The State of the Environment 1983

United Nations Environment Programme

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Selected Topics

United Nations Environment Programme

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FOREWORD

The present state of the environment report deals with three topics of international significance selected by the Governing Council of the United Nations Environment Programme at its tenth session: two contemporary issues (hazardous waste and acid rain) and one of a "futuristic" nature (environmental aspects of energy farms). In order to sharpen the focus of treatment of these problems, the presentation is given under four main headings: facts and figures, the problem, major actions taken or planned, and concluding remarks.

The report is based upon the viewpoints expressed in discussions with various members of the scientific communities on the above selected environmental problems. It does not suggest solutions or give recommendations, but is designed to stimulate discussion and public awareness from which solutions may emerge. It was initially presented to Governments at the eleventh session of the Governing Council of the United Nations Environment Programme, held in Nairobi in May 1983, and there was general agreement that the report realistically and accurately presented emerging environmental issues on which the international community at large and UNEP in particular should focus their attention.

PREFACE

1 One of the main functions assigned to the Governing Council of the United Nations Environment Programme as directed by the General Assembly of the United Nations in its resolution 2997 (XXVII) of 15 December 1972 is:

> "To keep under review the world environmental situation in order to ensure that emerging environmental problems of wide international significance receive appropriate and adequate consideration by Governments".

2 To assist the Governing Council in this task, the Executive Director prepares each year a report on the state of the environment. The first reports (1, 2, 3) discussed a broad spectrum of environmental issues, such as climatic change, the condition of the biosphere, the effects of toxic substances, food, energy and raw materials, population growth, stress and social tension and pollution. At its fourth session, the Governing Council decided (decision 47 (IV), sect. I, para. 10) that the annual state of the environment report should be selective in its treatment and that an analytical, comprehensive state of the environment be prepared every fifth year. Accordingly, subsequent annual state of the environment reports (4, 5, 6, 7, 8) dealt with some selected topics: the ozone layer, environmental cancers, land loss and soil degradation, firewood, chemicals and the environment, malaria, the use of agricultural and agro-industrial residues, energy conservation, schistosomiasis, resistance to pesticides, noise pollution, and tourism and the environment, carbon dioxide, heavy metal hazards, transport and the environment, military activity and the environment, the child and the environment, groundwater, toxic chemicals and human food chains and environmental economics. These and other issues dealt with in the annual state of the environment reports have been treated in greater depth in the first comprehensive analysis of the state of the environment carried out for the decade after the conduct at Stockholm of the United Nations Conference on the Human Environment, and was published on the tenth anniversary of the Stockholm Conference in 1982 (9, 10). This year, the state of the environment report deals with three topics selected by the Governing Council at its tenth session (decision 10/1, sect. II, para. 4): hazardous waste, acid rain and environmental aspects of energy farms.

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I. Introduction

1 Two of the most urgent tasks facing the world community are controlling dangerous pollution and finding secure and plentiful supplies of energy, particularly in developing countries. This report examines what to do about hazardous wastes that endanger human life and health, how to tackle acid rain which is damaging soil and water over large areas of industrialized countries, and the potential—and environmental impact—of harnessing the energy of plants.

2 Technological progress has brought enormous numbers of chemicals into everyday life. Five million substances have been identified; about 70,000 of these are marketed, about half of them in quantity. They have brought immense benefits to society, increased food production, improved health care, eradicated deadly diseases, and bestowed longer life expectancy and a better standard of living. But they have also brought new dangers, largely through the wastes generated in their manufacture. Tens of millions of tons of toxic and otherwise hazardous substances enter the environment every year as unwanted wastes. Managing and disposing of these hazardous wastes properly faces mankind with a significant problem. Until recently there were no standards or uniform regulations for disposal even in some industrialized countries. So an alarming number of critical problems built up over the years in places like Love Canal, near Niagara Falls in the United States, where homes were built on an old chemical waste dump and inhabitants were exposed to hazardous substances. Most developed countries have now passed laws controlling the disposal of these wastes. But there is a danger that companies will evade them by moving their processes or exporting their wastes to areas with less strict legislation, particularly developing countries.

3 Other unwanted wastes, sulphur and nitrogen oxides, are already often exported. They are pushed into the air, carried by the winds and spoil the rain which man has always valued as a prerequisite of life on earth. In many areas of the world the rain must pass through air polluted by these gases, which come from burning fossil fuels in industries, power plants, and cars. As it, and snow, falls, it reacts with the pollutants to produce something new, often a mixture of sulphuric acid, nitric acid and water. It has become *acid rain.* In Northern Europe, Canada, and the north-eastern United States, the rain is turning rivers, lakes and ponds acidic too, killing fish and decimating other water life. It assaults buildings and water pipes and tanks with corrosion that costs millions of dollars every year. It may even threaten human health, mainly by contaminating drinking water. It is a particularly modern, post-industrial form of ruination, and is as widespread and careless of its victims, and of international boundaries, as the wind that disperses it.

4 It is partly to avoid such pollution from fossil fuels that much attention has recently been given to developing renewable sources of energy. One of them is already the most important fuel for hundreds of millions of people, especially in developing countries. Trees, crops, aquatic plants and organic wastes of different kinds can all be valuable energy stores, and this "biomass" can be turned into usable energy by a variety of processes. Many countries are now

paying special attention to energy farms, areas of land or water exclusively devoted to growing plants for fuel. Any plant which is more valuable for energy than for other uses can be considered as a fuel crop, and there are many promising examples of using them for energy. Large-scale farms running into tens, even hundreds, of thousands of hectares are being considered both on land and at sea. But these could cause pollution and other problems that must be carefully assessed at an early stage to make sure that "green energy" is developed in an appropriate and environmentally sound way.

II. Hazardous waste

1 In the last decades there has been a chemical revolution. As industry has expanded, thousands of new chemical substances have been produced and put on the market, and their numbers increase every year. They are used in medicine, in the home, in agriculture and in industry itself and have done much to increase health and living standards. Yet they have also brought new dangers, for they find their way into the environment by many different paths, and can enter food and water supplies. Sometimes the environmental contamination results directly from their use; at other times because they are discharged in wastes.

2 Fears about their possible environmental effects were raised at the United Nations Conference on the Human Environment, held in Stockholm in 1972. That concern has since been justified, for there has been a succession of incidents where people have been affected by toxic chemicals in food, water and the environment.

3 One of the most worrying features of the problem is that very little is known about the long-term consequences of exposure to the chemicals. We know a good deal about their short-term effects from experiments on animals, and from the experiences of people who have been exposed to them at work. We know, too, that over longer periods some can cause cancer, delayed nervous damage, malformations in unborn children, and mutagenic changes that could produce disability and disease in future generations. Many other chemicals are likely to have similar effects, but because these take time to show and their causes are hard to pinpoint, we do not yet know which substances are the dangerous ones. The situation is made even more difficult because, once they are in the environment, chemicals spread in a very complex way and may be converted into other substances which have different effects.

4 Some risk from the use of chemicals is, of course, acceptable in return for the benefits they bring, but it is clearly prudent to limit the danger by preventing their release into the environment so far as is practicable. This is particularly important when it comes to disposing of hazardous waste. Yet some of the alarming incidents that have hit world headlines in the last decades happened because wastes were dumped with almost complete recklessness. Wastes have been considered to be worthless, and so there has been no economic incentive to recover them, and a positive encouragement to getting rid of them as cheaply as possible.

5 How a waste is handled is all-important. Bad disposal can make a relatively harmless substance troublesome, if not dangerous, while if a hazardous waste is properly treated, as much recent legislation requires, it will probably be safer than many others that are not officially classified as potential dangers.

A. Facts and figures

6 It has been estimated that over five million chemical substances have been identified; about 70,000 of these are marketed, maybe only half of them in quantity. Several thousand new ones are found every year, and about a tenth of the new discoveries reach the market. Not only are the numbers of substances growing rapidly in the chemical revolution; the quantity produced is

increasing just as fast. The total production of synthetic organic chemicals, for example, rose more than 50 per cent in the past decade (1). It is hard for public health officials, even in developed countries, to keep abreast of the information needed to control their use and disposal.

7 Recent laws require industries to notify the authorities of new chemicals before they are manufactured or put on the market, and lay down that they should be screened for hazards, or classified for toxicity after testing (2, 3, 4). These laws will help in controlling the use of these chemicals, but are less valuable in regulating waste disposal. By-products and intermediate chemicals, created during the manufacturing process, usually end up in the wastes, and they may be more active, chemically and biologically, than the finished products put on the market—and so potentially more harmful in the environment. Wastes are not covered by the notification schemes recently brought in by law; so this potential for damage may go unrecognized. Moreover, it is physically difficult to screen wastes for toxicity because they are highly complicated mixtures of substances. If these wastes are exported for disposal or used for other purposes they may do serious damage because people simply are not aware of the risks. There are obvious dangers here for developing countries (5), and even the wealthiest consumers in developed nations are at risk, as the experience of one horse-breeding farm in St. Louis, Missouri, shows. The farm was sprayed with waste sludge, which turned out to be contaminated by dioxin, a contaminant of the herbicide 2,4,5-T and a by-product of its manufacture. Half the valuable horses were killed, as well as pets and chickens, and two people were seriously affected. Sludge and liquors left in the bottom of stills used in the chemical industry have been sprayd on unpaved roads to keep down dust. This can lead to poisons being spread about without anyone realizing it, except, perhaps, companies that were not required to make the dangers known (6).

8 The United States of America is the biggest manufacturer of chemical substances, generating about 60 million tons of hazardous wastes a year (1), compared to an estimated 20 to 30 million tons a year in the whole of the European Economic Community (7). Hazardous waste is about 10 to 20 per cent of the world's manufacturing waste, and only a few per cent of all its solid refuse, which also includes municipal rubbish, agricultural waste, sewage sludge, spoil from mining and ash from power stations.

9 The term "hazardous waste" is restricted to wastes from chemical processes and those generated by cleaning or closing chemical factories or contaminated sites. These wastes are extremely varied, and so it is hard to give a simple, brief description of them. Under United States law hazardous wastes are defined generally as those that pose a substantial threat, present or potential, to human health or other life. Laws in other developed countries define them more strictly, specifying the processes giving rise to them, certain poisonous constituents or the results of toxicity tests (8). They include, to cite only a few of the many possible examples, cyanide and paint residues, wastes from metal refining and finishing, tar from refining and distilling, flue gas sludges, organic solvents, oily wastes, cyanide, asbestos, arsenic, mercury, cadmium, lead, phenols, herbicides and insecticides, acids and alkalis. Many of the damaging incidents that have arisen from bad disposal are related to the production of organic chemicals, which has advanced so spectacularly in recent years. However, the greatest tonnage of chemicals produced is still accounted for by the common inorganic acids, alkalis, metals and chlorine (9), and these can also be hazardous.

