Currently biotechnology is the dominant
technology in wastewater treatment.
It is also used in the treatment of soils
and solid waste.

Biotechnology 12

Biotechnology is used increasingly as the environmentally sound technology (EST) of choice in many applications, particularly pollution clean-up. It also offers enormous promise in tackling many more environmental problems. New applications are expected to include water treatment, treatment of solid wastes (including biodegradable plastics), biomining, agriculture (creating plants resistant to the most adverse weather conditions), combating desertification, and even to form the basis for cleaner production. But a key issue is the transfer of biotechnology know-how.

Biotechnology, broadly defined as any technique that uses living organisms to make or modify a product, improve plants or animals, or develop micro-organisms for specific use, is not new *per se*. However, modern biotechnology, based on the use of new tissue culture methods, and recombinant-DNA technology, or genetic engineering, is an exciting science and rich in potential. Advanced biotechnologies are moving rapidly from research into commercial production – opening up new frontiers in areas from manufacturing to health care to pollution clean-up. They will play an increasingly important role in fostering the economic and social development of developing countries, for example by improving health through providing powerful new diagnostics, vaccines and drugs.

Already, biotechnological techniques are making an important – in some cases, essential – contribution to the protection and clean-up of the environment. They rely on the ability of natural processes to degrade organic molecules. Microbes play a pivotal role digesting and degrading organic compounds to their mineral components and have become remarkably effective, to the point where they can mineralize most organic substances. There are several ways in which biotechnology can prevent or reduce environmental damage, including:

- added-value processes, which convert a waste stream into useful products;
- end-of-pipe processes, which purify the waste stream to the point where products can be released without harm into the environment;
- development of new biomaterials, leading to the manufacture of materials with reduced environmental impact;
- new biological production processes that generate less, or more manageable, waste.

Cleaning up pollution

At present, the main use for biotechnology is to clean up or remedy pollution. One of the first applications was wastewater clean-up, followed by air and off-gas cleaning. Now the focus of bioremediation is shifting increasingly towards soil and solid waste.

Biotechnology is already the dominant technology for wastewater treatment: biological treatment can cope with a wide range of effluents more effectively than chemical or physical methods, and is particularly suitable for treating wastewater containing the more common organic pollutants. In fact, it was first used to treat wastewater more than 100 years ago. Since then, both aerobic and anaerobic processes have been developed. Aerobic treatment has become the established technology for

BOX 12.1

Using micro-organisms against industrial pollution

Industries established long ago in then rural areas are now creating serious pollution problems for new communities that have developed nearby. In Monterey, United States – which has a cluster of industries including glass, cement, steel, chemical, paper and brewing – one company, producing rayon fibre and cellophane film, had to cope with serious sulphur gaseous emissions from two facilities close to houses built 20 years after the factories.

A search for a way to eliminate the foul-smelling emissions found that none of the available abatement technologies was suitable because they were all too costly. The plants, which provide 1,500 jobs and 25 per cent of the company's revenues, were not profitable enough to support an expensive solution.

It was decided to explore the use of micro-organisms, since both contaminants contained sulphur and theoretically were easily degradable by naturally occurring bacteria. Biological treatment was compared with four other methods – chemical scrubbing, carbon adsorption, catalytic and thermal incineration, and chemical and photochemical oxidation – and was chosen because biological reactors were easy and cheaper to install, maintenance was low, and the company had experience of biological processes for wastewater treatment.

A pilot bioreactor removed 95 per cent of both compounds within ten weeks of operation, and full-scale operation has yielded excellent results, confirming that the biotreatment option is competitive with other technologies.

low- and medium-strength wastes, and also for toxic and recalcitrant molecules. Anaerobic processes are more effective for highly organic wastes, such as food processing wastewaters, municipal sludges and animal husbandry slurries. During the past ten years, they have begun increasingly to replace aerobic systems in many applications. Anaerobic wastewater treatment plants are more compact, separate carbon compounds as a combustible gas (methane) and can achieve recovery rates of more than 80 per cent. Biotechnological methods are now widely used to remove nitrate, phosphate, heavy metal ions, chlorinated organic compounds and toxic substances. The main aim of water treatment used to be to reduce organic matter generally. Nowadays cleaning up industrial pollutants is becoming critically important and this is leading to the development of biological processes for removing specific pollutants.

Since the mid-1980s biological treatment has also been used in both Western Europe and the United States to control odours and volatile organic compounds in contaminated air. Traditional off-gas treatment methods – incineration, dispersion, catalytic oxidation, scrubbing and adsorption – are best suited to handling large volumes of well-defined waste gases. Malodour problems from waste plants in particular are usually caused by varying mixtures at very low concentrations. Biological control offers a simpler alternative to chemical oxidation, leaves no chemical residues and uses less energy.

The biotechnological processes used in air/off-gas treatment are primarily:

- biofiltration, in which immobilized micro-organisms, sticking to an organic matrix such as compost or bark, degrade the gas pollutants;
- bioscrubbing, in which the pollutants are washed out using a cell suspension, which is regenerated by microbial activity in an aerated tank;
- biotrickling filtration, in which immobilized micro-organisms sticking to an inert matrix degrade the pollutants while they are suspended in a water film and supplied with inorganic nutrients by a medium trickling through the device.

