eventualities. In fact, the diminishing foreign demand for these traditional items could be the development which causes the countries to pursue more advantageous alternatives. For example, oil cakes and rice bran could be used to build indigenous livestock and dairy industries (in India the poultry industry has been affected by rice bran exports); the rubber plantations could be gradually replaced by more remunerative oil palm, as in Malaysia. And to maintain foreign exchange earnings the affected countries could produce for export products from a few selected lines of high-tech biotechnology, which would use as feedstock the countries' most abundant industrial or agricultural wastes or raw materials.

Social aspects

Recent advances in biotechnology have raised some questions in regard to health, security, ethics and the environment. These issues are all the more important for the Third World because the industrialised societies which have developed the use of high-tech biotechnology are well aware of the implications and have been taking the necessary precautionary measures.

(a) Health

Antibiotics (a word first used by Waksman in 1945) produced from fungi have played an important and growing role in the treatment of human and animal diseases since the 1940s. The applications of high-tech biotechnology to pharmaceuticals, i.e. in relation to human and animal health, are being pursued at present through the production of proteins such as insulin, interferon and human serum albumin; antibiotics; MAB diagnostics; and vaccines for viral, bacterial and parasitic diseases. Interferon is particularly promising and has already shown potential for the treatment of viral diseases and possibly cancer. As more is learned about hormone growth factors, immune regulators and neurological peptides, their efficacy in the treatment of disease may increase dramatically.

Another important area in which high-tech biotechnology has shown promise is early diagnosis of diseases through specific tests. At present the physician is handicapped by having no specific tests for many human conditions from hepatitis B to AIDS, and for others like cancers, there is in many cases no easy way to early detection. Therefore, many new biotechnology firms have included diagnostics in their corporate plans. Much has already been achieved with monoclonal antibodies in pregnancy tests, predicting human ovulation, animal breeding, and identification of plant viruses (Fishlock, 1984).

(b) Security

In the early 1970s, when the technology of genetic manipulation was acquired and it became known that it was capable of creating new forms of life, a widespread apprehension was expressed by the public, as well as by some scientists, towards genetic engineering. Successful cloning of foreign genes in the bacterium Escherichia coli, which inhabits the alimentary tract and sometimes infects the kidneys and urinary tract, initially caused much apprehension regarding safety risks. However, subsequent developments, together with the precautionary and regulatory measures taken, have allayed much of that apprehension, and presently there seems no justification for alarm in regard to genetic engineering unless the technology is allowed to make inroads into human genetics (in ways different from artificial insemination and embryo transplants etc., which are of proven value, though about which religious and ethical views differ).

On the other hand, the pathogenic micro-organisms, in contrast to the conjectural hazards of rDNA technology, do present real risks. Surprisingly these did not cause so much concern regarding handling in new biotechnological processes.

In sum, public safety must be of prime concern in designing and operating technologies and handling the various agents, including organisms, employed in them. The OECD report (Bull et al, 1982) emphasized that all countries should have regulations concerned, on the one hand, with health and safety at work, and on the other, with protection of the public and the environment. Unification of standards for good laboratory practice and manufacturing procedures should be encouraged internationally. At a time when humanity is very concerned at the hazards of atomic weaponry, international controls at the early stages of biotechnology, especially genetic engineering, become all the more necessary as a safeguard against the production and stockpiling of the lethal biological weapons of war.

(c) Ethics

Some ethical aspects of biotechnology have already been touched in the foregoing. In the Symposium on Genetic Engineering of Plants, held in 1983 in Davis, California, an interesting ethical question was raised on the commercialisation of biotechnology (Simmonds, 1983). The trend towards the involvement of industrial conglomerate companies in plant breeding and related areas of biotechnology, including genetic engineering, was clear in the USA and likely to extend to other industrialised countries. The extension of plant breeding to private companies should in general be welcomed. However, care was required against certain hazards of private industrial involvement, e.g. the distortion of breeding objectives to satisfy other commercial objectives such as sales of agro-chemicals.