10 Undisciplined disposal of these wastes can cause fires, explosions, air, water and land pollution, contamination of food and drinking water, damage to people who get them on their skins or inhale their vapours, and harm to plants and animals. It is an alarming list, and in practice most of the things that could go wrong have indeed occurred. In fact the incidents that have hit the headlines are probably only a few of those that have actually taken place; many more are likely to have gone unreported. Even those incidents which have become internationally famous have not always been critically studied and analysed in a way that might help determine causes of the trouble and bring out other important lessons that developing countries could learn to avoid similar harm as they develop chemical industries.

11 Perhaps the most notorious incident of all is the outbrek of "Minamata disease" in Japan. Methylmercury discharged from a chemical factory into the sea, or produced in the sea from inorganic mercury discharges, contaminated the fish eaten by local people at the town of Minamata on Kyushu island, Japan. As a result of this and a similar incident at Niigata on the east coast of Honshu, nearly two thousand people have so far suffered neurological disorders; about four hundred have died (10). There have also been episodes of mercury poisoning in Puerto Rico and Brazil (5). Disposing of liquid waste from mines has also long been a problem. Chronic poisoning of humans (Itai-itai disease) ascribed to consumption of locally grown rice contaminated with cadmium from zinc mine drainage has been reported from Toyama Prefecture, Japan (11). More contamination of rice fields, this time from copper mining, is known to have occurred in Malaysia (12). Indeed there are many reports of pollution from mines throughout the world (13).

12 The Rhine and the Mississippi are classic examples of rivers continually polluted by industrial waste. Both are used for drinking water. The Netherlands draws water from the Rhine, downstream of many industrial waste discharges, and the Mississippi supplies New Orleans. Both rivers are so polluted by organochlorine and other compounds that it is doubtful whether they are suitable sources of drinking water. Studies have suggested that their contamination could be linked to the fact that the people who have to use these waters suffer slightly higher cancer rates than expected (14).

13 There have been several hundred cases of the contamination of wells by poisons from hazardous wastes—the most common of all the dangers to arise from improper waste disposal. These often occurred because the wastes were put into sand or gravel pits or old mine workings in fractured strata. Places like these attract people disposing of liquid waste and slurry because they are cheap and the liquid disappears quickly, flowing out into the subsoil and into ground water; but this is part of the problem because the soils contain little clay and other absorbent substances. As a result they do not filter the waste, trapping the dangerous chemicals, and so protecting the ground water from contamination. To make things worse, the wells were usually shallow, privately owned ones and the water received no treatment that could remove the pollution. Among the main poisons that have turned up in such water supplies are arsenic, pesticides, gasoline, phenols, chromate, and chlorinted hydrocarbons (6, 15).

14 Several serious incidents have been reported from the United States (6). Wastes from the manufacture of defoliants, pesticides and chemical warfare agents were stored in unlined canals and ponds at the Rocky Mountain Arsenal near Denver, Colorado, in alluvial deposits which allowed dangerous chemicals to get through to the ground water. An area of at least thirty square

miles was poisoned. From 1951 crops irrigated from shallow wells turned brown and died, and sheep and other livestock drinking from the wells perished. Even though over a million dollars was spent in trying to put the problem right, it has still not been permanently solved. At Toone-Teague Road, Medon, Tennessee, people suffered respiratory disease, dizziness and fatigue because private wells were contaminated by pesticides (heptachlor, endrin, dieldrin) dumped in an old river bed. At Perham, Minnesota, in 1972 11 people were poisoned by arsenic from a well recently drilled near a disused village rubbish tip. Just over 20 kg of grasshopper bait had been buried 40 years before (6).

15 Other dumping has exposed people to poisonous vapours from organic compounds at concentrations that could not even be permitted in factories (industries necessarily expose their workers under controlled conditions to higher levels than would be tolerated for the general public). The victims have suffered headaches, nausea, dizziness, and discomfort when breathing—and, after prolonged exposure, skin rash, sores, pimples, and numbness of the limbs. At Love Canal, near the Niagara Falls, United States of America, homes were built on a former dump containing pesticides, chemicals used in making plastics and the sludges from the bottom of stills. The dump was sealed with clay and sold to the local community. At Lekkerkerk, near Rotterdam, in the Netherlands, drums of paint solvents (aromatic hydrocarbons) were included in rubble used to reclaim land. Houses were then built on it. In both cases several hundred families had to be evacuated and decontamination measures costing tens of millions of dollars had to be undertaken (10).

16 Most developed countries have a heritage of contaminated sites where chemicals have been manufactured or hazardous waste deposited. Some have launched campaigns to find and clean up the sites, financed either with public money or with funds levied from the chemical industry (16). Others tackle the sites only when they turn up. At any rate, there is now considerable experience both of these problems and of cleaning sites contaminated by spills and accidents (17, 18).

B. The problem

17 Until recently, many hazardous wastes were disposed of without proper evaluation of the environmental consequences (1, 6). Among other bad practices, liquids were put in unlined pits on factory sites, allowing the waste to drain away, wastes were stored or dumped out in the open, or in derelict buildings, off company land and then unscrupulously abandoned; and contractors were hired to dispose of the waste who then got rid of it in the cheapest way they could, either because they did not fully know of the dangers, or because they did know, but did not care.

18 Meanwhile, new chemicals were being introduced to the market, although their effects on health and the environment had not been fully researched. Some of them were known to persist and spread in the environment and were suspected of causing long-term health damage. There were fears that uncontrolled disposal of hazardous waste could cause those chemicals—and particularly those which are toxic, persistent and accumulate along food chains—to spread widely and cause health damage and environmental harm even outside the countries of origin. The spread of polychlorinated biphenyls (PCBs) is often cited as proof of this danger.

19 The incidents cited in section A above may seem anecdotal and devoid of any statistical significance. This is a fair reflection of the truth. There is a lack of information on the magnitude and frequency of such incidents. Many authori-

ties speculate that the full extent of the problem has yet to be revealed. They point to the damaging incidents that have been reported and the fact that they have only been discovered when things have gone badly wrong. Sometimes the discoveries have been by chance. Incidents may well go unreported unless someone has diligently investigated them. In this somewhat haphazard situation, it is very difficult to get scientifically sound information on how many incidents have been caused by disposing of hazardous waste or how serious the problem is world-wide. So it is hard to say whether the true extent of the damage has been appreciated or not. Nevertheless, even countries that have not uncovered serious problems do appreciate that past practices have been unsatisfactory and need to be improved (19).

20 Laws controlling the disposal of hazardous wastes are now in effect in most developed countries. The immediate need is to make sure that they are enforced in a cost-effective and environmentally sound way. Some developed countries have still to create an effective enforcement system staffed with adequately trained people. Developing countres following the same legislative path may have greater problems in recruiting the right staff. International organizations could consider publishing manuals and providing training facilities, though these should be directed at dealing with the actual wastes generated in developing countries rather than at establishing comprehensive theoretical principles (9).

21 The lack of trained staff is only part of the problem. There are so many companies carrying out so many operations with hazardous waste that even well-staffed authorities cannot guarantee full inspection. In the United States of America, for example (20), there are about 57,000 firms licensed to generate the waste, 14,000 licensed to transport it, and another 14,000 facilities licensed for disposal. Much, therefore, depends on the integrity and competence of firms—reinforced by the fear that they will lose their licences if they are caught misbehaving.

22 As the controls have tightened in many developed countries, chemical industries have had to pay more for getting rid of their wastes. Some have been tempted to avoid these extra costs by moving their operations or exporting their wastes to countries where the laws are less strict, or less strictly enforced. These countries could well become international dustbins, and end up with the same sort of problems that brought the strict legislation in the first place. There have even been a few cases where companies have shipped waste to another country, ostensibly for storage, and then abandoned it. Waste from the Netherlands ended up in the United Kingdom in this way, and wastes from the United States of America have been stored in a warehouse in Mexico. Recently, dioxin-containing waste from Seveso, Italy, disappeared during transfrontier transport and was finally found to be inadequately stored in an abandoned slaughterhouse in France. Developing countries would be particularly vulnerable to such pollution exports.

23 Companies setting up in developing countres often stipulate that their processes must remain secret (5). If they insist that the composition of their wastes should also be cloaked in secrecy the countries may never know exactly what hazardous substances, in what quantities, have been put into their disposal sites—and will find it almost impossible to control the situation. In fact, so much secrecy can rarely be necessary, and, if companies do insist on it, countries should require them to give assurances about the hazards posed by their wastes, and to accept financial liability for any problems caused.

C. Major actions taken or planned

24 The major actions are the national laws for controlling the disposal of hazardous waste now in force in the developed countries (9, 20, 21) and international agreements on limiting marine pollution either from disposal at sea (the London Convention) or from discharges from the land (the Paris Convention). These conventions on pollution of the sea have been supplemented by regional agreements where countries bordering particular seas like the Baltic, the North Sea and the Mediterranean make possible more effective action to solve their local problems. On land, there have also been major clean-up operations on hazardous waste sites in a few developed countries.

25 The laws have in general laid down that the disposal of hazardous waste should be approved by regulatory authorities, either on a case-by-case basis or through general regulations (22, 23). They have brought about a marked improvement, by setting standards where few existed before. Companies have had to pay greater disposal costs, and this has encouraged them to save money by introducing better ways of dealing with wastes. They have increasingly included good waste management in the overall design of new processes, and chosen ones that generate as little waste as possible. They have paid more attention to using waste as a resource, reclaiming materials and fuels from them for re-use. They have even begun waste exchange schemes, where companies advertise their wastes for sale to other firms that can use them as raw materials. And they have increasingly separated out and segregated different types of waste so that they can be re-used or disposed of more economically (9). These resources have already had short-term results; for example solvent wastes, contributors to some of the major pollution incidents of the past, have been reduced. More pollution reduction can be expected in the longer term as these changes are introduced widely.

26 Countries have drawn up their own statutory definitions of what should be regarded as hazardous waste under these laws. There are also different definitions for the international agreements and for EEC directives. The wastes are defined as hazardous because they possess certain characteristics, like flammability, persistence or toxicity; because they are generated by certain listed processes, or because they have certain listed toxic constituents. The laws usually provide that small quantities of hazardous wastes should be exempt from the regulations. This is controversial because it can allow companies to evade controls by breaking larger amounts of wastes down into small packages. Besides, even small amounts of hazardous waste can produce quite serious effects on health when they are disposed of inadequately—as the incident in Perham, Minnesota, illustrated (6). The underlying reason for the exemption is that there has to be a compromise in practice between the ideal of full control and the need to limit the burden of inspection to what is practicable and reasonably effective. In the United States, for example, well over 97 per cent of all the hazardous waste is generated by just five per cent of the factories, which each produce over five tons of it a month. Ninety-one per cent of the factories produce less than a ton a month each (20). In situations like these, authorities can concentrate on the main waste producers with a relatively small staff; but if they decide to cover all firms, including the smallest producers, they could find themselves having to inspect ten times as many factories.