Biofilters are mainly used to abate odours and treat volatile organic solvents, and can be found in wastewater treatment plants, fish processing plants, gelatin works, foundries, resin processing plants and in plywood production. Biofilters have also been used to remove easily biodegradable compounds emitted by oil cracking or off-gases from the petrochemical industry, and the feed and food industries. Here biofilters replace physical or chemical air treatment techniques. Bio-scrubbers and biotrickling filtration systems have been introduced successfully in sectors such as food, brewing, some chemical processes, wastewater treatment units and agriculture. Biofiltration is relatively cheap, but cannot treat all types and concentrations of pollutants. Bioscrubbers can clean highly contaminated off-gases, but require larger investment and have bigger running costs.

Overall, biological treatment of air/off-gas problems competes favourably with other techniques in terms of energy consumption, materials balance and cost. For example, operating costs for biological gas treatment typically work out at 20 and 40 per cent of the costs of chemical and thermal processes respectively. A major advantage is that pollutants are totally converted into harmless substances, without the accumulation of toxic residues or side products. A wide range of gaseous wastes has been identified as treatable by biotechnological means, and commercial processes are already available for most of them. Moreover, it has been demonstrated that biotreatment technologies will remove gaseous air pollutants from industrial units located in the centres of heavily populated industrial zones.

Industrial biotreatment of industrial or domestic solid waste is largely confined, at present, to composting wastes with a high proportion of organic materials. Most municipal waste contains a high amount of organic, biodegradable material, for example, food waste, lawn clippings, and wet and soiled paper unsuitable for recycling. In industrialized countries, organic material can account for 50 per cent of household waste. Composting uses controlled or engineered biodegradation, taking several weeks, or even months, to recycle organic materials into compost. Using the compost in farming or horticulture improves soil quality, reduces irrigation needs, and cuts both soil erosion and the use of chemical fertilizers. Composting solid waste is attractive in places where the use of landfills or incinerators is limited or expensive and where natural soils are of low quality, such as in the arid countries of the Middle East.

For industrial solid waste, anaerobic digestion is increasingly replacing aerobic processes because it converts organic materials to usable methane, a fossil fuel substitute. The value of generating methane as a fuel versus actual waste disposal varies according to circumstances. For example, it is not the priority in developed countries. However, in developing countries anaerobic fermenters are used extensively in rural areas to produce biogas for

BOX 12.2

New modular composting system

A German composting process uses a new containerized, modular box system to separate all metals and other ‘foreign materials’ from household waste. It then shreds and screens a mixture of 80 per cent biowaste, 20 per cent green waste (from public amenity sites), before feeding it automatically by conveyor into the composting box.

Two bunkers, or containers, store the shredded and unshredded woody material, while a third bunker receives the biowastes. The boxes can be used for a single stage process, which entails leaving the waste in the box for 7-10 days before it is allowed to mature outside for 12 weeks. A final screening process removes any oversized or contaminated items. The facility has 14 composting boxes, each with its own temperature and carbon dioxide controls, and an air circulation system, which blows dry air through the floor into the piled organic material, and withdraws moist air through pipes in the roof of the box, passing it on through the filtration system.

The plant can produce 12 different soil mixes, each tailored for various applications, such as golf courses, landscaping and plant cultivation. The bunkers containing the product mixes are computer controlled to ensure a consistent mixing process and can produce 60 tonnes an hour of end product. A sophisticated water purification system using high performance micro-biological techniques in a sealed system ensures that no wastewater is discharged.

Facilities using this system have now been built in Germany, Canada, Austria, the United Kingdom and Luxembourg. The boxes – each weighing 50 tonnes and capable of a throughput of 1,250-1,500 tonnes of organic material a year – are built at the company’s factory, then taken by road for final installation.

An overview of our management philosophy on the environment

Fertiberia is Spain's leading manufacturer of fertilizers and the fourth largest fertilizer company in the European Union, with eight factories and nearly 2,000 employees. Company turnover, including that of its fully owned subsidiary Sefanitro, is 85,000 million Pta. (approximately US$550 million). Exports are about 15 percent of total sales. Between 1995 and 1997, the company's investments were 9,200 million Pta. (approximately US$60 million). Fertiberia has been owned by Grupo Villar-Mir, an independent industrial family group, since April 1995.

We know it is vital to ensure our operations do not harm the environment. So environmental issues are given the highest priority.

The company has invested over 3,400 million Pta. (approximately US$22 million) over the last four years to implement a plan to reduce air and water emissions, solid wastes and contamination. This has involved modifying processes and installing end-of-pipe technology solutions, including recycling, to prevent or minimize discharges to water systems and the ground, and washing gaseous effluents. The goal is zero-liquid discharge.

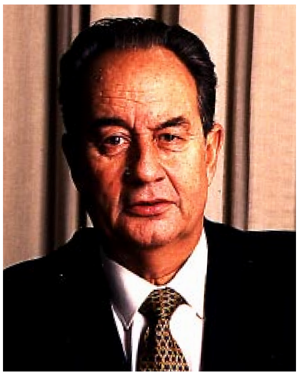
These solutions – many of them developed by our own engineers – will enable Fertiberia to comply with both Spanish legislation and standards set by the European Fertilizer Manufacturers Association (Efma). Through our internal audit system, personnel from one factory checks the results of others.

In fact, Fertiberia's environmental performance depends on our employees, and the company conducts an ongoing environmental awareness programme among all of its 2,000 people, at all levels and in all departments.

Local communities also need to know what we are doing – so the company holds an Environment Week in every factory every year. Events include round tables involving employees, local authorities and union representatives.

In addition, we compare our performance with that of other Efma member companies – using annual benchmarking to match ourselves against the Best Available Techniques (BAT) emission levels set out in the Efma booklets on BAT.