Similar questions of commercial ethics arise in promoting sales of biotechnology products by transnationals and other commercial companies, especially in the Third World. It is well known that products whose use has been banned in the countries of origin, continue to be consigned to the developing countries. Prominent among them are pesticides and, despite the strong stand taken by the WHO, baby foods, together with multivites and various tonic preparations of doubtful benefit which have no market in the industrialised countries. It is also common knowledge that many drugs, especially antibiotics, have long been sold by transnationals in poor countries at prices which bear no relation to their manufacturing cost and are higher than those charged in the (industrialised) countries of their manufacture. Some regulatory measures are necessary against such unethical commercial practices. Third World countries, moreover, should not be allowed to become the testing ground for new products of doubtful safety. As the application of biotechnology expands, new ethical issues will doubtless arise. These will need constant vigil by governments and public bodies.

(d) Environment

The applications of biotechnology which have environmental implications include mineral leaching and metal concentration, production of degradable plastics, treatment of sewage and municipal garbage, control of pollution, degradation of toxic waste, and enhanced recovery of oil. Such applications may take longer to reach the market for large scale usage. However, regulations and safeguards will be necessary because these applications use micro-organisms that are deliberately released into the environment. There may also be risk of disturbing the balance of nature or the eco-system in certain cases and care will have to be taken to avoid such an eventuality.

Biotechnology in Developing Countries: the Potential and Some Policy Issues

The applications of biotechnology have opened new potentials for developing countries in their quest to alleviate food shortages, to supplement energy supplies, to treat human and animal diseases, to produce a wider range of goods and services, and thus generally to achieve higher economic growth and an improved quality of life. The potential is such that developing countries cannot afford to be second or third in certain aspects of biotechnology (Hartley, 1984).

Traditional biotechnology

This will continue to be crucial for the Third World (as for the industrialised countries), especially for those countries which have not yet fully benefited from the developments in plant and livestock breeding, in the use of *Rhizobium* cultures for enhancing legume yields, in techniques for post harvest loss reduction, biogas and ethanol production, etc. The same is true for other technologies of proven value, e.g. tissue culture used to produce virus-free seed potatoes since the early 1950s (Vasudeva and Azad, 1950) but subsequently much further developed and refined (Simmonds, 1983), and the artificial propagation of fish, whose benefits are yet to reach many developing countries.

According to the FAO, by the early 1980s 55 countries in the Third World, with more than a billion inhabitants, were no longer able to feed themselves adequately using traditional methods of agriculture; in almost two-thirds of these countries, livestock was lost because of disease and inadequate management techniques; some 225 million people were under-fed in Africa alone, where 22 countries were facing acute food shortages and in some cases famine; the destruction of the environment was continuing inexorably and the deserts were spreading in Africa and elsewhere. To meet these major problems, the traditional biotechnology has much to offer.

The high-yielding varieties programmes introduced in the mid 1960s ushered in the 'green revolution' in many parts of the developing world, especially South and South-east Asia. For instance, in India food production increased from about 52 million tonnes in 1950 to 152 million tonnes in 1983-84, and milk production went up from 17.4 million litres in 1951 to 32.9 million litres in 1982; this was achieved through breeding as well as by better management practices, and led to improved nutrition and health.

The continuing importance of traditional biotechnology has been emphasised by many writers. For example, Borlaug (1983) asserted that "since it is doubtful that significant production benefits will soon be forthcoming from the use of genetic engineering techniques with higher plants, especially polyploid species, most research funds in crop improvement should continue to be allocated for conventional plant breeding". Similar sentiments were expressed by the Rockefeller Conference on Genetic Engineering for Crop Improvement (Anon., 1981).