27 Some national laws have set up systems of manifests, papers which ensure that the people who handle the waste as it passes from factory to disposal site acknowledge responsibility for it while it is under their control. These systems are designed to stop irresponsible dumping, but they can be evaded without much difficulty by unscrupulous operators. The United States, the Federal

Republic of Germany, and the Netherlands have what are probably more powerful safeguards. They require firms that generate, transport or dispose of the waste to be licensed. Even these systems are by no means watertight, however, if only because so many firms are involved that it is impossible to provide very detailed inspection.

28 The United States has developed the most elaborate system of control of all (20). There, the licensed firms are required to provide financial bonds (promises of money) and vehicles and other equipment to deal with emergencies. They also have to conform to strict conditions laid down in codes of practice for the various means of treating and disposing of waste. These provisions are backed up by a system of inspection which can, for example, demand that incinerators are demonstrated to show they do the job properly. These measures impose a considerable financial burden on both industry and government administration. One result may be that industry moves its operating or exports its wastes to less demanding places—and this could cause more environmental damage in the end.

29 In some countries central or local authorities provide special disposal centres (24); when this is done there should be enough facilities to cope with their hazardous wastes. In others, however, the provision of disposal facilities is left entirely to private enterprise, and there may be a shortage. Entrepreneurs may not think it worth their while to go into business to set up facilities under the codes laid down by government. When this happens, government, industry and disposal firms will have to collaborate closely and rigid codes aimed at almost entirely eliminating the release of hazardous wastes to the environment may have to be relaxed somewhat in the interest of reaching a more practicable solution.

30 It may often be better for Governments to delegate control of hazardous wastes to local or regional authorities than to set up detailed codes that apply throughout the country (16). This, for example, is the case in France where regional authorities are responsible for "special" waste management and a national network of disposal facilities has been created (25). National codes may be designed to control the worst possible cases and require all disposals to be treated in the same way. Local authorities can take a more pragmatic, cost-effective approach, for they can use their local knowledge of what has happened in the past to modify the more restrictive rules without increasing the risk to the environment. If a Government does delegate authority in this way it should also retain some control by setting broad guidelines within which the local authorities will be required to work.

31 There are various ways of pretreating waste so that it is easier or safer to transport or ultimately dispose of it. Some of these methods are disposal methods in their own right. They may be classified as technologies aimed at volume reduction such as precipitation and dewatering. immobilization of toxic components through solidification into cements, bitumens, polymers or synthetic rocks; or detoxification through chemical or biological treatment. It has been said that treatment technology is generally available for most hazardous wastes (26). Among the options for disposal are sanitary landfill, incineration, marine or underground disposal, and deep well injection (8, 16). The choice of appropriate technology for a particular waste depends on many factors including waste characteristics; distance to the site; geological and hydrological factors; acceptable risk and cost.

32 Naturally, national laws and codes of practice do not necessarily provide a reliable guide to what actually goes on in a country. That depends on how rigo-

rously the regulations are enforced and on whether codes are merely seen as targets or used as manuals of working practice. It does seem, though, that there are significant differences among the developed countries. This reflects variations in national aims and practices and results in different costs. The United States legislation was aimed, among other things, at outlawing unlined lagoons, and a containment philosophy is now in force. The high water table of the Netherlands has strictly limited disposal in the ground. Disused salt mines in very stable strata in the Federal Republic of Germany make particularly good disposal sites and supplement special local treatment facilities. The United Kingdom and the CMEA member States (21) share a preference for mixing hazardous and other wastes, including household garbage, and disposing of it in the ground in carefully selected sites. This practice protects water supplies by relying on the hazardous wastes being degraded and fixed in the site and undergoing chemical changes in unsaturated and impermeable strata. Developing countries can benefit from the experience of these different approaches when selecting the most economic solution to their particular disposal problems.

33 The marine conventions and the EEC Directive on Ground Water control disposals on a case-by-case basis (27). They have black-lists of banned substances whose discharge into the sea or ground water is prohibited. Another list comprises substances that can only be discharged with specific permission, while the rest are subject to general authorizations. The specific permissions are given if assessments of how the wastes behave in the environment, and the damage they are likely to do, show that the likely harm is acceptably small if appropriate safety measures are taken. The assessments, however, are necessarily based on models which cannot precisely forecast what will happen and can only make approximate predictions, because we do not yet know enough about the subject. So the permissions are based on probabilities rather than certainties of safety.

34 The marine conventions, coupled with measures by the International Maritime Organization to restrict pollution from oil spills, have had a positive effect. The dumping of chlorinated hydrocarbons has been reduced, if not eliminated (28), and partly replaced by incineration at sea. This operation releases acids which fall out into seawater, and was brought under the provisions of the London Convention in 1978.

35 A recent United Nations study concluded that noticeable pollution of the marine environment is confined to coastal areas, and generally concentrated there in "hot spots", whereas contaminant concentrations in the open oceans are not raised significantly above background levels (29). This has lead to the conclusion (30) that the use of the sea for disposal of certain wastes may still be acceptable, provided that such introductions are carefully regulated and controlled. However, much caution is necessary because of the limited data base and the serious lack of understanding of the likely ecological effects resulting from chronic exposure to pollutants at low concentrations. Similar concern was expressed during the Third United Nations Conference on the Law of the Sea. As regards radioactive wastes, the Seventh Consultative Meeting of the Contracting Parties to the London Convention, in February 1983, adopted a resolution requesting that an expert meeting be held to review the scientific and technical considerations relevant to recent proposals for the amendment of the Annexes to the Convention related to the dumping of such wastes. The Contracting Parties were called upon to suspend the dumping of radioactive wastes at sea pending the outcome of the Expert Meeting.

36 Several international organizations have become deeply involved in the manifold aspects of the handling, transport and disposal of hazardous waste. The important work of the International Maritime Organization related to international marine conventions has already been mentioned. The Waste Management Policy Group of the Organization for Economic Co-operation and Development has been dealing with, *inter alia*, the economics of hazardous waste management and the siting of waste management facilities. Guidelines on transfrontier movements of hazardous wastes are in their final stage of preparation and will be submitted to the Environment Committee before the end of 1983. UNEP, jointly with the World Health Organization's Regional Office for Europe, has prepared an authoritative text on policy guidelines and on the technical aspects of the management of hazardous waste (9). A meeting of government experts to deal in greater depth with the legal problem of international transport, handling (including storage) and disposal of hazardous waste, as recommended by the Ad Hoc Meeting of Senior Government Officials Expert in Environmental Law, will be convened by UNEP during early 1984.

D. Concluding remarks

37 The laws controlling the disposal of hazardous wastes passed in developed countries in recent years will go a long way towards preventing the careless disposal practices of the past which contributed to serious incidents of damage to health and the environment. Developing countries can do much to avoid similar problems by studying the incidents and the laws now in force. The further development of processes that generate little waste, the designing of new ones with proper waste disposal management built into them, recycling techniques, and other measures aimed at minimizing the amount of waste produced and improving ways of dealing with it, should all be strongly encouraged. They can be seen, at least in part, as results of the increasing demand for regulation and control.

38 Disposal practices and the degree to which they are controlled differ widely among developed countries. This is, no doubt, a reflection of differing public attitudes to the risks of environmental contamination by low levels of chemicals with largely unknown long-term effects. The differences are important enough economically to affect industry's costs. So there is a threat that some chemical processes and some hazardous wastes may be moved to less demanding locations, including developing countries which may not be equipped to adequately control these polluting activities.

39 Hazardous waste can easily be slipped across frontiers. National definitions of it differ. It can be shipped, without difficulty, under labels which fail to inform customs officers what it consists of (there is no international agreement on how wastes should be characterized), and it is very difficult for them to carry out checks. So the export of hazardous wastes is a distinct possibility—and incidents caused by careless disposal may follow. Transfrontier shipment of hazardous waste should therefore be regulated on the basis of internationally agreed procedures for prenotification and the provision of adequate information to the designated controlling authorities of both the exporting and the receiving countries. UNEP and other international organizations will have an important role to play in this area.

40 Avoiding incidents in future, as far as that is possible, requires both vigilance and the provision of adequate and environmentally acceptable facilities for disposal at reasonable cost, preferably near the point of generation of the waste. Policies that are based on reasonable assessment of the risks involved

with hazardous wastes, but which resist imposing excessive safety regulations, may be the most effective. Rather than starting off with preconceived notions, countries should adopt a pragmatic approach, based on calculating what should be done to overcome the risks of each particular waste at each particular site.

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III. ACID RAIN

1 Only farmers really like to see the rain, but everyone realizes how important it is. Mankind has always reverenced what Tennyson called "the useful trouble of the rain" (1). Without the 110,000 cubic kilometres of it that fall each year (2) the continents would be barren, for the land has never been more than an outlying province of the kingdom of life. Long unconquerable by living things, late to be colonized from the waters, the land could still not sustain them if it were not for this constant support from life's home country—the sea.

2 Yet now the rain in parts of the earth has taken on a new and threatening complexity. It mixes in the air with pollution from burning fossil fuels—particularly in power stations, factories and motor vehicles—and brings down dilute sulphuric and nitric acid. This is killing fish and other water life, and corroding buildings, including some of the world's most important ancient monuments. It may also damage forests and croplands, and possibly pose a substantial threat to health.

3 Acid rain is not a new phenomenon—the term was first coined by a chemist, Robert Angus Smith, who described pollution in Manchester, England (3) over a century ago. What is new is the realization that it is an international problem. The air of towns like Manchester has been largely cleaned, partly by building tall chimneys at power stations and factories, which push pollution high into the air. These chimneys have made things better locally, by dispersing the pollutants, but aggravated the international difficulties. For the sulphur and nitrogen compounds emitted by burning fossil fuels can be blown thousands of kilometres by the winds, to cause acid rain in countries far from their points of origin.

4 Acid rain was first raised as an international problem by Sweden at the United Nations Conference on the Human Environment in Stockholm in 1972, and it has now developed into a major international environmental issue. At first the Swedish views were treated with some disbelief, particularly by some of the emitting countries. Over the last decade, however, there has been a great deal of international research into the issue. Ample information was available by the end of 1982 through the activities of the Co-operative Programme for Monitoring and Evaluation of Long-range Transmission of Air Pollutants in Europe (EMEP), under the Convention on Long-range Transboundary Air Pollution 1979, and through activities conducted in accordance with the Memorandum of Intent Between the Government of Canada and the Government of the United States of America concerning Transboundary Air Pollution. Furthermore, a special conference on acidification of the environment was held in Stockholm in 1982, and reviewed and assessed a large amount of scientific information not previously available. This information has been of great help in preparing this chapter.

