69992

THE ECONOMICS OF TECHNOLOGY
WORKING PAPER NUMBER 11

ENVIRONMENTAL TECHNOLOGIES FOR DEVELOPING COUNTRIES

By: Nicholas R. S. Evans
SRI International

February 1991

Bureau for Program and Policy Coordination
U.S. Agency for International Development

Technology Assessment Policy Analysis Project
A.I.D. Contract No. PDC-0091-C-00-9092-00
SRI International

TABLE OF CONTENTS

INTRODUCTION 1

ENVIRONMENTAL ISSUES 2

SOURCES OF WASTES 5

THE TECHNOLOGIES 5

- Pollution Detection 7
  - Remote Sensing 7
  - Biological Sensors 8
  - Other Sensors 9
- Waste Removal/Treatment Techniques 10
  - Water Treatment 10
  - Gas Treatment 13
- Waste Disposal 15
  - Discharge into Waters and Air 16
  - Dumping at Sea 16
  - Burial 17
  - Incineration 18
  - Bioremediation 20
- Waste Storage 22
  - Deepwell Injection 23
  - Storage Tanks 23
  - Solidification 24
  - Encapsulation 25
- Waste Recycling and Materials Reclamation 25
- Alternative Materials and Processes 27
  - Materials Substitution 27
  - Process Modification 28
  - Alternative Energy Sources 29

CONCLUSION 30

SOURCES OF INFORMATION 32

ENVIRONMENTAL TECHNOLOGIES

INTRODUCTION

Industrialization and economic growth in developed and developing nations alike are often achieved at the expense of the environment. The problem is particularly acute in those developing countries that experience rapid economic growth, where the pace of industrialization and urbanization outstrips the capacity for adopting sound environmental technologies. Globally, several developing countries have become major contributors of greenhouse gases, with Brazil, China, and India respectively ranking as the world's third, fourth and fifth largest producers of carbon dioxide. Locally, inefficient energy use and inappropriate methods of disposing industrial and consumer wastes have caused various forms of damages such as smog and acid rain, polluted rivers and streams, and disruption in local ecosystems.

Incorporating environmental considerations into overall development objectives is an emerging issue within USAID. The current task is threefold. First, it is vital to examine alternative methodologies that determine the acceptance level (or optimal level) of environmental damage for a given amount of economic benefit to the developing country concerned. Second, it is important to identify the suitable incentive systems and effective regulatory mechanisms to enforce the environmental standards. Finally, it would be helpful to assess the costs and

effectiveness of various existing environmental technologies and identify those feasible options as targets of USAID financial and technical assistance.

USAID has a potentially significant role in espousing sound environmental policies, sponsoring research and disseminating practical information on the feasible options, and providing technical assistance where appropriate. To respond effectively to environmental challenges requires a firm grasp of the issues involved, their priorities, and the available options to achieve the necessary levels of protection. Unfortunately, research literature on the environmental impact of development is still poor, and very few comprehensive assessments have been carried out on the feasibility of various environment technologies for developing countries. This working paper is an attempt to contribute to the existing body of literature by identifying and assessing the relative costs of some of the currently available environmental technologies.

ENVIRONMENTAL ISSUES

The major source of environmental damage is poor or short-sighted management of industrial, agricultural, or consumer wastes. The introduction of natural and unnatural organisms into the environment and changes in land-use or agricultural practices take their toll on the environment. The environmental impact of various type of pollution varies with factors such as geographical

location, and the concentration or combination of wastes at any location.

The extent of the damage itself can range from being a mere nuisance or visual disturbance, to the destruction of plant and animal lives, to drinking water contamination, to global climatic threats brought about by the rapid increase of atmospheric carbon dioxide. Such ecological disturbances can be treated at several levels, either independently or as a coordinated program depending on the severity of the actual or potential damage, the desired level of treatment, and the capabilities and resources of the waste management authorities.