What is needed in Africa is the adaptation of dry-land farming techniques and drought resistant crop varieties to local conditions, an intensification of the search for new varieties, more emphasis on agro-forestry, the exploitation of all possible irrigation resources, the organisation of location-specific R&D and the development of the necessary infrastructure and management techniques for agriculture. Many traditional crops of great importance to Africa, the Caribbean and the South Pacific islands have been receiving too little attention by research scientists and extension workers. This has been true of cassava, aroids, sweet potato, cooking bananas, grain legumes (except for a few species such as pigeon pea), drought resistant crops like finger millet (*Eleusine corracana*), and traditional foods such as pandanus, taro, and bread fruit.

Another area needing attention is the improvement of existing biotechnologies used extensively in developing countries for fermentation, brewing etc. in order to raise the quantity and quality of output. For instance, fermentation processes are widely used in Africa for producing alcoholic beverages (palm wine, *pito* from sorghum and maize, *buro kuto* beer from sorghum and *gari*) and non-alcoholic fermented foods, e.g., *gari* from cassava, *ogi* from maize and millets, vinegar, and soy-ogi - an infant weaning complete protein food recently developed in Nigeria (Ekundayo, 1980). It is highly desirable that the fermentation processes for making these products are improved.

Conservation of genetic resources

Some estimates suggest that tree formations are being lost at the rate of 11 million hectares every year. For every 10 hectares of forest lost, barely one hectare is being replanted in tropical America, Africa and Asia. This has serious implications, not only for the integrity of the environment and the eco-system but also for the preservation of genetic variability, especially when it is recalled that the variety of flora and fauna is much greater in the tropics than elsewhere. Some estimates indicate that so far only one in six tropical plants and animals has been given a scientific name (Swaminathan, 1983 *a*). Of an estimated 30 million species of living organisms on earth, only 250,000 are plants; of a global total of 80,000 species of edible plant, only about 150 have ever been cultivated on a large scale, and 90 per cent of the world's food is produced from less than 20 species. Many examples exist of under-exploited plant species with proven potential in food, medicine and industry (source: CSC). Hence, it is not even known what is being lost by the destruction of forest canopies, apart from the creation of recurrent droughts and increasing desertification.

High-tech biotechnology

The Third World has long since contributed essential raw materials for the industrial development of the 'North'. Likewise, developing countries have potential raw material resources for new biotechnological products which would be of interest to both the 'North' and the 'South'. Some of these raw materials are listed in Table 5 below. In using them, however, developing

Table 5

TYPICAL BY-PRODUCT SUBSTRATES FOR USE IN MICROBIAL PROCESSES IN DEVELOPING COUNTRIES

Agricultural	Other
Molasses	Animal Manures
Maize Stover	Sewage
Straw	Municipal Garbage
Bran	Paper Mill Effluent
Coffee Hulls	Cannery Effluent
Cocoa Hulls	Fishery Effluent
Coconut Hulls	Slaughterhouse Effluent
Fruit Peels	Milk-Processing Effluent
Fruit Leaves	
Bagasse	
Oilseed Cakes	
Cotton Wastes	
Tea Wastes	
Bark	
Sawdust	

Source: Anonymous, 1979, Microbial Processes: Promising Technologies for Developing Countries, National Academy of Sciences, Washington, D.C.

countries will have to be vigilant that they do not once again become victims of exploitation by nations which are already rich.

The exploitation as biotechnology feedstock of raw materials possessed by the Third World could take many different forms. To cite one hypothetical case, if all 20 million cars in West Germany were to be powered with ethanol, one half of the country would have to be turned into sugarbeet fields. Otherwise, if West Germany and Brazil were to cooperate, all German and Brazilian cars could be powered by ethanol, produced by converting some 2 per cent of Brazilian land from forest into sugar cane fields (Hans-Jurger Rehm in Gierch (Ed), 1981). But what would be the consequences to Brazil in terms of its environment and social structures which would be caused by the uprooting of forest dwellers?