5 It is now universally recognized that acid rain does cause environmental damage and it does give rise to an international problem. The evidence indicates this is the case even though a number of scientific and technical questions are still not resolved. International arrangements—like the Convention and the Memorandum of Intent referred to above—are now available that could be used to work out a solution.

6 So far, acid rain has been seen as an essentially regional problem, confined to the industrial areas of the northern hemisphere. But, though the problem was first perceived there, it may become much more widespread—for acid rain is likely to occur wherever fossil fuels are intensively used.

A. Facts and figures

7 Acidification is an environmental problem, or becoming one, in parts of Europe and North America. Around five to ten million square kilometres of these continents are affected (4, 5). Similarly polluted areas are likely to exist elsewhere in the world, especially around large urban and industrial conglomerations. We do not yet know where they are, because so far no evidence on them has been sought.

8 Industrial regions of the world suffer much more acidic fall-out than they did before the industrial revolution. This is because power plants, some industrial processes, vehicles and homes emit sulphur and nitrogen compounds, mainly from the burning of fossil fuels, and have greatly increased the amount of them in the environment.

9 Natural processes also put sulphur and nitrogen compounds into the air, besides man-made sources. Nobody knows precisely how much they contribute around the globe. Estimates vary between 78 and 284 million tons of sulphur a year in the form of sulphur oxides (6-10), and between 20 and 90 million tons of nitrogen a year in nitrogen oxides (6, 7, 11, 12).

10 In comparison, man emits between 75 and 100 million tonnes of sulphur a year. So, despite the differences in estimates on natural sources, it can be concluded that man-made and natural emissions of sulphur are, globally, of the same order of magnitude, although in areas of concern in Europe and North America the ratio of natural to man-made emissions may be as high as 1 to 20.

11 Burning coal provides about 60 per cent of the man-made emissions, burning petroleum products gives rise to another 30 per cent, and various industrial processes account for the remaining 10 per cent (6). Approximate estimates indicate that burning fuel in electric power stations and industry provides almost three-quarters of sulphur emissions in the European Economic Commission countries.

12 There are indications that sulphur dioxide emissions (the main pollutant in Europe and North America) have not increased during recent years, as they were predicted to do, and are not likely to rise over the coming decades either (13). This is the result of two factors: better pollution control, and less burning of fossil fuel as a result of energy conservation and, possibly, slower economic growth in the West than had been expected.

13 Like sulphur-oxide pollution, pollution from nitrogen oxides is also of the same order compared to natural sources (12). Fossil fuel combustion (5, 13, 14) yields about 20 million tons of nitrogen a year which have already caused environmental problems on a regional and local basis in industrialized countries.

14 Not all the pollution is acid rain, i.e. sulphuric and nitric acid dissolved in precipitation. Some of it happens when the sulphur and nitrogen oxides as such fall out on the land, in what is known as "dry deposition". In general this tends to be the main form of the pollution near its source, and the longer the gases stay in the air, the more likely they are to go through the complex changes that will turn them into acid rain (or wet deposition), to fall perhaps thousands of kilometres from where they began their journey (5, 15). Wet deposition rates are fairly well known, but dry deposition is harder to assess

and rates remain more uncertain. Both types of deposition can be intercepted by vegetation canopies. The canopies of evergreen forests, in particular, can be subjected to high deposition rates.

15 Each country gets part of its acid fall-out from its own pollutants, but receives the rest on the winds from neighbouring countries. EMEP has worked out estimates of how much sulphur is emitted, and how much deposited, in individual European countries. This reveals which of them are "net importers" and which "net exporters" of air pollutants (16, 17).

16 Government agencies and departments in the United States and Canada are monitoring acid deposition under the National Atmospheric Deposition Programme (NADP) and the Canadian Atmospheric Network for Sampling Air Pollutants (CANSAP). These, too, aim at working out deposition rates and identifying which areas export, and which import, the pollution. Co-operation between the two countries was greatly enhanced in 1980 when the Memorandum of Intent Concerning Transboundary Air Pollution was signed by their Governments.

17 Reductions in emissions might well not benefit everyone equally. Because of the complex changes the pollutants undergo in the air, fall-out might decrease unevenly from place to place. But the experts attending the Stockholm Conference on Acidification of the Environment agreed that total fall-out over a whole continent like Europe or North America would be reduced approximately in direct proportion to cuts in the amounts of sulphur and nitrogen emitted there (13).

B. The problem

18 Lakes and rivers were the first victims of acid rain to become evident. Hundreds of lakes in parts of Scandinavia, the north-east United States, south-east Canada and south-west Scotland have turned acid. Parts of these areas are particularly vulnerable because their soil and bedrock offer little protection against acidic rain. They are made up of minerals like granite, gneiss and quartz-rich rocks which contain little lime and do not weather easily, and therefore can do little to neutralize the acid when it falls. In Sweden damage to fisheries attributed to acidification has been observed in 2,500 lakes, and is assumed to have taken place in another 6,500 where signs of the process have been found. Meanwhile, out of 5,000 lakes scattered over 28,000 square kilometres of southern Norway, 1,750 have lost all their fish and 900 others are seriously affected. In Eastern Canada, some 52,000 km^2 of surface waters are receiving excessive amounts of acid rain and have a low to moderate ability to cope with them (18). Nearly 20 per cent of all the lakes that so far have been examined in Ontario have either been turned acid, or are extremely sensitive to the process. Between 30 and 60 per cent of the lakes in various areas of south-west Quebec are considered to be sensitive or highly sensitive. And in Canada's Atlantic provinces many lakes have been turned 10 to 30 times more acid during the past two decades (4, 5, 18). Similar situations have been observed in the north-east of the United States.

19 As the water becomes more acid, the amount of aluminium in it starts to increase rapidly. Concentrations as low as 0.2 milligrams per litre of the metal in acid water kill fish. Large-scale fish kills have been recorded in some Swedish lakes, and these have been attributed to aluminium poisoning rather than to high acidity alone (19).

20 At the same time, phosphates, which nourish phytoplankton and other aquatic plants, attach themselves to the aluminium and become less available as a nutrient. So increasing aluminium levels may reduce primary production on

which all other water life depends. As the water gets more acid still, other metals, like cadmium, zinc, lead and mercury, also become increasingly soluble. Several of them are highly toxic, and some may be taken up by water life through food chains, though little evidence of this is available so far.

21 Soils are normally much better able to resist acidification than lakes, rivers and streams, and so can take much more acid without noticeable ecological drawbacks. Their vulnerability differs depending on their type, the kind of bedrock they cover, and the use to which man puts them. The most vulnerable lands are those that have bedrocks poor in lime, covered with shallow layers of soil containing low concentrations of protective substances. Large parts of Scandinavia are like this.

22 The acidification of soils is not merely due to acid deposition; it arises from a natural process as well as the result of biological processes within the soils. Normally the acids thus produced are neutralized during the weathering of mineral soil particles but, depending on the composition of the soils, their capacity to neutralize more than a definite amount of acidity is limited.

23 Acidification may cause nutrients like potassium, magnesium, calcium and other micro-nutrients to leach more rapidly out of the soil, decreasing soil fertility. Aluminium concentrations would rise, just as they do in water, thus damaging plants and reducing the availability of phosphorus to them. As in water, too, metals like cadmium, zinc, lead, mercury, iron and manganese would spread through the environment more readily with acidification.

24 Intensive experimental research into the effects of acidification on forest, land and wood production was carried out in the 1970s in Scandinavia. It is still going on, but so far the results are inconclusive. Acid fall-out does seem to have a distinct effect on soil microbiology, chemistry and fauna—but the effects on the growth of plants, including trees, are far less clear. Indeed, depositions of nitrogen may even have a fertilizing effect and increase productivity significantly, at least in the short term. Studies on the trends of tree growth in southern Sweden between 1950 and 1974, for example, failed to reveal any statistically significant pattern (20).

25 In the Federal Republic of Germany, on the other hand, 7.7 per cent of the forest area has been reported in 1982 to be damaged (75 per cent of the damage being light, 19 per cent medium and 6 per cent heavy) by a wasting disease due to the consequences of deposition and accumulation of air pollutants (21), as a consequence of which trees have suffered more storm damage and experienced regeneration difficulties. These forests receive much more fall-out than Scandinavian ones because they are close to cities and big industrial areas, such as the Ruhr, with many polluting sources.

26 One reason postulated to explain this damage is the combined effects of surges of naturally produced acid, extreme climatic situations (very high or low rainfall, temperature extremes) and atmospheric acidic deposition. The consequent release of aluminium into the soil makes it easier for bacteria to damage the fine roots of the trees. This reduces their vitality, leads eventually to a rotting disease, and may make them more vulnerable to storms (22). High concentrations of sulphur dioxide in the air may damage leaves, and so cut the trees' productivity. Acid fogs, persisting for several days, may also damage trees in mountain areas. The role of photo-oxidants in the causation of tree damage is also suspected and being actively investigated (23).

27 As well as the health of important ecosystems, human health may also be put at risk by pollution. High concentrations of sulphur dioxide, nitrogen oxides and dust have long been known to be harmful. This issue is only marginally

related to the problem of acid rain, since such concentrations are usually only found close to the sources of pollution, and sulphur oxide levels in many European and North American cities have been decreasing recently. The health effects from such direct pollution have been dealt with extensively under the Criteria Programme of the United Nations Environment Programme and the World Health Organization (22, 23) which is now part of the International Programme on Chemical Safety (a joint programme of the United Nations Environment Programme, the International Labour Organisation and the World Health Organization), and they need not be discussed here in detail. Suffice it to say that the minimum concentrations of sulphur dioxide and nitrogen dioxide which the Task Groups considered to cause health damage are: sulphur dioxide, 250 micrograms per cubic metre as a 24-hour average or 100 micrograms per cubic metre as a long-term average; nitrogen dioxide, 190-320 micrograms per cubic metre, as a maximum one-hour exposure not to be exceeded more than once a month (24, 25).

28 Other, indirect, health hazards are suspected. These would be caused by metals such as lead, copper, zinc, cadmium and mercury released from soils and sediments by increased acidification. They can get into groundwater, rivers, lakes and streams used for drinking water, and be taken up in food chains leading ultimately to man. The releases of cadmium in particular may give rise to a growing problem as acidity increases, since normal levels in human food are already close to the acceptable daily intake. Acid water may also cause galvanized steel and copper water pipes to release metals, and it seems that the risk develops as soon as the acidity of the water rises above normal (26, 27). Most drinking water in industrialized countries, however, is supplied by public water works which eliminate this problem with proper treatment techniques; but much remains to be done in developing countries.