We are not standing still. We are now developing an environmental management system which, when implemented, can be certified. That will be the final step in our environmental policy, following an approach completely in line with the EU's directive on Integrated Pollution Prevention and Control (IPPC).



The environment – as well as quality, client service and competitiveness – is a major challenge, a key to making our business sustainable. We intend to succeed.

Juan Miguel Villar-Mir, President

Fertiberia, Juan Hurtado de Mendoza, 4, 28036 Madrid, Spain

cooking, heating, and even as a fuel for small electricity generators.

Soil and land treatment is another important application for biotechnology. Soil can be contaminated by both organic pollutants (spillages from chemical plants, gas works and other manufacturing sites) and inorganic pollutants (heavy metals and anions such as sulphate). Biotechnology is most effective against organic pollution: the micro-organisms use the contaminants as a food or energy source to turn the pollutant into microbial biomass. Bioremediation treatments fall into two groups: one is *in situ*, which has the advantage that the remediation does not disturb the site, and the other is *ex situ*, which consists of digging up the soil and treating it above ground, which is much easier to control.

The technology of land bioremediation has been successful enough in the United States, Europe and elsewhere to demonstrate that it works. In the Netherlands, one company using both biological and non-biological techniques can handle up to 100,000 tonnes of contaminated land a year. Its major advantage over other technologies is cost: it is the cheapest option, other than taking the contaminated soil to landfill. Experience in the United States shows that using biological instead of physical or chemical methods can achieve savings of 65-85 per cent.

However, any remediation process must be reliable. This is especially so with polluted sites which are extremely complex, and the choice of technology is also very site specific. The problem with bioremediation is that it needs to build up a bank of results to confirm it is predictable, yet there is a hesitancy about using it until its reliability is proven. Remediation can also be a time-consuming process, tying up capital and preventing land use. Its big advantage is that because micro-organisms are used to break down the organic matter, the end products are minerals, carbon dioxide, water and biomass, unlike all other technologies – except incineration – which concentrate the material without changing its form.

In biomining, biological treatment processes are being used to remove cyanide and metals from mine water, while micro-organisms have been used to detoxify solutions by separating out heavy metals and to recover precious metals from industrial waste.

A rapidly growing number of biotechnologies have been developed for agriculture, some of which have environmental relevance. For instance, agricultural biotechnologies targeted towards increasing productivity can – through improving yields per unit of input, or reducing inputs and costs per unit of output – mean that the same amounts of food are produced with less land, water and

BOX 12.3

Viet Nam focuses on composting

Solid waste has reached unmanageable proportions in many cities in Viet Nam – and the government's strategy is to build composting plants in and around urban centres. Since the waste stream in Hanoi and other Vietnamese cities and towns contains a high share of organic material, with a high moisture content, it is potentially compostable – especially since it is relatively uncontaminated by either plastics or pollutants.

In Hanoi, collected waste is taken to a newly opened engineered sanitary landfill site or to a pilot composting plant. Built in 1993-1994, with funding from the United Nations Development Programme (UNDP), the plant uses an aerobic forced air process to produce 7,500 tonnes of compost a year.

The pilot plant has proved a success, but lack of funds prevents the government from building more. Therefore part of its strategy is to use the composting plant to produce fertilizers, for which there is a big demand, with the aim of largely replacing imported artificial fertilizers.

In Viet Nam, farming and household wastes in rural areas are mostly used as fuel for cooking or as fertilizers. Biogas tanks which would allow methane recovery have not been widely introduced – mainly because of lack of money and also because of the lack of appropriate technology.

BOX 12.4

Research projects produce results in the United States

The Environmental Protection Agency (EPA) in the United States is leading a major effort by government scientists, private industry and the academic community to find new ways to use naturally occurring micro-organisms to clean up environmental contaminants.

The technology moved into the public spotlight during the clean-up operation after the Exxon Valdez oil spill in Alaska, when EPA scientists applied fertilizer to parts of the coast to stimulate natural oil-degrading bacteria. Subsequent studies showed that this treatment caused oil to degrade twice as fast as the oil in untreated areas.

Since then, research into bioremediation in the United States has increased three or four times, and the EPA's Office of Research and Development has set up a five-year Bioremediation Research Programme, one of the aims of which is to speed up the transfer of new discoveries from the laboratory to the field.

- In one study, EPA scientists applied white rot fungus to samples contaminated with pentachlorophenol and other toxic compounds: preliminary results showed that pentachlorophenol concentrations of up to 1,000 parts per million were reduced by 85-90 per cent.
- At another site, petrochemical wastes were treated with a process which involved injecting air into the liquid to encourage aerobic degradation, adding nutrients, using centrifugal pumps to emulsify the waste, and mixing the subsoil in with a hydraulic dredge. Within 120 days, volatile organic compounds in the waste were reduced from 3,400 to 150 parts per million, benzene concentrations from 300 to 12 parts per million, and vinyl chloride levels from 600 to 17 parts per million.
- Treating ground water contaminated with benzene, toluene and xylene from an aviation fuel spill by adding hydrogen peroxide as an oxygen source to stimulate indigenous microbes, brought the water within EPA's drinking water standards within six months.

These results demonstrated that while bioremediation is a slow process, it is less costly than alternative clean-up methods. By converting toxic chemicals to other materials, it actually removes the toxic elements from the environment, rather than just separating them for disposal later on.

agrochemicals. In livestock production, hormones that can increase milk yields in cows can now be mass-produced by genetically altered bacteria, while tissue culture, which has advanced considerably in recent years, can allow whole plants to be generated from single cells, or small samples of tissue.