(a) Priorities

Priorities will differ according to the situation of individual developing countries. They can be determined in different ways. It is suggested that criteria for determining priorities might include: import substitution; developing alternative uses for raw materials whose export demand might diminish (e.g. cattle feed concentrates); manufacturing biotechnological products aimed at solving chronic national problems (e.g. pharmaceuticals for endemic diseases); and exploiting a country's natural advantage in certain feedstock for high-tech biotechnology products.

Table 6 (page 393) lists some biotechnology products categorised according to volume and value. Perhaps a developing country could start with 'high volume, low value' products and move to 'low volume, high value' lines as its infrastructures and human resources develop.

Table 6

BIOTECHNOLOGY: BASED ON VOLUME AND VALUE

Category	Products
High volume, low value	methane, ethanol biomass animal feed water purification,effluent and waste treatment
High volume, intermediate value	amino and organic acids food products baker's yeast acetone, butanol polymers metals
Low volume, high value	antibiotics and other health care products enzymes vitamins

From: Bull *et al*, Biotechnology: International Trends and Perspectives, OECD, Paris, 1982

What is important is that the developing countries take early steps to decide their national priorities and objectives in regard to biotechnology. A multidisciplinary team of experts could be set up to advise the government, as the Spinks' team (Anonymous, 1980) has done for Britain.

The areas of biotechnology (both traditional and high-tech) which will probably be of most immediate interest to Third World countries are given in Table 7 (page 394) Some of these will be of particular interest to those countries in a position to invest. Historically this has been shown with respect to oil exporting countries, eight of which (viz. Algeria, Indonesia, Iran, Iraq, Mexico, Nigeria, Saudi Arabia and Venezuela) achieved a per capita income growth rate of 5.6 per cent from 1970 to 1977. During this period, higher incomes caused an extraordinary rise in food demand in these countries, and as a consequence, their food imports grew at an unprecedented rate of

Table 7

AREAS OF BIOTECHNOLOGY OF IMMEDIATE INTEREST TO DEVELOPING COUNTRIES

Anaerobic digestion	Biological pest control
Biological nitrogen and phosphorus removal from waste water	Vaccine production (human and animal)
Plant breeding to evolve crops and crop varieties for meeting specific needs, e.g.drought resistance/tolerance, and to improve staple foods	Enzyme production (e.g. of isomerases, proteinases and urease)
Livestock improvement	
Aquaculture development	
Biological nitrogen fixation	Fermentation (alcohol, antibiotics,gluconic acid, phenylglycine)
Dairy and other food biotechnology	
Vegetable clonal propagation of crop plants using tissue culture techniques	
Application of *in vitro* techniques to breeding and selection of crop plants relevant to local situations	

19 per cent per year (Swaminathan, 1983). Some of these countries should be able to achieve higher domestic production of food by taking advantage of advances in biotechnology. Even high-tech biotechnology should interest them as a means of sustaining incomes when their oil resources are depleted.

(b) Infrastructure and management

It has earlier been pointed out that many Third World countries have not derived the full benefits of traditional biotechnology. The main causes, apart from issues such as price policy for agricultural production, have been lack of infrastructures and management support. To help remedy these deficiencies, it is suggested that those countries which have not already done so, should set up high-powered national biotechnology boards or commissions to advise governments, oversee developments, coordinate measures, and sponsor R&D, etc. For small island and other countries in areas which have effective regional organisations, such bodies could be set up regionally, e.g. in CARICOM, SPEC, and SADCC.

The universities and other relevant academic and research institutions should become more involved in biotechnology and be encouraged and supported in taking up R&D projects according to national priorities. There should be better links between academic institutions and industry in the development of biotechnology.

More effective long-term planning will be needed for human resource development. New courses will often have to be designed and more training inside and outside the country will be essential. Commonwealth institutions can help to organise such training programmes.