29 Meanwhile, acid accelerates corrosion in most materials used in the construction of buildings, bridges, dams, industrial equipment, water supply networks, underground storage tanks, hydroelectric turbines, and power and telecommunications cables. It can also severely damage ancient monuments, historic buildings, sculptures, ornaments and other important cultural objects. Some of the world's greatest cultural treasures, including the Parthenon in Athens and Trajan's column in Rome, are being eaten away by acid fall-out.

30 Tests have shown that materials corrode between twice and ten times as fast in polluted urban and industrial atmospheres as they do in the countryside. Carbon steel (both coated and uncoated), zinc and galvanized steel, copper, nickel and nickel-plated steel, sandstone and limestone all corroded faster as the amount of sulphur dioxide in the air increased (28). On the other hand, materials such as aluminium and stainless steel were only negligibly affected. According to an ECE study the corrosion of painted and galvanized steel structures causes the greatest economic losses to society. The costs average between $2 and $10 each year for every European (28).

31 Like direct health damage, this problem is mainly confined to urban and industrial areas where pollution levels are high. In Central Europe, however, polluting areas are so heavily concentrated that the countryside suffers more than in other parts of the world. And if surface and ground waters turn acid, submerged constructions may suffer from corrosion over a much wider area.

C. Major action taken or planned

32 The damage to water can be alleviated by adding lime to lakes, rivers and streams and/or their catchment areas. Many chemicals such as caustic soda, sodium carbonate, slaked lime, limestone, or dolomite can be used to counter-

act the acidity. Slaked lime and limestone are the most popular. Sweden began a liming programme in the autumn of 1976, and by the summer of 1982 about 1,500 Swedish lakes had been limed at a total cost of about $15 million (5).

33 Liming alleviates some of the symptoms of acidification, but it is no real cure, is not practicable for many lakes and running waters, and does not attack the causes of the problem. It should, however, be considered as an interim measure which offers some defence until the emissions of pollutants can be reduced to a satisfactorily low level (5).

34 Liming can also be used to counterbalance the increasing acidification of cropland. Lime has, of course, been used to improve acidic and calcium-poor soils for centuries. The cost of the extra liming needed to offset acid fall-out in Europe ranges from less than $1 to about $10 per hectare a year.

35 The only lasting solution is to reduce the emissions of the pollutants in the first place. Apart from the effect that strict controls would have in protecting waters and forests, they could save millions of dollars by avoiding corrosion. The Organisation for Economic Co-operation and Development (OECD) made a first attempt in 1981 to find a way of quantifying corrosion costs (29). This came up with the estimate that strict emission control measures in 13 European countries could save about $1.2 billion in corrosion costs every year. But the report acknowledges that this is a very approximate figure and more work is being carried out to improve the estimates.

36 The easiest way to control the pollution is to use fuels that are low in sulphur; but this will not be feasible for long because the world supply of these fuels is believed to be limited. A more permanent solution is to use other sources of energy instead of fossil fuels, and to improve energy conservation. Many users could reduce their energy consumption, and technical improvements could ensure that various processes burned fuel more efficiently. These measures will help cut down emissions of sulphur and nitrogen oxides, but, obviously, acidity of rainfall will not be reduced to agreed acceptable levels unless work is done to remove sulphur from fossil fuels, emission gases, or both and such work is therefore likely to acquire increasing importance in the future. It may also be necessary to remove nitrogen oxides from emission gases.

37 According to some recent estimates, including ones submitted to the 1982 Stockholm Acidification Conference, taking sulphur out of fuel oils would cost about $20 to $40 for every ton of oil, depending mainly on the type of the oil and the size of the plant, among other factors (13, 30). This would add about $5-10 to the cost of every megawatt/hour of energy produced (in 1980 prices), adding about 10 to 20 per cent to the cost of electricity production. Industry, on the other hand, puts the costs at $40 to $85 for every ton of oil (31). To look at it another way, the estimated cost of removing each ton of sulphur from oil ranges from $1,100 to $2,200 (32, 33).

38 Coal contains two kinds of sulphur—pyrite (iron sulphide) and organic sulphur. Washing coal, after first crushing and grinding it, will remove pyrite sulphur. The cost of this mechanical process is estimated to be $1 and $6 per ton of coal (5, 13, 30, 34, 35). On average it will remove about half of the pyrite, though at best the process can be made to remove up to 90 per cent of it from some coals (13). The chemical methods are more effective, but also more expensive and have not yet been fully developed. They can remove organic sulphur as well as pyrite. The cost of getting rid of 90 to 95 per cent of the pyrite and half the organic sulphur would be around $20 to $30 per ton of coal (5). The extra costs for coal washing range from less than $1 to about $3 per mega-

watt/hour, adding between one and six per cent to electricity costs. Chemical desulphurization would cost much more, about $8 to $12 per megawatt/hour, and this would add between 15 and 25 per cent to electricity costs.

39 Nitrogen oxide emissions can be reduced by changing the ways of burning fuel, particularly in heat and power stations. One of the main ideas for doing this is to reduce the combustion temperature to below about 1,500° C and/or to allow only low intakes of air. Such changes could cut in half the amount of nitrogen oxides emitted.

40 Various "fluidized bed" technologies offer a promising way of reducing pollution by both sulphur and nitrogen oxides in heat and power plants. Coal is burned in a "bed" of tiny particles that bubbles like a boiling fluid. Sulphur dioxide emissions can be controlled effectively by adding limestone or dolomite to the bed. And because the fuel is burned at a much lower temperature than in conventional boilers, nitrogen oxide emissions are substantially reduced. These technologies are now feasible and economic in coal-fired installations able to produce up to 250 megawatts of heat (5, 34).

41 Such techniques reduce the amount of pollutants created when the fuel is burned. Another approach is to remove them from the gases just afterwards, before they are pushed out into the air. Sulphur oxides can be taken out by a process called "scrubbing". "Wet scrubbing", the kind predominantly used at present, typically costs between $5 and $10 a megawatt/hour at 1982 prices, depending on how efficiently the pollution is removed (34), and would normally increase the cost of electricity by around 8 to 18 per cent. (36) Other methods are being developed which will reduce these costs, possibly by 30 per cent (5).

42 Removing sulphur from fuel and gases creates waste products—solids and slurries—which have to be disposed of properly to avoid water, ground-water, or soil pollution. Naturally, this problem grows as emission controls are increased.

43 Japan is already applying on a large scale a very effective method of flue gas denitrification. Used together with the changed techniques for burning fuel, it would cut nitrogen oxide emissions by 90 per cent. According to information from Japan, the cost would be $4 to $6 per megawatt/hour, or about five to six per cent of the total electricity cost (34, 35).

44 OECD estimated that if the best combination of these control measures were applied from 1980—and, as a result, the pollution from sulphur dioxides was cut in half in its European member countries by 1985—this would cost $4.6 billion a year (36), about 0.2 per cent of Western Europe's gross national product.

D. Concluding remarks

45 The acidification of the environment is a major problem in several regions of the world, and may become one in others. Yet different regions vary in their ability to withstand it. So the first thing to do is to work out how much each environment can resist acid fall-out. This assessment would then form the basis for implementing pollution-control measures that would keep the deposition within acceptable levels. Thus, as a general basis for action, the Canadian members of a Work Group convened under the United States-Canada memorandum of intent have proposed (18) that present deposition of sulphate in precipitation be reduced to less than 2 grams per square metre per year in order to protect all but the most sensitive aquatic ecosystems in Canada. On the other hand, the experts participating in the working group on deposition-soil-water interactions of the Stockholm Conference on Acidification of the

Environment (37) have suggested that highly sensitive lakes with high alkalinity would tolerate up to 1 gram of sulphate per square meter per year. However, even if such targets were universally agreed to, they would be difficult to achieve in practice because pollutants are carried over long distances in the air and distributed unevenly, so that we are not able to predict, except very broadly, the effects that reducing emission in one area will have on deposition rates in another. A stepwise approach to controlling acidification therefore seems to be more feasible, both politically and economically.

46 Adding lime to water and soil could control the effects of acidification to some extent, but this does not offer any lasting solution to the problem. So the most feasible approach is to control air pollutants at source. Several technologies for doing this are readily applicable to full-scale plants. They include removing sulphur from fuel, techniques for burning fuel that give rise to low levels of pollution and ways of cleaning the gases given off (especially of sulphur). Of course, full advantage should be taken of energy conservation, and of the use of low-sulphur fuels and non-polluting or less-polluting sources of energy.

47 According to preliminary calculations by OECD, it costs a total of some $800, on average, to stop a ton of sulphur from getting into the air (27). More recent estimates suggest that the costs may be somewhat higher (31, 34). If north-western and southern European countries were to cut their annual sulphur emissions by about half (around 5.9 million tons) within the next 10 to 25 years by controlling the emissions of conventional power stations, it would cost them about 10 per cent of the total cost of producing their electricity.

48 OECD has also made estimates of the benefits resulting from emission controls, as part of a methodological study (27). These suggest that the benefits would outweigh the costs, but the uncertainties surrounding the estimates are so wide that they cannot be used to provide a quantitative and reliable evaluation of the balance between costs and benefits.

49 There are, moreover, other factors that complicate such analyses. One—common to many other instances of damage to shared natural resources—is that the countries which would benefit from the reduced pollution would often be different from those that would have to bear the cost of cutting it back. Another is that all the estimates of benefits assume that the damage caused by acid rain can readily be reversed if enough pollution control is implemented—and in reality this may not be so. It might be a long time before the ecological damage, in particular, began to be reversed. Unfortunately, scientific information on the recovery process is extremely scanty.

50 This is only one of the problem areas in the whole field which, despite considerable progress in research on the subject, still remain unknown or only superficially understood. Research is needed on dry deposition of polluting gases and particles, and their effects on water, soil, young and old foliage, and other recipients of their pollution; on how the pollutants undergo changes in the atmosphere, and how they are transported and deposited; on how bedrocks weather under different acid inputs and release nutrients; on how acid affects the soil, particularly in the long term; and on the possible adverse effects of acid fall-out on forest growth.

51 In addition to these meteorologically and ecologically orientated research topics, information is needed on the effects on health of the increasing spread of cadmium and other toxic metals as a result of acidification. Among other things, the levels of the metals in food, human tissues and body fluids must continue to be monitored.

52 Furthermore, there must be more effort to research and develop ways of improving energy conservation, environmentally appropriate technologies for

producing heat and power, and techniques for removing sulphur from fossil fuels and gaseous emissions.

53 So far the acidification of the environment has been seen as a regional problem, restricted to parts of Europe and North America. Other industrialized areas are almost certainly exposed to the same problem, but there is too little information to assess it. Besides, the problem may well spread to new areas as a result of rapid industrialization and the growth of cities in other parts of the world, particularly developing countries. So it is important that areas affected by acid deposition and susceptible to damage from acidification are identified as soon as possible. If they are, the damage could be mitigated, or even avoided, at a minimum cost to society by initiating research, and applying what we already know about pollution control and environmentally appropriate energy-production technologies at an early stage.