Bioreactors are used to produce biogas from biomass, a lignocellulosic (woody plant) material, which is often a primary or waste product from the agricultural and forest products industries. Bioreactors use bacteria and archaebacteria to produce methane and biogas from three main sources: landfill; dedicated sources of biomass; and as a by-product from anaerobic treatment processes for sewage sludge, animal slurries and high-strength industrial waste streams. Biogas formation is an efficient method of recovering chemical energy from very wet organic waste, and can be burned in furnaces or in modified internal combustion engines. Removing water vapour and carbon dioxide creates methane which, after further purification, can be compressed and used in natural gas pipelines.

An exciting future

Biotechnology is an established environmentally sound technology (EST) with many applications, and already plays a significant role in tackling a number of pollution problems. The future offers even more promise.

For water treatment, new biotechnology methods are being developed that will remove nitrogen, phosphorous and sulphur compounds. Bioprocessing is being extended to various industrial processes, including a number in the petrochemical and chemical industries. Specialized, highly active strains of micro-organisms are being used to treat specific pollutants in other industries. These include industries using catalysts, textiles, leather production, cellulose and starch processing, electro-plating, mining, surface degreasing and coating, and printing. Biosorption may replace physical or chemical methods such as precipitation, adsorption or ion exchange in scavenging heavy metals ions.

Future solid-waste applications are expected to include:

- detoxification, to selectively remove heavy metal ions, leaving only trace amounts of pollutants;
- digestion of wastes with an organic content;
- transformation of waste into biogas, allowing a more rapid waste turnover;
- the development of biodegradable plastics to reduce the volumes of solid wastes.

The International Solid Waste Association reported recently that "there can be little doubt that methods of organic waste treatment are of high priority in all countries".

Biodegradable plastics can be degraded into water and carbon dioxide by micro-organisms in the environment. However, their development and commercialization presents some problems, such as the definition of biodegradability and methods for testing it, labelling and costs. One bacterial polymer, polyhydroxybutyrate, has been commercialized. It is a thermoplastic polymer which may help with problems associated with the disposal of non-biodegradable petroleum-based plastics. However, its efficacy remains to be validated. Currently, the Japanese government is supporting a number of research and development projects looking into biodegradable plastics.

Work is moving ahead rapidly to develop advanced bioreactors to handle industrial effluents. Because they are highly alkaline or acidic and have heavy salt concentrations, these effluents can resist micro-organisms. The aim is to use membranes to separate the organisms from the effluent and allow only the organic pollutants through. A second generation of biofilters, bioscrubbers and biotrickling filters for industrial air/off-gas treatment will employ specialized micro-organisms as well as combinations of biological with chemical or physical techniques such as membrane technology. This will allow the treatment of higher concentrations, and a wider range, of pollutants and toxic pollutants – markets currently dominated by ESTs such as active carbon filtration, scrubbers and incineration. In time, biotechnology may replace these technologies, which are relatively expensive in terms of investment and operation costs.

Biotechnology solutions are also expected to make an increasing impact on land clean-up problems. They are especially suited to treating complex organic contaminants and moderately contaminated sites where it is costly, or impossible, to disrupt existing activities. There is also likely to be increasing use of bacteria for reducing pollution in the mining industry. The National Institute of Standards and Technology in Japan is investigating the use of metal-metabolizing micro-organisms for resource recovery, bioremediation and coal cleaning.

Trends in agriculture

In agriculture, a priority of modern plant genetics is to replace nitrogen fertilizers, a major source of pollution, with nitrogen fixation within the plant. An example is the development of cereals with the ability to fix some of their own nitrogen. Breakthroughs in genetic modification methods could increase plant resistance to virus and other diseases, as well as to drought, salt, cold and heat, thus increasing the land resources available for crop production, or raising crop yields, and so lessening the pressures on marginal lands. Another major benefit would be a reduction in the use of fertilizers and pesticides.

Converting agricultural raw materials into food and non-food products – such as wood, pulp and paper, and leather – contributes large amounts of industrial waste. Using biotechnology to improve production processes, such as replacing harsh leather-tanning chemicals by enzymes, could reduce and ultimately eliminate waste generation by converting wastes into useful products. Already 10 per cent of the value of the wheat crop is derived from using

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We all depend on natural resources, biological productivity and healthy global markets to survive. Preserving these elements for the future will require imagination and bold action. As a global, science-based company, Monsanto believes we have the expertise to help find technical solutions that will allow the world to move toward a sustainable future.

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new enzyme technologies to convert straw into starch and other industrial products.

According to the International Energy Agency (IEA) and the Organisation for Economic Co-operation and Development (OECD), new biotechnology "can affect every stage of plant life, breeding, growth, harvesting and residue treatment" – and at every stage there could be "a consequent benefit for the environment in the form of more efficient, less resource-consuming, less polluting agricultural practices". For example, agricultural land can be either a sink or a net source of methane gas, depending on the cultivation techniques. Methods to reduce methane emissions may actually increase emissions of nitrogen oxides. Solving this problem may involve a combination of natural methods and artificially created organisms.