(c) Communication and information exchanges

Conflicts can arise between the desire to publish scientific findings and the need to protect inventions. A system which allows the free flow and interchange of scientific knowledge and, at the same time, encourages investment by providing protection to commercial companies (under some regulatory control against unethical and exploitative practices) is the ideal towards which practice should aim.

At the international level a body similar to the Consultative Group for International Agricultural Research (CGIAR) seems necessary for biotechnology. Sponsored in 1971 by the World Bank, FAO and UNDP, the CGIAR has subsequently been involved in the establishment of several first-rate international institutions for agricultural research, including the

International Board for Plant Genetic Resources (IBPGR). International agricultural research institutes established earlier have also been linked to the CGIAR. This linked system offers a formidable network for the diffusion and potential development of new technologies and applications. The Microbial Resource Centres (MIRCENs) established by a joint programme of UNEP/UNESCO/ICRO should help to fill the gap. Such a network, with established local centres in the Third World, should prove effective and useful. An interesting contemporary development is the 'Technical Centre for Agricultural and Rural Cooperation', envisaged by the EEC for the third Lome Convention which, it has been suggested, would link EEC R&D programmes in science and technology with the national programmes of the ACP countries (FAST Report, 1984). The establishment of the International Centre for Genetic Engineering and Biotechnology (ICGEB) in India and Italy will also be of value to Third World countries.

But despite the above international developments, more positive action is necessary to establish a network for communication and information exchanges in biotechnology and to sponsor and support R&D in the developing countries. The Commonwealth has the potential to play a significant role in this regard by virtue of its composition.

Some Conclusions

Biotechnology is multidisciplinary in nature and its full potential is yet to unfold. It has no universally accepted definition, but in view of its relevance to the Third World, this Paper has suggested that a wide ranging conception should be used, including both traditional and new or high-tech biotechnology.

The potential benefits from achievements in traditional biotechnology, like plant breeding, *Rhizobium* cultures, biogas, aquaculture, etc., have yet to be realised in many developing countries. The new biotechnology has even greater potential for benefits in these countries, offering possible solutions to some of their major problems. In fact biotechnology should now be considered fundamental to the future optimal global use of renewable resources. The Third World is richly endowed with many of the resources which supply feedstocks to biotechnology products. Recent advances have opened up vast fields for its application in food and agriculture, waste recycling and pollution control, alternative energy sources, chemicals and pharmaceuticals, medical and veterinary care, etc.

Clearly there are areas of vast potential for biotechnology in the Third World. And in an age of great scientific and technological advancement, developing countries cannot afford to be second or third in some of these crucial areas. These countries must decide their own priorities in developing and using biotechnology according to their own particular situations. In deciding priorities, the determining factors could be, e.g., import substitution, optimal use of raw materials for biotechnological products, alternative uses of raw materials which might ultimately not have much export demand, manufacture of biotechnological products to solve problems such as endemic diseases and pests, malnutrition, pollution, etc.

Biotechnology also offers vast potential for North-South collaboration. The developing countries should, however, be vigilant against the industrial countries exploiting their feedstock resources or using them as testing grounds for products of uncertain public safety. They should also guard against any unethical commercial practices by transnational companies.

Governments should support R&D in biotechnology and encourage the involvement of universities and academic and research institutions, as well as provide appropriate inducements to private enterprise. There will be need to develop the human resource base and establish sound infrastructures.

Support for the Third World in developing biotechnology is also needed at the international level, particularly in regard to assistance in establishing a network for communication and information exchanges and making available technical and financial assistance.

There is much to be done.

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APPENDIX I

SOME RECENT DEFINITIONS OF BIOTECHNOLOGY

1. 'Biotechnology is concerned with the use of biological activities in the context of technical processes and industrial production. It involves the application of microbiology and biochemistry in conjunction with technical chemistry and process engineering.'

   Biotechnologie, Eine Studie uber Forschung und Entwicklung, Dechema (1976).

2. 'The application of biological organisms, systems, or processes to manufacturing and service industries.'