54 Some areas in the tropics may be highly or moderately susceptible to acidification, and this could cause special problems (5). We need to work out the nature of these problems. In dry tropical areas, acid rain itself cannot play a major role owing to scarce precipitation, but the role of dry deposition is unknown. In humid areas ecosystems, temperature and moisture levels are different from those in the temperate areas where acidification has been studied so far, and quite different problems may arise.

55 Besides, some soils have too little sulphur in them or are highly alkaline. These could benefit, to a certain extent, from extra sulphur and nitrogen fallout—or merely from more acidic rain. This could add a significant new factor to calculations of costs and benefits from the pollution, but the issue has not yet been explored.

56 In the near future the crucial issue is whether countries are ready to take the measures needed to cut back emissions to an acceptable level. Evidence of their determination has already been provided by some of the major emitters, notably the Federal Republic of Germany. The consensus reached by the Ministerial Conference on Acidification of the Environment, held in Stockholm in June 1982 (13), was extremely encouraging about this. Representatives of 21 countries agreed that urgent action should be taken under the Convention on Long-range Transboundary Air Pollution, including:

(a) establishing and implementing concerted programmes to reduce sulphur and, as soon as possible, nitrogen oxide emissions;
(b) using the best technology available that is economically feasible to reduce these emissions, taking account of the need to minimize the production of wastes and pollution in other ways;
(c) supporting research and development of advanced control technologies;
(d) developing and implementing energy conservation measures further;
(e) developing the North American monitoring programmes and EMEP further, through better geographical coverage, improved data on emissions, standardizing sampling and measurement techniques, and improved modelling, among other measures.

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IV. The environmental aspects of energy farms

1 The 1970s brought into focus the general realization that fossil fuel resources, especially oil and natural gas, are finite in nature and that countries should explore the possibilities of using other sources of energy as well, establishing thereby an appropriate energy mix to meet their demands for sustainable development (1). Recently, much attention has been given to the development of renewable sources of energy. An important social advantage of these sources of energy is their potential for promoting development in rural areas of the developing countries (1, 2).

2 One way of exploiting solar power has already been used for thousands of years—and it is still the main source of energy for hundreds of millions of people, especially in developing countries. It is used every time someone cuts down a tree, and burns its wood—for (despite the proverb) energy, and therefore money, does grow on trees. Plants collect energy from the sun by photosynthesis and store it as they grow. Extensive research and development work is under way in many countries to find better ways of using trees, crops, water plants and wastes for fuel. Biomass,* as these natural energy stores are known, can be turned into usable energy in several different ways. It can be burned to produce heat, which in turn can be used to raise steam and drive electric turbines. It can be turned into solid or liquid fuels or gas by heating processes, or into methane gas or alcohol by biological ones (1, 2).

3 There is an enormous amount of biomass on the globe; every year natural productivity adds enough energy to meet at least ten times all the world's commercial energy demands, in theory (3). In practice, of course, it is very unevenly distributed around the world, and in some regions the reserves are being rapidly dissipated because they are being burned faster than they can be replaced by growth. In practice, too, biomass must be economic to harvest and turn into fuel. Almost any crop produced by farmers anywhere in the world, whether its main use is for food, animal feed, fibre or other products, can technically be turned into some form of energy. But in most cases it would not be economic, practical, or even sensible, to do this.

4 Many countries are seeking to solve these problems by paying special attention to energy farms—areas of land and water devoted exclusively to growing plants for energy. Fuel crops can be fast-growing trees, conventional crops, or water plants—any plants, or mixture of plants, which are more valuable as fuel than as anything else.

A. Facts and figures

5 Wood has been the primary source of energy for cooking, heating, and other basic needs for almost all man's history since prehistoric times. It remains so in developing countries, in many urban areas as well as in the countryside.

*Biomass is an ecological term for the total amount of living matter present at any time in a population or a given area. In an energy context, it is used loosely to mean biologically produced material.

Well over two billion people, about half the population of the world, use it for cooking, their most important use of energy (4). People in developing countries on average each use between 1.3 and 2.5 cubic metres of it a year (1, 5). Until recently the sheer weight of fuelwood burned in the world was not realized—and neither was the effect of gathering it on the environment.

6 Uncontrolled and indiscriminate wood collection helps fell forests and turn productive land to desert. A recent estimate suggests that 11 million hectares of tropical forests disappear every year (3). Between 1976 and 1980 ASEAN countries lost 1.2 million hectares of forest a year, and South Asian countries 339,000 hectares a year (6). A recent assessment of tropical forest resources shows that Asia is losing 0.61 per cent of its open forest each year, the Americas 0.59 per cent and Africa about 0.48 per cent (7). While this shows that the world's tropical rainforests are not in imminent danger of total destruction, important forests and ecosystems are being lost in many places, and some individual countries face losing all their rainforests within a few decades. Cutting wood for fuel is one of the major causes of tropical forest destruction. At the same time, the productivity of millions of hectares is being destryed or impaired annually (3), because, as trees go, land becomes poorer. The more treee that are cut down the further people have to go to find wood, hacking further into forests, creating ever-widening bare circles round settlements, and making ever-longer back-breaking journeys which undermine their health and take them away from productive work in the fields. When the wood has gone, people collect dung and other wastes to burn, impoverishing the land even more.

7 By 1980, 96 million people in the countryside of developing countries were acutely short of firewood and could not meet their needs (8, 9). They lived on the dry land south of the Sahara, in east and south-east Africa, and in mountainous parts of the continent; in the Himalayas and the hills of South Asia; on the Andean Plateau and the arid lands on the Pacific coast of South America. Another 150 million lived in cities surrounded by countryside with not enough firewood.

8 In 1980, too, another 1,283 million people (about 1,050 million country-dwellers and 231 million urban people) lived in areas where they could still get enough wood, but only by cutting down trees faster than they grow. Seventy million lived in the countryside of North Africa and the Middle East, and 143 million in dry parts of the Latin American countryside: 131 million lived in rural Africa South of the Sahara, mainly in savannah areas in the west, centre and south-east of the continent; and no less than 710 million lived in the countryside and small towns of Asia, mainly in the great plains of the Indus and Ganges rivers and in South-East Asia (9). As long as this situation continues, the trees will steadily disappear, until the people of these areas become acutely short of firewood around the year 2000. By then, of course, populations will have grown and, in all, about three billion people will be facing acute scarcity or cutting down trees faster than they grow.

9 The logical, immediate response to this growing crisis is to manage forests better and to plant more trees in energy farms. There are three main types of fuelwood plantations: large-scale forest usually planted on publicly owned land; smaller village woodlots, meeting the needs of rural communities; and even smaller, scattered plantings, including house gardens, fences and groups of trees to provide shade, protection, fruit or fodder for livestock. In some places, rural communities traditionally grow fuelwood integrated closely with food crops. Even in such crowded areas as Java or the Mekong Delta tradition-

al farming systems set aside between two and five per cent of the agricultural land for tree planting, with great effect (8).

10 Many countries have recently been paying a good deal of attention to wood plantations. The Republic of Korea's 'New Community' movement, which began in 1971, planted 40,000 hectares of trees by 1976. An estimated 30 million hectares of land was under plantation in China by 1970. A recent assessment by FAO and UNEP shows that plantations of wood for industry, fuelwood, charcoal, other products and soil protection, cover about 2.7 million hectares in Indonesia, 2.6 million in India, 400,000 in Bangladesh, 300,000 in the Philippines and over 200,000 in Thailand. Plantations were also under way in Sri Lanka, Pakistan, Malaysia, Nepal, Burma and Brunei (6).

11 There is a lot more to such silviculture than planting trees. It will not succeed unless the local people are fully involved in making the decisions about how it is to be done. And technical help in choosing the right sites and providing the trees, in supervising planting and harvesting, and for training, is also essential.

12 In energy farms, specially selected fast-growing trees should be planted in closely spaced rows and harvested every four to seven years. They will need fertilizers, weed and pest controls, and, possibly, irrigation—more intensive cultivation than is normal in forestry. If this is done, yields should be well above those obtained from present forestry practices, which allow trees to grow longer and harvest them less intensively. Productivity will also depend on how well trees suit local conditions. They should be chosen to grow quickly even on poor soil, need as little care as possible, resist pests and diseases, and be able to survive droughts and similar crises. They should also be suitable for coppicing—sprouting anew from their stumps after they have been cut close to the ground, so that they produce crop after crop from the same roots. Their wood should, naturally, have a high heating value. And they should be suitable for as many uses as possible so that their trunks and branches could be exploited for firewood, or charcoal, while their leaves are used for cattle food or fertilizer, or turned into energy in biogas plants (10, 11, 12).

13 Some suitable species have already been identified. One important group of them is the tropical legumes, which automatically provide their own fertilizer by "fixing" nitrogen from the air. As they grow they therefore actually improve the soil. *Leucaena leucocephala*—the giant "ipil ipil" is one variety—is the best known member of the family. It is particularly bountiful, for it also produces high-protein seeds and foliage which makes an excellent animal feed supplement and green fertilizer. Other tropical legume trees, such as various *Acacia, Calliandra* and *Sesbania* species, also grow fast. So do some trees from other families: *Eucalyptus* and *Casuarina* trees are among the most promising (13).

14 Fast-growing trees like these are enormously productive if they are well matched to local conditions. Many species will produce more than 20 cubic metres of wood per hectare every year when grown on reasonably good soil. In exceptional cases *Leucaena, Eucalyptus* and several other species are reported to have produced as much as 50 cubic metres per hectare a year (14).

15 Once the wood is harvested it can be used to generate heat, steam or electricity. "Ipil ipil" plantations have already been established in the Philippines to produce electric power. They are intended to fuel several stations with a total capacity of 200 megawatts by 1987—and by the year 2000, 700,000 hectares of wood plantations and 2,000 megawatts of electricity are planned (15). In Tamil Nadu, India, 11,500 hectares of *Casuarina* trees would provide fuel for a power plant generating 100 megawatts (16).

16 Alternatively, wood can be turned into charcoal, gas or liquid fuel. None of these uses is new. Charcoal has been produced since the dawn of civilization; some say that making it was the first chemical process ever discovered by man. Relatively large *Eucalyptus* energy farms (8,000 hectares), dedicated to charcoal production for steel mills, have been in operation since the early 1950s in Argentina and Brazil (13). Wood alcohol was used as a liquid fuel for most of the eighteenth and part of the nineteenth centuries. Kerosene and other fuels took its place; but now there is new interest in it, mixing with gasoline for motor fuel.