Plant researchers are investigating the way in which nitrogen is fixed and made available to certain plants (for example, legumes) in order to improve nitrogen-fixing efficiency. Through biotechnology, it is likely that it will be possible to transfer nitrogen-fixing genes to non-fixing organisms. Plants fix carbon dioxide in various ways, and the carbon loss also varies between species. A major cause is photorespiration, where oxygen is fixed and carbon dioxide respired. Photosynthetic improvement might increase carbon dioxide yields by 10-20 per cent. Advanced genetic engineering may also make it possible to separate the two fixation processes and make it easier to transfer genes for efficient carbon metabolism from one species of plant to another. Ultimately, it may also be possible to reduce photorespiration through the genetic manipulation of photo-synthetic enzymes.

Genetic technology could also have a significant impact on rice growing. Paddy fields are a major emitter of methane worldwide. At the moment, their ecosystems are too complex and too little understood to introduce 'foreign' organisms. Improving management techniques is currently the only way to reduce methane emissions. Dry-rice cultivation causes much lower methane emissions, so a shift from wet to dry cultivation would reduce global methane releases. The problem is that paddy fields have a much higher yield, and with so many people depending on the success of a particular rice crop, such a shift would be an enormous move. The key to the switch is to use biotechnology to produce new kinds of rice that are adapted to dry cultivation and give high yields.

> 'The future of sustainable development rests largely in local and national hands. Commitment to an eco-revolution will be bottom up, if at all'
>
> Simon Upton,
> Minister for the Environment,
> New Zealand

> 'International cooperation has waned, and the political will to implement Agenda 21 has continued to recede'
>
> Alhaji Abdullahi Adamu,
> Minister of State for Works and Housing, Nigeria

Further applications

Biotechnology can also help reverse the impact of desertification. About 35 per cent of the Earth's land area is desertified, or threatened by desertification, and reclaiming the use of some of these areas would put more land back into productive and profitable use. One role for

BOX 12.5

Promoting biotechnology transfer

There are a number of initiatives under way to promote the transfer, development and use of environmentally sound biotechnologies in developing countries.

- UNEP supports a network of regional Microbial Resources Centres (MIRCENs) which collect and maintain microbial genetic resources and also provide research and training in pilot applications. Examples include biodegradation of persistent chemicals used in agriculture and industry, and bioremediation. Each MIRCEN acts as a centre of excellence for training in environmental microbiology and biotechnology, including their application in environmental management. These centres are supported by selected institutions in developed countries to increase exchange of expertise. The United Nations Educational, Scientific and Cultural Organization (UNESCO) collaborates on this. UNEP also conceived and supported the establishment and use of the international Microbial Strain Data Network, a referral system of information on microbial strains and cell lines.

- The Global Environment Facility is funding a project involving eight countries which includes agricultural biotechnologies and genetic engineering components. The BioInformatics Network on Biotechnology and Biodiversity – run by the United Nations Industrial Development Organization (UNIDO), the United Nations Development Programme (UNDP) and the Food and Agriculture Organization of the United Nations (FAO) – is an information-sharing network linking eight Asian countries. Non-governmental organizations and the business sector in each country are encouraged to take part. The United Nations Economic Commission for Europe has also held seminars and workshops on bioremediation of polluted groundwater, technologies for containing water, biological methods for treating pollution in unsaturated zones above groundwater, and treating extracted contaminated soil.

- UNIDO focuses on the role of modern technology for bioremediation of contaminated land and water, providing technical advice and assistance, and running regional workshops on the strategic development of appropriate technologies and combinations of technologies, including new biotechnology for treating polluted land and water, and industrial effluents. UNIDO's International Centre for Genetic Engineering and Biotechnology, created in 1983, provides advanced research and development training facilities in biotechnology and genetic engineering for scientists from developing countries, at two centres in Trieste, Italy, and New Delhi, India. Particular attention is given to strengthening biotechnology activities in India. Cooperative research programmes at the centre include environmental biotechnology.

biotechnology includes water retention and prevention of salt damage. A Japanese research group has developed a new 'super-bioabsorbent' material that can absorb and hold water more than a thousand times its own weight. Using gene recombination and cell fusion techniques, the longer-term aim is to breed plants that can survive in desert conditions and even to produce genetically engineered crops which would thrive on seawater irrigation.

Biodesulphurization of oil and coal is also emerging as a promising technology. Removing sulphur from fossil fuels is important. However, while current oil desulphurization technologies are efficient, they require high temperatures and pressures and do not remove all the organic sulphur compounds. Several biological micro-organisms are capable of removing pyritic sulphur from coal: other microbes are being evaluated to remove organic sulphur. Biotechnology also offers possibilities for reducing methane emissions at a number of stages of the coal fuel cycle, and it may also be possible to use micro-organisms to convert low rank coal into methane. Preliminary studies have demonstrated that coal liquefaction can be achieved in a single step by using enyzmes to produce a flammable liquid with potential as a fuel.

Biomass, for example, could be a long-term option for the production of electricity. The basis could be existing forestry and agricultural residues, produced in huge quantities. The most promising option for biomass power is integrated gasification/gas turbine technology. Assessments suggest that modest-scaled power plants (20-50 megawatts) could achieve thermal efficiencies of more than 40 per cent in a few years, and 50 per cent by 2010, at much lower capital costs than conventional plants. Low and high pressure gasifiers using biomass are being developed. Lignocellulose has a negligible sulphur, low ash and high volatiles content, and high char reactivity, all of which make it a

A bacterial polymer, polyhydroxybutyrate, has been commercialized to help with the disposal of non-biodegradable, petroleum-based plastics.

potentially ideal feedstock in a modern gasification system.