Environmental damage or pollution may be a result of accidents, such as the Valdez oil spill, or deliberate neglect. In each case the actual or potential damage is assessed by applying what is usually a complex cost-benefit equation, often with conflicting parameters contributing to the overall balance which will dictate the direction of any action. The appropriate action should not be viewed as merely a retrospective response to the damage already done, but more importantly, preventative measures.

It is important to look beyond the technical aspect of the solutions. There are few problems that cannot be solved from a technical point of view. In most instances, however, the appropriate response requires large capital expenditure or a switch

to an alternative, more expensive resource, and such costs are often the overriding factor determining the course of action in developing countries. Moreover, some solutions have political implications that cannot be ignored. For example, the decision to import low-sulfur coal for power generation rather than use domestic high-sulfur coal may lead to labor unrest with political repercussions. There is also scientific and political controversy over some environmental issues, such as the safe levels of emissions or the causes of the greenhouse effect. They add to the general confusion which delays effective legislation and other preventative actions.

In making decisions as to what level of control and protection is economically feasible, developing country governments may diverge from the standards of the developed countries. Developing country governments preoccupied with economic development typically place a higher priority on industrial growth than on clean air or rivers. Some developed country companies admitted to investing over 20 percent of their annual capital expenditure in order to comply with current and expected environmental legislation. Similar levels of investment in developing countries would be difficult to attain as they may hamper industrial growth and discourage foreign investments. In the long run, however, it is of global interest to control environmental damage worldwide. Developing countries could benefit from the lessons learned in the

developed countries, and have access to the appropriate technology to alleviate the problem of wastes.

SOURCES OF WASTES

Wastes come in various forms, with each having potentially different effects on a particular environment, and to each a number of possible means of effective management can be applied. Waste is often the result of mismanagement of industrial growth and development, and can be broadly categorized as:

- Chemical by-products which may be hazardous or non-hazardous solids, liquids or gases, the source of which is usually industrial, but could also originate from agricultural activities and domestic consumption.
- Waste from unwanted or unused materials such as industrial surplus and scrapped products, or domestic refuse and scrap.
- Inefficient use of resources (including energy) through poor selection of substrate materials or processes.
- Another significant cause of environmental damage--accidental spillage of hazardous materials--may also be blamed in many cases to poor management and inadequate safety considerations.

THE TECHNOLOGIES

The technical solutions to removing, minimizing or preventing these different types of wastes comprise a series of waste management (or environmental) technologies. Due to the diversity

of both the sources and the wastes, a wide range of technical solutions can be applied. These technologies can be split into two broad categories:

- o Containment or removal of a necessary waste before it reaches the environment through:
  - Pollutant Detection
  - Waste Removal/Treatment Techniques
  - Waste Storage
  - Waste Disposal
- o Reducing the creation of unnecessary waste through:
  - Waste Recycling and Materials Reclamation
  - Use of Alternative Materials and Processes (including conservation of energy and alternative energy sources)

There is considerable overlap of environmental technologies across the different classifications, as each environmental problem usually comprises a combination of chemical and physical conditions. Thus, the proper choice of technologies would depend on the type, quantity and location of the material or pollutant in question, the degree of waste reduction or elimination required by local regulations, and the costs involved. The bulk of the technologies described below will focus on waste removal and disposal techniques. The description is classified according to the aforementioned categories.

Pollution Detection

Pollution detection is an important means of determining whether or not an environmental problem exists or warning that one may arise. As the effects of individual pollutants become better known, early detection helps to prevent exacerbation of the problem. Moreover, pollution cannot be controlled, nor regulations enforced, unless the levels of pollutants are effectively monitored. Three basic methods of pollution detection are currently available:

- **Remote sensing** Remote Sensing through satellite or aircraft borne detection/observation can give an indication of large area changes due to pollution. Changes in the known characteristics of a geographical area are observed using a number of imaging technologies by means of visual, infrared and microwave radiations. The images can be used to help determine damage to crops, location of emission particle clouds, soil and water temperature changes as a result of contamination, and the build up of algal populations in seas and lakes. Remote sensing is a highly effective method to detect pollution. It can pinpoint pollution in areas with difficult access, help to give early warning of major pollution threats, or can be used to monitor clean-up attempts.