   Biotechnology - Report of a Joint Working Party, UK (1980).

3. 'The application of biological organisms, systems or processes to manufacturing or service industries.'

   Biotechnology in Canada: Promises and Concerns (1980).

4. 'The utilization of a biological process, be it microbial, plant or animal cells, or their constituents, to provide goods and services.'

   Biotechnology: A Development Plan for Canada (1981).

5. 'The science of production processes based on the action of micro-organisms and their active components, and of production processes involving the use of cells and tissues from higher organisms. Medical technology, agriculture and traditional crop breeding are not generally regarded as biotechnology.'

   Biotechnology: a Dutch Perspective (1981).

6. 'The devising, optimising and scaling-up of biochemical and cellular processes for the industrial production of useful compounds and related applications. This definition envisages biotechnology as embracing all aspects of processes of which the central and most characteristic feature is the involvement of biological catalysts. Plant agronomy falls outside this definition but plants provide the raw material for most biotechnological processes, so research in plant breeding and productivity is of direct importance.'

   Biotechnology for Australia (1981).

7. 'The collection of industrial processes that involve the use of biological systems (in glossary). The use of living organisms or their components in industrial processes.'

   OTA Report - Impacts of Applied Genetics (1981).

8. 'The industrial processing of materials by micro-organisms and other biological agents to provide desirable goods and services.'

   FAST (Forecasting and Assessment for Science and Technology).

   Sub-programme Bio-society - research activities.

9. 'The integrated use of biochemistry, microbiology and engineering sciences in order to achieve technological (industrial) application of the capabilities of micro-organisms, cultured tissue cells, and parts thereof.'

   European Federation of Biotechnology (1981).

10. 'The application of biochemistry, biology, microbiology and chemical engineering to industrial processes and products (including here the products in health care, energy and agriculture) and on the environment.'

    International Unions of Pure and Applied Chemistry (1981).

11. 'The application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services.'

    OECD Report (1982).

12. 'Biotechnology deals with the introduction of biological methods within the framework of technical processes and industrial production. It involves the application of microbiology and biochemistry together with technical chemistry and process engineering.'

    Federal Republic of Germany.

13. 'Biotechnology consists of the industrial exploitation of the potential of micro-organisms, animal and plant cells, and subcellular fractions derived from them.'

    France

14. 'A technology using biological phenomena for copying and manufacturing various kinds of useful substances.'

    Japan

15. 'The Swiss Government uses the same definition the European Federation of Biotechnology uses.'

    Switzerland

<u>Sources</u>

No.1 to 11: Bull et al, Biotechnology: International Trends and Perspectives; OECD, Paris, 1982.

No.12 to 15: Office of Technology Assessment, Commercial Biotechnology: An International Analysis; US Congress, Washington D.C., January 1984.

APPENDIX II

BIOTECHNOLOGY: ACCORDING TO INDUSTRIAL SECTORS

Sector	Activities
Chemicals: organic (bulk)	ethanol, acetone, butanol organic acids (citric, itaconic)
organic (fine)	enzymes perfumeries polymers (mainly polysaccharides)
inorganic	metal beneficiation, bioaccumulation and leaching (Cu, U)
Pharmaceuticals	antibiotics diagnostic agents (enzymes, antibodies) enzyme inhibitors steroids vaccines
Energy	ethanol (gasohol) methane (biogas) biomass
Food	dairy, fish and meat products beverages (alcoholic, tea and coffee) baker's yeast food additives (antioxidants, colours, flavours, stabilizers) novel foods mushroom production amino acids, vitamins starch products glucose and high fructose syrups functional modifications of protein, pectins toxin removal
Agriculture	animal feedstuffs veterinary vaccines ensilage and composting processes microbial pesticides Rhizobium and other N-fixing bacterial inoculants mycorrhizal inoculants plant cell and tissue culture (vegetative propagation, embryo production, genetic improvement)
Service Industries	water purification effluent treatment waste management oil recovery analytical tools

Source: Bull et al, Biotechnology: International Trends and Perspectives; OECD, Paris, 1982.