Biotechnology may also be used to produce hydrogen. The oil-refining process requires large amounts of hydrogen – usually produced from fossil fuels and thereby releasing carbon dioxide. Scientists believe that biotechnology could be the key to using sunlight as an energy source, leading to biotechnological processes to replace present chemical processes, so saving significant amounts of energy and natural resources, and reducing waste.

Biotechnology may also become the basis for cleaner technology by eliminating specific pollutants, either through replacing them or making their use unnecessary. One example is using biological methods to destroy excess solvents during industrial processing. In principle, biotechnologies can play a role at virtually every stage of energy production, transmission and consumption, in reducing greenhouse gas emissions. The possibilities range from the development of cleaner fuels (biomass, hydrogen) or cleaning traditional fuels, to cutting energy use in agriculture and energy-intensive industries by improving traditional production processes.

UNEP's Cleaner Production Programme has a working group on Biotechnology for Cleaner Production, which focuses on biotechnological processes that lead to the prevention of industrial wastes and emissions. For some industrial processes, there are biotechnological alternatives which, when implemented, produce less waste and fewer emissions than traditional processes. The Biotechnology for Cleaner Production working group is collecting case studies to illustrate the development of these processes. Some examples are given below.

- A small electro-plating company is using biological degreasing with activated microorganisms, in combination with a closed rinse water system, as an alternative to degreasing using alkalis. The main environmental benefits are reduction of sludge by 50 per cent, reduction of water use by 90 per cent and reduction of acid use by at least 20 per cent. Running costs have been reduced by US$80,000.
- A textile finishing company is using an enzymatic bleach clean-up process. Natural fabrics such as cotton are normally bleached with hydrogen peroxide before dyeing. Bleaching agents are highly reactive chemicals and even very small amounts of hydrogen peroxide can interfere with the dyeing process. The new clean-up method removes hydrogen peroxide after bleaching and before dyeing by using a small dose of the enzyme catalase which decomposes hydrogen peroxide to water and oxygen. The benefits are reduced water and energy consumption.
- The enzyme lipase can replace traditional solvent extraction of fats from animal hides and skin, reducing the use of organic solvents and improving the quality of the finished leather.
- Instead of the traditional use of pumice stones in jeans finishing, enzymes can be used to give them the same look and better quality. Productivity is increased because laundry machines contain more garment and less stone.
- Using the enzyme amylase in the desizing of textiles means that smaller quantities of aggressive chemicals, such as ammonium persulphate and hydrogen peroxide, are required. Using fewer chemicals also reduces damage to the fibres.

Approach causes concern

Despite its proven benefits – and clear advantages over other ESTs in a number of applications – there is anxiety in some people's minds over using biotechnology for pollution clean-up. A particular example is recombinant DNA (r-DNA) technology, which is being used to develop superior strains of micro-organisms to speed up degradation and expand the range of easily degradable compounds. It may be especially useful in degrading hydrocarbons or producing biopolymers. While suitable micro-organisms may develop naturally, r-DNA technology can achieve results faster and more efficiently. There is concern about possible environmental risks arising from using r-DNA to create such new strains, as genes from genetically engineered varieties could spread back into naturally occurring organisms. The experience of the pharmaceutical industry, which has developed a number of new, useful and safe products based on r-DNA technology, may help to set people's minds at rest.

Biotechnology transfer

Biotechnology is no exception to the issue of EST transfer and is subject to similar constraints (see Chapter 3). However, the United Nations Commission on Sustainable Development (CSD) has noted that while every country needs to be able to "acquire, absorb and develop" all and any technology, the transfer of biotechnology "poses new challenges" to developing countries. This is why Agenda 21, Chapter 16, is devoted to the environmentally sound management of biotechnology, particularly in its transfer to developing countries.

Many developing countries have neither the technological resources nor the scientific competence to take up bioscience research and development, and they also lack the technical capability to develop scaled-up and downstream industrial processes. A lack of scientists and engineers prevents research institutions from conducting the multidisciplinary research that can bring biotechnology to fruitful result. Most of the research and development in biotechnology is carried out in well-funded universities, research institutes and major companies in developed countries.

All these factors contribute to a clear gap between developed and developing countries and there is the risk that this will widen further. However, thanks largely to the efforts of several United Nations organizations, a number of developing countries are now giving increasing attention to biotechnology development in key areas such as agriculture, food and pharmaceuticals, conversion of low-cost or marginalized raw materials into high added-value products, and marginalized lands into more productive

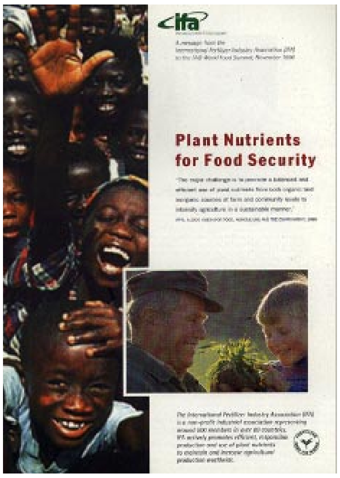
BOX 12.6

Developing environmentally sound biotechnologies in India

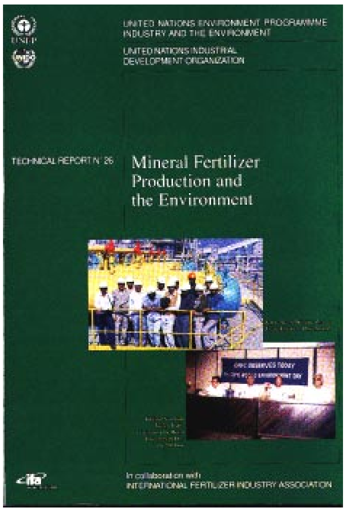
India's National Environmental Engineering Research Institute has developed a number of environmentally sound biotechnologies – demonstrating that not all advances take place in developed countries. They include the following.