However, remote sensing is technically complex and it involves high capital expenditure and operational costs. Satellite or aircraft are needed to transport the sensors, and in large or remote areas, sensing from aircraft would be necessary to cover the area under survey. Thus, the remote sensing technique is not considered a highly feasible option for developing countries.

- **Biological Sensors** Since many biological organisms are sensitive to specific pollutants, their sensitivity and response can be used to determine whether a certain pollutant is present at a site where the organism is naturally located, artificially established, or used in biosassays under laboratory conditions.

The advantage of biological sensors is their effectiveness, if properly applied, and their relatively low cost and low levels of technical complexity. However, inspite of the active research and interest in biological systems, there do not offer an immediate answer to most problems of pollution detection. An ideal biological system of detection must possess the following characteristics:

- High sensitivity to changes in concentration of a single chemical;
- The change should be easily recognizable;

- The population should be established very close to the source of possible pollution to avoid the confusion caused by contamination from other sources.

These conditions are extremely difficult to establish in most pollution sites in both developing and developed countries. Until further research increases the sensitivity and the flexibility of positioning biological sensors, it would not become the most widely used method of pollution detection.

- **Other Sensors** Location of gases and liquid pollutants using open-path and guided-wave optical sensing techniques, biosensors and thin-film sensing technologies, together with analytical instruments in external locations, the laboratory, or within a process plant, will establish the presence and concentrations of specific chemicals, allowing suitable action to be taken if levels exceed a predetermined safety threshold.

By far the most often used and most important systems are those under the category "Other Sensors." Gas and liquid detection sensors in particular play a very important role in all fields of waste monitoring. A number of new sensors are under development, and they vary according to methods of detection, the pollutants they detect, the accuracy required, and the conditions under which they can be applied. Accuracy

requirements for detection play an important role in determining the type of sensor chosen for any specific application.

Sensor units range from hand held units to systems installed as fixed components in a process plant. Advanced sensors are already an essential component of many chemical process plants controls. Some of the high tech sensing techniques are quite sophisticated, but most of them do not require massive capital expenditure. AID has an important role in providing technical assistance and financing to help developing countries institute the appropriate sensing mechanisms to achieve effective pollution monitoring.

Waste Removal/Treatment Techniques

The purpose of waste removal and waste treatment is to prevent materials and chemicals from reaching sites where they may inflict damage. Waste treatment is a well established industry, and many different technologies have been developed to remove and treat specific types of wastes from different sources.

- **Water Treatment** Water treatment comprises a major classification within this category. Discharge of waste into water is a common and major source of pollution in many industrialized and industrializing countries. Since untreated water is more widely used by the population in developing

countries, the direct effects of water pollution on the population and other life forms are more serious. Waste water treatment technologies are therefore of prime importance to developing countries.

Aside from domestic sewage, waste water is also generated in many industrial processes in which chemicals and other waste particles are either deliberately or accidentally discharged into the water. In open systems this water is returned to the source, usually a river. To a certain extent, the river and eventually the sea or other large bodies of water will dilute the waste and minimize its effects on the environment. Damage could be done by every kind of chemical, however, when its concentration exceeds a critical threshold.

Once this concentration and the corresponding potential or actual damage are known, the discharge of the harmful chemicals must be restricted through water treatment to avoid damage to the environment. Treatment includes chemical conversion, physical conversion, or biological conversion of the pollutant to a less harmful substance that can be safely released to the environment or removed more easily from the water than the original contaminant.