APPENDIX III

SOME EXAMPLES OF APPLICATIONS OF GENETIC MANIPULATION IN BIOTECHNOLOGY

HUMAN HEALTH

1. Monoclonal antibodies (for purification techniques, assays, tissue typing, in vivo tumour location, clinical diagnosis, therapy, including targeting of chemotherapeutic agents).
2. Interferon (possible use for cancer treatment, antiviral therapy, inflammatory diseases).
3. Vaccines (against, e.g., hepatitis B, influenza, malaria, encephalitis, cholera, herpes, adenovirus).
4. Hormones (e.g. growth hormones, insulin, prolactin, relaxin, gastrin, erythropoietin, thrombopoietin, chorionic gonadotropin, menopausal gonadotropin, steroids).
5. Enzymes (e.g. urokinase, heparinase, alcohol dehydrogenase).
6. Other proteins (e.g. specific antigens, blood factor, albumin, antithrombin, fibronectin).
7. Improved and new antibiotics, drugs, vitamins.
8. Gene therapy for genetic diseases.

B. : FOOD, AGRICULTURE AND HORTICULTURE

1. Enzymes (e.g. amylases, rennin, B-galactosidase, invertase, glucose isomerase, pectinases).
2. Food additives (e.g. sweeteners, aromas, flavours, colouring matter, thickeners and stabilizers, vitamins, amino acids, antioxidants, preservatives, surfactants).
3. Additions for animal feed (e.g. new antibiotics).
4. Improved and new plant varieties (including enhanced yields, crops specifically designed for particular land use, genes for proteins such as casein introduced into carbohydrate predominant crops) .
5. Pesticides and herbicides with increased specificity (e.g. use of bacillus thuringensis products, verticillium, taculoviruses, parasitic nematocides, protozoan, piperidine derivatives).
6. Vaccines (against, e.g., diarrhoeal colibacillosis, foot and mouth disease).

...Cont.

7. Plant growth hormones (e.g. cytokinins).

8. Fertilizers, microbial nitrogen fixation and manipulation of symbionts.

9. Diagnostic reagents for plant and animal diseases.

ENERGY, RAW MATERIALS, CHEMICALS AND ENVIRONMENTAL MANAGEMENT

1. Biomass from chemicals, wastes, residues and fuel crops (including production of ethanol, methanol, methane and SCP).

2. Enhanced oil recovery (e.g. xanthan gum, surfactants).

3. Improved algal cultures for use in photobioreactors (production of, e.g.,carbohydrate, protein, lipids, hydrocarbons).

4. Hydrogen and carbon dioxide production.

5. Chemicals and solvents (acetic acid, adipic acid, butanol, isopropanol, acetone, furfural, glycerol, waxes, polymers, alkene oxides and glycols, lubricants).

6. Metal extraction (e.g. copper, uranium, nickel, zinc, lead) from low grade minerals and recovery of valuable metals (e.g. mercury, cobalt).

7. Decomposition and detoxification of chemicals (e.g. oil spills, dalapon, pentachlorophenol).

8. Improved microbial systems for environmental control of air, water and soil.

Source: Bull et al, Biotechnology: International Trends and Perspectives, OECD, Paris, 1982.