- A chemo-biochemical technology for desulphurizing gaseous fuels and emissions containing hydrogen sulphide, which also recovers elemental sulphur. The process removes 99 per cent of the hydrogen sulphide. The recovered sulphur, with a purity of up to 99.7 per cent, can be used commercially.
- A technology for producing biosurfactants – active compounds derived from biological sources which, like synthetic surfactants, exhibit characteristic physical and chemical properties. Biosurfactants can be used *in situ* to enhance oil recovery, in remediation of oil spills, and as detergents.
- The bioremediation of mine spoil dumps, which involves excavating pits on the eroded, stony dumps, filling them with bedding material (organic waste and spoil), and planting selected saplings pretreated with microbial cultures. The process reclaims spoil dumps, mined land and wastelands within three to four years without using chemicals. The degraded ecosystems recover fast, providing carbon dioxide sinks.
- A process using a microbial treatment which removes 85 per cent of high pyritic sulphur and 89 per cent of ash from coal before it is burned, leaving coal which is usable in thermal power plants, coal gasification plants and for generating cleaner liquid fuels.

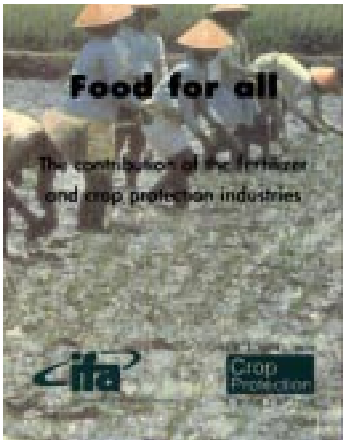
The institute's cost-benefit analysis of these and other biotechnologies shows that the initial investments, annual operating and maintenance costs, benefits and investment returns are attractive to small-scale enterprises in developing countries.



'Plant Nutrients for Food Security'
IFA – FAO World Food Summit 1996



'Mineral Fertilizer Production and the Environment'
IFA/UNEP/UNIDO



'Food for All' – IFA/GCPF

Fertilizer Feeds the World

Sustainable agriculture and the development of food security rely on effective management of plant nutrients.

- Nutrients removed by harvests must be replenished.
- The fertility of soils low in nutrient reserves must be enhanced.
- Depleted soils must be rehabilitated.
- Other constraints which inhibit crop response to plant nutrition must be remedied.

Integrated plant nutrition promotes the combined use of various nutrient sources, especially those which can be mobilized locally by the farmers themselves. The benefits of organic matter extend beyond its nutritional value, but organic inputs alone are not sufficient to maintain high yields.

Properly applied fertilizers contribute to meeting the demand for food while at the same time avoiding the need to clear forests and cultivate fragile soils.

The fertilizer industry is committed to the promotion of both efficient and responsible use of its products.

International Fertilizer Industry Association

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http://www.fertilizer.org

IFA is an integral link in the International Agri-Food Network

The International Fertilizer Industry Association (IFA), whose membership numbers around 500 companies in over 80 countries, includes manufacturers of fertilizers, raw material suppliers, regional and national organizations, research institutes, traders and engineering companies. IFA collects, compiles and disseminates information on the production and consumption of fertilizers, and acts as a forum for its members and others to meet and address technical agronomic, supply and environmental issues. IFA also sponsors research related to the efficient use of plant nutrients in agriculture, and liaises closely with relevant international organizations, such as the World Bank, FAO, UNEP and other UN agencies.

Responsible Environmental Management

Agrium's vision is to be a leader in helping to achieve a world of abundant food and fibre by being an environmentally responsible supplier of products and services to the food and fibre industries.

We pursue this vision by:

- Promoting partnerships with employees, customers, suppliers and neighbours to:

  (i) responsibly manage and use our products and services while, at all times, safeguarding public health and the environment, and

  (ii) recommend balanced use of inputs to maximize yields and ensure the maintenance of soil quality, both of which are critical to sustainable agriculture.

- Actively supporting the environmental activities of industry organizations such as the International Fertilizer Industry Association, The Fertilizer Institute, the Potash and Phosphate Institute, and the Canadian Fertilizer Institute.
- Auditing and continuously improving our processes, practices and policies.
- Researching and developing new products and services that sustain and preserve our shared environment.
- Conducting all aspects of our business in conformance with applicable laws, regulations and guidelines and, in the absence of such, utilizing responsible practices at all locations.

Agrium

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BOX 12.7

Biotechnology goes mobile

The Latona Project addresses three major problems particularly affecting developing countries:

- pollution and disease caused by open-air rotting of municipal rubbish and sewage sludge;
- loss of fertility and essential trace elements from the soil;
- contamination from over-use of synthetic fertilizers.

The project proposes a totally biodegradable solution – ideally suited to developing countries which typically generate up to 80 per cent of their waste stream in organic matter. The alternative is landfill, which can create health problems and contaminate drinking water.

The project involves a high-tech but entirely natural biological process that biodegrades the putrefactive organic components of municipal solid waste, sludge and food processing wastes. It co-composts waste materials inside sealed, rotating bioreactors, and turns them into a high-quality humus or organic fertilizer. The process also biodegrades most highly toxic polychlorinated biphenyls and other synthetics in a natural microbial, enzymatic system that includes using sophisticated computer automation. The bioreactors can handle wastes ranging from those of a small-town population up to those from large cities, emit no gases, odours or leachates, and produce no undesirable by-products.