17 Making gas from wood and charcoal is another old technology that is being revived. Several European countries and Japan had projects for fuelling engines with the gas before the Second World War. By late 1941, 70,000 cars in Sweden alone used it, as did 55 per cent of the trucks and 70 per cent of the buses (12). Farm equipment also made good use of it. After the war most vehicles switched to gasoline because it was a better and more convenient fuel. Now the gas is coming into its own again in several countries, particularly in the countryside. In the Philippines, for example, the process is used to run fishing boats, water pumps and some public service vehicles, and to produce electricity (15).

18 Wood may be the most obvious and widely used form of "green energy", but it is far from being the only one. Some plants, for example, produce materials like hydrocarbons, some of which are the main constituents of oil and natural gas. Once again, this has been known for centuries—pre-Columbian civilizations in Latin America systematically cultivated trees which produced liquid that could be made into rubber. Even today the natural rubber tree, *Hevea braziliensis,* is much the best known of these plants. Its latex is no use for energy farming, since it is made up of hydrocarbons of a very heavy molecular weight; hydrocarbons of lower molecular weight are needed for fuel. Some studies have shown, however, that many species of plants may produce just what is required. Bushes of the *Euphorbia* group seem to be particularly promising. Experiments with two species (*Euphorbia lathyris* and *Euphorbia tirucalli*) have shown that they can yield between 17 and 36 barrels per hectare a year. Better still, many of the 8,000 or so known species in the family will grow on semi-arid land, which means that they can be cultivated where many other plants will not flourish, and can be particularly useful in developing countries that are prone to droughts (12, 17).

19 Other plants, including soya beans, sunflowers and groundnuts, also produce oils. Most of them can be used to fuel diesel engines without further processing, either by themselves or blended with diesel fuel. Most of them, too, can grow in a wide range of soils, provided that they get the right amount of water and the right temperature, though their ability to tolerate different climatic conditions varies significantly between species. But such "peanut power" or "beanzol" is unlikely to do much to replace diesel, because the oils cost much more and are, of course, wanted for food.

20 Some crops contain sugars and starches that can be turned into fuel by fermentation. Sugar cane and sweet sorghum are the main sugar crops, and both grow fast in good conditions when farmed by modern agricultural methods. Fifty tons of sugar cane will grow each year per hectare in Brazil, and yields may go up to as much as 120 tons per hectare per year as they do in Hawaii. Sweet sorghum will produce an annual crop of about 45 tons per hectare. Both their sugars can be directly fermented to produce ethanol, a form of alcohol. Sugar

cane will produce about 3,600 litres of alcohol per hectare and sweet sorghum about 3,500 (1, 18).

21 Cassava (mandioca)—a subsistence crop in many developing countries— is the primary starch crop of interest. It has many advantages. It tolerates poor soil and adverse weather conditions much better than the sugar crops mentioned above, and unlike them, it does not need high levels of fertilizer or pesticides to give good yields. About ten to twelve tons of cassava are produced per hectare each year—and this can be turned into about 2,160 litres of alcohol (11, 18).

22 Other plants, like corn, rice and other cereals, can also be turned into ethanol. Corn is indeed used to produce alcohol, particularly in the United States (about 6 tons of corn is produced annually per hectare, yielding about 2,200 litres of alcohol). But of course, these cereals are more valuable for food than for fuel.

23 Ethanol can either be used as a fuel on its own or blended with gasoline. A motor running on ethanol is 18 per cent more powerful than one using gasoline (1, 18). Internal combustion engines need some modification if they are to be fuelled entirely by it. No changes at all are needed, however, if up to 20 per cent of ethanol is mixed with gasoline. The alcohol increases the octane rating of the fuel and so eliminates the use of lead additives, which are suspected of causing pollution that lowers the intelligence of young children. Such "gasohol" or "alcogas" is now used in Brazil, the United States and the Philippines, among other countries. Brazil has the largest programme for making alcohol from biomass. Its National Alcohol Programme, PROALCOOL, aims to be produng about 10.7 million cubic metres as early as 1985 (19). Already nearly all the country's cars run on gasohol, and more than 300,000 run on pure alcohol. By 1985, two and a half million cars will have been converted or manufactured to take neat alcohol, and all the rest of Brazil's 12 million strong car fleet will be fuelled by gasohol (20).

24 Sometimes even soft, green herbaceous plants may be a viable source of "green energy". Some tropical and savannah grasses, ideally adapted to their conditions, grow extremely fast. Elephant grass (Napier Grass) is one notable example. Another is *Imperata cylindrica*, a noxious weed known as *lalang* in Asia. Very little research has been done to see what yields they could sustain if harvested for fuel—but it is likely that they would need less fertilizer, water and similar requirements than more sensitive crops like sugar cane. So they could well be viable energy sources in countries where land is available which cannot be used effectively for agriculture. They have a high cellulose content, and so (unlike the sugars and starches) are not well suited for conversion into ethanol by current techniques. But they could be used effectively to make charcoal and could also provide a feedstock for gas or liquid fuels (11).

25 Not only land crops, but water plants as well can be farmed for energy. In fact energy farming could solve a particularly intractable problem. At present plants like water hyacinth (*Eichhornia crassipes*) and duckweed (species of the genus *Lemna*) are a major environmental problem in many countries because they spread and clog up lakes and waterways. So harvesting them for animal feed or energy would be a happy solution. They grow very plentifully in the best conditions, producing about 50 tons of dry matter per hectare a year. Better still, some aquatic plants, including the water hyacinth, have the power to purify water, extracting many organic and inorganic compounds from it. So the same plants could be used simultaneously to clean up pollution and produce energy. Most species can be digested easily by bacteria in airless conditions, as in a biogas plant, and this is the best way of turning them into fuel. A methane-rich gas is produced, and the residue left when the gas is given off is

useful as a fertilizer. A single hectare of water hyacinths, grown on sewage, can both purify the waste and yield 0.8 tons of dry material a day, which can be turned into 200 cubic metres of biogas—enough to generate about 250 kilowatts of electricity daily (12).

26 Seaweeds can be farmed too. Large-scale seaweed farms are already moored near the Japanese and Chinese coasts, producing the food that has been a delicacy in the Orient for centuries. The open oceans are much the biggest under-used part of the world's surface, and so plans for farming them for energy, as well as food, are receiving considerable attention. Experiments on growing kelp (*Macrocystis*) for fuel have reported yields of as much as 90 tons per hectare a year (12).

27 Ocean energy farms would be strange-looking structures, enormous offshore platforms with long spokes and ropes sticking out of them. The kelp would grow on these protuberances, fed by nutrient-rich water specially pumped up from great depths. It would then be harvested, and like the fresh-water energy crops, turned into methane. The Ocean Farm Project, California, foresees that there will be a vast demonstration sea farm, covering some 40,000 hectares, by the end of the century. Each hectare of cultivated kelp would yield about ten million kilocalories of food and nearly a hundred million kilocalories of methane energy a year (21).

B. The problem

28 All energy production presents practical and environmental problems; and "green power", for all its attractiveness, is no exception. Conditions have to be right for growing energy crops. When they are, the energy farms could absorb resources needed for food production. Energy crops could impoverish the soil and destroy important wildlife habitats. Some could use up more energy to grow and harvest than they would ever produce, and others could cause pollution and possibly affect the climate.

29 Many of the problems can be solved or avoided if enough attention is paid to them. The problems of finding the right conditions for a crop, for example, can often best be solved by finding the right crop for the conditions! In relatively dry areas it is better to find plants that need little water than to lay on expensive irrigation, which itself uses up a great deal of energy if pumping is involved. Similarly it is worth considering plants that do not need a lot of nutrients (notably those that fix nitrogen from the atmosphere like the leguminous trees), rather than following the strategy used by the Green Revolution in agriculture, which greatly increased crop yields in some countries, but only by using special strains of plant that needed much more fertilizer, pesticides and water.

30 Trees, of course, are much the most important energy crop, and they present the most immediate problems. They are a renewable resource, provided they are managed and conserved properly—but, as the steady advance of the deserts and the retreat of the tropical forest bear witness, this rarely happens. Feasible ways of using wood for energy will vary from country to country, and there are many different approaches. Countries that have large existing forests merely need to harvest and manage them on a sustained-yield basis for a new use—fuel. Others will need to develop new plantations, and this takes capital, energy and land. These countries will differ in the quality and quantity of land they have available for plantations. The technologies countries choose for converting wood to energy—and the scale on which they use them—are other obvious factors that will influence how much wood is grown, of what species. Economics are, of course, equally important. Where wood is more valuable for use as fibre, building materials or chemical feedstock, it will be likely to be used for these purposes rather than for energy. Where it is scarce or more expensive than other suitable fuels, it is again unlikely to be used for energy. On

the other hand, wood may receive considerable attention if there is an acute need for energy, or there are plenty of trees, or there are strong objections to other fuels.

31 Even when all the conditions are right for new plantations, they are often never establsihed. This is because some Governments do not give enough support to tree-growing in the countryside. They are not aware enough either of the effort that will be needed to meet their countries' energy needs in future, or of the opportunities for tree planting. At the same time, some local peoples often show just as little interest, for they see firewood as something that has traditionally been free for the taking. This apathy is reinforced by incapacity. Some nations just do not have the institutional framework to implement major fuelwood programmes, and have only a limited capacity to organize and support tree-growing by local villages and farms.

32 Countries that overcome these problems of attitude and structure face a new set of practical difficulties in setting up large-scale and extensive plantations. Allocating the land for the new trees is the first problem. The countries' best and most accessible land will usually already be used for agriculture. So the main areas that are readily available for trees will either be remote, or on poor or impoverished land. Both pose problems. Producing fuelwood in faraway parts of a country is only economically feasible if it can be transported very cheaply, which is most unlikely, or turned into charcoal before transportation, a process that requires capital and skill unlikely to be present in such remote areas. Developing poor land requires careful choice of species and sometimes special techniques in establishing plantations. Even when good or moderate land is available for plantation development it would seem, on economic and natural-resource grounds, that such areas should be developed to produce timber and pulpwood, rather than fuel, because these will attract more revenue. lastly, it is hard to get enough skilled and semi-skilled labour to implement the kind of planting programmes necessary to meet fuelwood requirements from large-scale plantations.

33 Agroforestry has much to offer when land is scarce. It involves intercropping trees and field crops, so that both food and fuel can be produced from the same land. Naturally, the crops must be chosen carefully so that they complement rather than compete with each other. *Eucalyptus*, for example, is not a good choice for agroforestry because it soaks up a lot of moisture and tends to produce toxic substances. *Leucaena*, on the other hand, helps to fertilize the whole area around it because it is a legume. It also has an open leaf structure which does not shade out ground crops as much as some other trees (11). Many of the tree-planting schemes based on fast-growing trees have several complementary objectives and are aimed at providing jobs, improving the environment, and bringing social benefits to the local people as well as growing renewable energy. The Philippines Dendrothermal Programme illustrate this well (15). The programme, which includes fuelling a series of small (three megawatt) power plants with ipil ipil trees, aims in the long term to provide rural development and to settle shifting cultivators.