APPENDIX IV

SOME BIOTECHNOLOGY MARKET FORECASTS

Commercial area	Estimated Market	Time Scale
1 PHARMACEUTICALS		
(a) Diagnostics	$2,000m including non-radioactive kits and monoclonal RAA kits	Already on the market. Could reach full potential by 1990. Best short-term return.
(b) Drugs	$8,000m by early 1990s, increasing thereafter according to new developments	Only one product (Humulin) on the market to date. Up-front costs and regulatory delays make this a vast but long-term field.
(c) Veterinary	$2,000m by 1990	Good short-term potential due to less stringent regulations. Market growth depends on farming economics.
2 AGRICULTURE	Impossible to quantify	Attractive medium-term area with worldwide potential once scientific problems overcome.
3 WASTE PROCESSING/ POLLUTION CONTROL	Biotech applications could reach $2,000m by 1990. Increased environmental concern would help	Already in use in some areas. Medium/long-term view.
4 BIOTECHNOLOGY EQUIPMENT & SUPPLIES	Currently estimated at about $200m per year: growth very rapid	A good short-term 'backdoor' method of gaining profits from biotechnology.
5 FOOD & DRINK	Impossible to quantify	Human food likely to encounter consumer resistance. Fair medium-term potential for animal feedstuffs.
6 MINERALS/OILS	Has been estimated at $4,500m by end of century	Interesting but speculative area, dependent on economics of mineral and oil extraction.

....Cont.

Commercial area	Estimated Market	Time Scale
7 INDUSTRIAL CHEMICALS		
(a) Enzymes	Uncertain. Dependent on economics of alternative non-biotech methods of enzyme	Long-term view necessary
(b) Amino acids	$3,600m by 1990	Most promising area for biotechnology in the chemical industry
(c) Plastics	Uncertain.	Unlikely to become economically viable before end of the century.
(d) Bulk chemicals/ synfuels	Uncertain.	Outlook depends on long-term oil price prospects. Could become attractive by end of century.

Source: Elkington, J., Biotechnology and Employment: the Integration of Traditional Economic Activities; Case study prepared for ILO, October 1983.

(Based on Laing and Cruickshank, slightly modified.)

APPENDIX V

MARKET PREDICTIONS FOR IMPLEMENTATION IN PRODUCTION OF GENETIC ENGINEERING PROCEDURES

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 Tryptophan	5 5
Vitamins	6	667.7	Vitamin C Vitamin E	10 15
Enzymes	11	217.7	Pepsin	5
Steroid hormones	6	367.8	Cortisone	10
Peptide hormones	9	268.7	Human growth Hormone Insulin	5 5
Viral antigens	9	n.a.	Foot-and-mouth disease virus Influenza viruses	5 10
Short peptides	2	4.4	Aspartame	5
Miscellaneous proteins	2	300	Interferon	5
Antibiotics	4*	4,240	Penicillins Erythromycins	10 10
Pesticides	2*	100	Microbial Aromatics	5 10
Methane	1	12,572	Methane	10
Aliphatics (other than methane)	24	2,737.5	Ethanol Ethylene glycol Propylene glycol Isobutylene	5 5 10 10
Aromatics	10	1,250.9	Aspirin Phenol	5 10

...Cont.

Product Category	Number of compounds	Current market value (million $)	Selected compound or use	Time needed to implement genetic production (years)
Inorganics	2	2,681	Hydrogen Ammonia	15 15
Mineral leaching	5	n.a.	Uranium Cobalt Iron	
Biodegradation	n.a.	n.a.	Removal of organic phosphates	

n.a. Not available.
* Number indicates classes of compounds rather than number of compounds.

Source: Bull et al, Biotechnology: International Trends and Perspectives; OECD, Paris, 1982.

(Quoting U.S. Congress Office of Technology Assessment; Genex Corporation; Industry Week, 7 September 1981, p.68.)

APPENDIX VI

VALUE OF APPLIED GENETICS AND NEW BIOTECHNOLOGIES IN VARIOUS SECTORS OF UNITED STATES MARKET

Market Sector	1981 $m	1985 $m	1990 $m	Average annual increase (%)
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	120.00	63
Total	59.11	732.5	13,378	82.6

Source: Elkington, J., Biotechnology and Employment: the Integration of Traditional Economic Activities; Case study prepared for the ILO, October 1983.

(Quoting Business Communications Co.)

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