The project also includes two special elements designed to promote the new technology and "take the classroom to the people":

- special mobile units which can perform the same co-composting processes as larger plants, converting waste into humus. Each unit also carries video cassette players to run short educational programmes for anyone wishing to see them;
- a 5,000 tonne ship, outfitted with two large bioreactors, a soil-testing laboratory, a technical library and a conference room where seminars can be held at most ports of call.

areas. Biofertilizers (to increase crop yields and reduce the use of agrochemicals in farming), tissue culture, vaccines and some new diagnostics are all being transferred successfully.

Several countries (among them Brazil, China, Cuba, India, the Republic of Korea and Singapore) have set biotechnology as a major priority for development, investing significantly themselves, and encouraging foreign investment. Biotechnology-based enterprises have been set up and modern biotechnology research programmes have increased. The countries with economies in transition generally have a strong foundation in science and technology, and a critical mass of people skilled in biological sciences so, potentially, they can move forward quite rapidly in biotechnology development. But their lack of finances raises serious questions about how fast they can move.

Despite the advances in many developing countries, biotechnology is not yet widely used in cleaning up industrial processes or contaminated land, even though the CSD says the need to do this is "urgent". This is not for want of effort. For example, the United Nations Industrial Development Organization (UNIDO) Programme on Clean Industry which covers ongoing activities in waste minimization and industrial effluent treatment, includes biotechnology among the ESTs it promotes (see also Box 12.5). However, the CSD says there remains "enormous scope" in many countries for using existing environmentally sound biotechnologies "that are available, but not applied".

The reasons for this particular situation are the same as those inhibiting the general introduction of biotechnology. Biotechnology development has increased most rapidly in industrialized countries, with the result that the technical and information gaps between them and most developing countries have also increased. This raises concerns about the developing countries' ability to both acquire and manage new biotechnologies. Lack of resources adds to their difficulties, preventing them from restructuring their science and technology infrastructures, acquiring new technology management skills, and adjusting to new standards in biosafety. Some countries can cope – most cannot.

Even where international and bilateral support programmes in developing countries have introduced new initiatives in biotechnology

– and demonstrated successfully the potential for biotechnology applications – they have been financially constrained from moving faster and further. The CSD also states that the level of financial support is "far below" what is required if developing countries are to participate in, and benefit from, biotechnology development. Moreover, there is "major potential" for expanding the role of financial institutions at various levels in promoting biotechnology programmes and projects. The private sector – business, industry and the banks – can play a key role in applying biotechnology for sustainable development. "As commercial biotechnology development increases in scope and volume, and with the trend towards a globalized economy, the impact of biotechnology itself is likely to become increasingly global in nature", the CSD predicts.

Developing countries can also do more themselves by integrating biotechnology more fully into wider policy-making, for example. The CSD says national policies should address issues such as developing managerial skills to choose, assess and prioritize biotechnologies, applying appropriate standards and regulations, and perhaps "special economic measures" to encourage businesses to commercialize more applications.

Clear benefits

Biotechnology can offer both environmental and economic benefits. The Institute for Applied Environmental Economics in the Netherlands conducted a comparison between biostoning and pumice stoning of jeans, and concluded that biostoning was more environmentally sound. Other studies in the Netherlands suggest that biotechnology could be the cheapest method for treating soil, air and water problems. Moreover, biotechnology does not require raw materials or energy and produces hardly any secondary wastes – unlike other ESTs which, while extremely effective, require chemicals and/or energy and often shift wastes to other environmental areas, for example, from water to air.

The OECD has concluded that many biological ESTs are already competitive and have now become indispensable to environmental protection and clean-up. Certainly industry expects biotechnology to play an increasing role in all areas, not necessarily as the only solution, but as an important tool within a broader set of ESTs. Industry has no prejudices for or against biotechnology. The test is whether, compared with conventional technologies, it improves the cost-effectiveness of industrial processes.

Sources

Backs to the Future: United States Government Policy Toward Environmentally Critical Technology, 1992, World Resources Institute.

Biochemical Treatment of Geothermal Waste, Technology Brief, 1995, Brookhaven National Laboratory.

Biotechnology and Sustainable Development, Fact Sheet, 1993, UNIDO.

Biotechnology for a Clean Environment, 1994, OECD.

Energy and Environmental Technologies to Respond to Global Climate Change Concerns, 1994, IEA/OECD.

Environmental Economic Comparison of Biotechnology with Traditional Alternatives, 1996, Institute for Applied Environmental Economics.

Environmentally Sound Management of Biotechnology, 1995, United Nations Commission on Sustainable Development.

EPA Journal, May-June 1992, United States Environmental Protection Agency.

International Workshop on Biotechnology for Cleaner Production, 1995, Institute for Applied Environmental Economics.

Managing Solid and Hazardous Waste, Green Paper Series, 1996, United States Information Agency.

National Environmental Engineering Research Institute Annual Report, 1995.

New Era for Third World Biotechnology, Information Note, 1996, UNIDO.

Technologies for Cleaner Production and Products, 1995, OECD.

The Latona Project, Insight, Summer 1995, UNEP International Environmental Technology Centre.

Warmer Bulletin, various issues, World Resource Foundation.

Waste Management Technologies: Opportunities for Research and Manufacturing in Australia, 1990, Australian Department of Industry, Technology and Commerce.

Wider Application and Diffusion of Bioremediation Technologies, 1996, OECD.