34 Environmental protection is an important part of any successful plan for energy farms, because, despite appearances, growing trees is not always benign. The whole process of producing wood for fuel can cause environmental problems, from preparing the sites and planting the trees to managing the forests with fertilizers and pest controls, from cutting the wood and converting it to energy to burning the fuel and disposing of its wastes.

35 Intensive tree farming might impoverish the soil in the long term by removing nutrients and organic matter from it. This process, which, it is feared, could be caused by the shorter growing times and more thorough harvesting of modern methods, would, of course, cause productivity to decline as the soil grew poorer. Intensive harvesting will remove many times more nutrients than conventional methods (22). Several studies of whole-tree harvesting

(which removes the complete tree, twigs and all, leaving little debris behind) have noted that nutrients in the soil have declined (23). Fertilizers can alleviate nutrient depletion, but they may not work well unless those who use them fully understand what is going wrong. In some cases using fertilizer to increase growth will actually make the problem worse; the fertilizer will cause chemical reactions in the soil which decrease its supply of other nutrients (23). And inorganic fertilizers cannot replace any loss of organic matter, which is often identified as critically important in maintaining the productive potential of forest soil (23).

36 Soil erosion and leaching can also follow felling, with far-reaching consequences. The result, again, is that the soil becomes poorer as it loses nutrients, and productivity eventually declines. Once good, nourishing soil is lost, natural processes can take several thousands of years to replace it. Wildlife habitats can also be changed. Usually there is merely a temporary shift after felling when species that like open areas replace their neighbours from the forest until new planted trees grow up. The effects are much more severe when the habitats of endangered species are totally eliminated, so that they can never return (22).

37 Whatever the crop, whether wood or anything else, it is important to work out how much net energy it produces. This is because the crops themselves consume energy as they are produced, transported, turned into usable fuel, stored and distributed. Several studies (24, 25, 26) have shown that sugar cane shows the best energy balance sheet in ethanol production, followed by sweet sorghum and cassava. All of them produce more energy than they consume.* When ethanol is produced from corn, on the other hand, there is a net energy loss, generally because a great deal of energy is used to grow the crop. Besides, all the energy needed to turn sugar cane into ethanol can be provided by burning its own by-products, while cobs and stalks provide at most a third of the energy needed to do the same for corn.

38 Many countries do not view energy production in strict economic terms. They see dependence on other countries for energy supplies and the chronic balance of payment deficits incurred by buying expensive fuel from abroad as major threats to their social and economic development and, indeed, to their political stability. So some countries promote domestic energy production even though it costs more than buying fuel on international markets, as long as the bulk of the money invested is in their currencies and the projets are expected to produce a net balance of payments surplus. This climate favours the development of biomass energy programmes, as the Brazilian alcohol production programme shows. In strict microeconomic terms no ethanol should be used as fuel in Brazil today, because it is much more expensive than gasoline. Gasoline costs about $45 a barrel when it leaves the refinery, whereas water-free ethanol (suitable for mixing with gasoline) is being produced at about $68 (27). Nevertheless, Brazil supports the use of locally produced ethanol fuel for wider national motives, particularly reducing energy dependence. The expanding industry has also provided jobs and helps regional development in many parts of the country. So the Government subsidizes ethanol by taxing gasoline so that at the pump the home-brewed fuel costs about 65 per cent of the imported one, even though it is so much more expensive to produce (27).

39 Recently there has been concern that energy crop plantations may absorb agricultural resources that would otherwise be devoted to food production (1,18). In Brazil, sugar cane agriculture has expanded to some degree at the expense of food cropland because incentives were given to ethanol production

*It should be noted that the net energy balance for producing ethanol from the same crop will vary from place to place depending on what techniques are used to grow and convert it and how much energy they use.

when sugar prices were low (before 1980) (19). The United States faces a rather different situation. Producing ethanol from crops like corn there poses no direct competition to its food supplies, because about 60 per cent of its corn is fed to animals and there is surplus grain; but some argue that it will mop up grain that could otherwise be provided as aid to impoverished third-world countries, or that it will affect international trade. Not every country in the world can resort to producing ethanol by fermentation for fuel. Only those that produce enough food, but too little energy, for their needs, may embark on a programme of making alcohol fuel from biomass, and then only if their climate, soil, water supplies and other environmental conditions are favourable for the programmes.

40 Ethanol production can be very polluting. Every cubic metre of the fuel produced from sugar cane generates 12 to 13 cubic metres of effluent. If this is discharged without treatment into inland or coastal waters, it can cause as much pollution, in terms of biological oxygen demand, as the sewage produced by 6,000 to 6,500 people in one day (19). The potential impact of this pollution is so great that strict measures to control the discharge of this effluent, called stillage, must be used from the start. Delay in introducing them causes serious environmental damage and sizeable costs, as recent examples in the Brazilian states of Mato Grosso and Rio de Janeiro have shown (27). Discharging stillage is, anyway, causing waste in more senses than one, for it can be a valuable raw material. It is normally not contaminated by disease-carrying organisms or toxic compounds, so recovery of mineral and organic substances from it is a potentially attractive undertaking. It is technically feasible to turn it into methane gas to provide energy for the ethanol-producing process or other means, or to convert it into marketable products like fertilizers or feed additives (28, 29). In Brazil, raw stillage is sprayed back onto the sugar cane fields, reducing or eliminating the need for mineral fertilizers on the energy farm (30) – but in some areas the soil is not suited to it, and the effectiveness of this particularly satisfying form of pollution control does depend considerably on the characteristics of the soil.

41 Water energy farms present a different set of problems. Growing water hyacinth or duckweed on public lakes or streams would be unpopular, because they are thought to be such objectionable weeds. Artificial ponds would be expensive to make, particularly since vast areas of them would be needed, though they would provide sanctuaries for a great variety of water life and birds. Using salt marshes and coastal lagoons, in direct contrast, would be cheap but could well be environmentally destructive. They are highly important ecological systems, providing both valuable wildlife refuges and vital stages in food chains on which much ocean life depends. So the impact of any developments of these vulnerable environments would have to be carefully studied before a decision could be made which would upset them. In any case, there are not enough of these wetlands left in the world to make a major contribution to energy needs.

42 Ocean farms may have other undesirable effects. Pumping huge amounts of cold water, rich in nutrients and supersaturated in dissolved carbon dioxide, to bathe and fertilize the seaweed could change the temperature patterns and chemical balance of the water, the network of life, and the direction of currents both in the immediate area of the farm and in its surroundings (31). An immediate consequence of this is cooling of the air and increasing cloudiness near the farm. These changes in turn could cause regional climate changes and even affect the climate of the whole globe. The process will also release large quantities of carbon dioxide which could also influence the climate.

43 Besides, dense offshore mats of plant growth, like the proposed ocean farms, can absorb and damp down storm waves, change local current patterns, and interfere with conditions that produce both the area's plant and animal life and the natural upwellings of nutrient-rich water from the deep sea that sustain much of it. Then, if past experience in producing high-yield crops both on land and water is anything to go by, measures may have to be taken to control weeds, pests and sea animals that would graze on the crops. Some seaweeds could themselves become a nuisance if they escape from the farm and spread over areas unaccustomed to them. Depleting the nutrients in the intermediate depths of the major oceans is a serious long-term problem, like soil depletion on land farms. And last, but not least, seaweeds, like many other living organisms, may give off poisonous wastes. These could affect other life both inside and immediately outside the farm area and create specialized environments where only certain species (and not necessarily the original ones) could survive—like those already produced on land by large-scale growing of field crops (31).

C. Major actions taken or planned

44 Many countries have recently given proper recognition to the importance of developing renewable sources of energy, and both developed and developing nations are giving special attention to harnessing it from biomass. France, for example, gives "green energy" a high priority and is concentrating research on energy crops like *coppices*, Donax reed, sweet sorghum and water hyacinths. It expects to get fuel equal to 4 million tons of oil a year from biomass by 1990. Energy plantations are being intensively researched in Sweden, and special plantations of willow (*Salix*) and poplar (*Populus*) trees are expected to produce 20 tons of dry material per hectare a year. Ireland claims to be a world leader in rapid-harvest forestry, and some 400,000 hectares will be planted there by the year 2000. Alcohol is already being produced in the United States, mainly from corn, and extensive research and development work is being done there on energy farms, especially wood plantations and ocean farm systems.

45 A great deal of activity is also under way in developing countries. Many countries, including China , Kenya, the Philippines, the Republic of Korea, the Sudan and Thailand, have reafforestation programmes aimed at producing new firewood as fast as it is used. The Philippines is also one of the countries giving considerable attention to energy farms using fast-growing species. Co-operation between countries over fuelwood plantations is remarkably strong. Other developing countries have recently embarked on alcohol production programmes similar to the Brazilian sugar cane one. Colombia, Cuba, Kenya and the Philippines are among those that have made a start, though the Brazilian programme remains much the largest.

46 Several United Nations intergovernmental bodies have embarked on some activities for harnessing energy from biomass. The main focus of efforts directly related to energy farms are forestry and agroforestry projects, and FAO is the lead agency here, carrying out about 40 national and regional projects concerned with fuelwood production. Meanwhile, the World Bank and UNDP are giving financial and technical help to some developing countries for similar projects. The World Bank is also financing feasibility studies on alcohol production from biomass. FAO and UNEP are planning studies on some of the wider issues raised by "green energy"—looking at the socio-economic costs and benefits of energy plantations, studying environmental aspects of energy farms, and assessing the effects of using agricultural crops

for fuel on the security of the world's food supplies, with particular emphasis on the food needs of the less developed countries.

47 There is no doubt that biomass is an important renewable source of energy. It has long been used by countless millions of people, particularly in developing countries, to meet their basic energy needs. Recently the subject has gained new and special attention, as governments and scientists have decided to work out ways of developing "green energy" and turning it into fuel. Many questions are still largely unanswered. What type of plants are best for energy farming and which can be disregarded, at least for the time being? What are the best sizes of programmes? What fuels should be produced, and how should this be done? What long-term research and planning is needed, and what should countries be aiming at? Beneath these essentially practical questions lies an even more fundamental one; is large-scale energy farming really feasible economically, socially and environmentally? Economics is critically important because all the costs of growing and harvesting energy crops, and of turning them into fuel, have to be met by selling the end products. Serious social and institutional problems could be caused by conflicts over how much land, water and fertilizer should be given to energy farms, and how much to growing food. And pollution and other environmental problems could result from the large-scale energy farms—running into tens, even hundreds of thousands of hectares—that are being contemplated: they will have to be carefully assessed at an early stage to make sure that "green energy" is developed in an appropriate and environmentally sound way.

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