Generally, although it may be possible to remove some of the waste through simple insertion of a filter across an

outlet, or the addition of a chemical into the waste stream, treatment of waste water in all but the simplest process plants requires building of a treatment plant. Whether this is on site or further down stream depends on the quantity and type of the pollutant. Although water authorities will treat water under their protection at various stages, the responsibility is increasingly placed on the polluter to treat the waste at source. Chemical, physical, and increasingly biological treatments are combined in many treatment plants.

Chemical conversion is usually applied through oxidation, reduction, and chelation, which require relatively low technical complexity and low capital requirements, but only yields moderate effectiveness. Physical conversion involves the use of activated carbon. It is highly effective but more costly and more technically complex compared to chemical conversion. Biological conversion involves such processes as digestion and oxidation of the pollutant. It is highly effective if appropriately applied and it represents a relatively low cost means that should be explored by developing countries.

These cost comparisons are based on capital expenditure. Cost varies with the choice of the technique selected in the chemical, physical, or biological conversion categories, but in general, physical treatment entails higher operation costs

due to the high material and maintenance costs of specialized features in the treatment plants.

Table 1.
Physical Treatment Costs

Technology	Applicability	Capital Cost	Capital to Operation & Maintenance Cost Ratio
Carbon Absorption	Broad	Medium	50:50
Sedimentation/Filtration	Broad	Low	Cap.<O&M
Ion Exchange	Specialized	High	Cap.<O&M
Reverse Osmosis	Specialized	High	Cap.<O&M
Thermal Oxidation	Broad	High	Cap.<O&M

Treatment can also be a direct physical separation of the contaminant from the water. Filtration is the prime means of separation, through a variety of systems which vary in complexity depending on specific site and waste requirements. Some systems simply physically separate materials from the water, others go on to further treat the waste by appropriate means. Physical separation is achieved through restriction of the passage of particles by physical size, sedimentation, and by specific absorption onto treated surfaces.

- **Gas Treatment** Treatment of gases is the second major classification of waste removal and treatment. The key gases requiring emission control are carbon dioxide, sulfur dioxide, and nitrogen oxides -- simply because of the high volume being generated all over the world. High levels of concentration

of sulfur dioxide and nitrogen oxide cause acid rain, while carbon dioxide, chlorofluorocarbons, methane, and nitrous oxide are believed to be the major contributors to the depletion of the ozone and the greenhouse effect.

Table 2
Major Sources of Various Gases

The Primary Sources	The Gases Produced
Coal-burning power plants, and all other industries that use large quantities of fossil fuels to provide heat and energy, e.g. steel furnaces	carbon dioxide, nitrogen oxides, sulfur oxides
Vehicle emissions	carbon dioxide, carbon monoxide, nitrogen oxides
Rain forest destruction	carbon dioxide
Refrigeration, electronics, air conditioning, foams, and aerosol sprays	chlofluorocarbons
Decay of organic matter in the absence of oxygen	methane
Agricultural fertilizers	nitrogen oxides

Similar to water pollutants, uncontrolled gas emissions can have a direct effect on the health of people in the vicinity of the source. Due to their physical nature, however, air pollutants is often dispersed over far greater distances than water pollutants, and their cumulative effects may be felt on a regional or global scale. Thus, continued international coordinated control of the

most damaging gases is essential for global protection. As with water pollution, physical separation can remove some of the pollutants from the waste gases, but gas washing with solvents (scrubbing), chemical and physical absorption and conversion through catalyzers combine to provide the technical means to remove noxious gases from emissions. Though highly effective, such treatment requires a relatively high capital expenditure and involves a high degree of technical complexity. Legislation and effective monitoring are necessary to ensure compliance by companies.

Waste Disposal

Various means of waste disposal have been devised, most of which only serve to shift environmental problems from one site to another, although some modification (through treatment) of the waste may have taken place. In general, options for waste disposal remain limited to companies. Waste disposal is not restricted to domestic waste or industrial waste. Waste also emanates from contaminated land or water cause by accidents or mismanagement of industrial sites. The scale of the problem can be judged from the thousands of U.S. sites identified under Superfund and Resource Conservation and Recovery Act regulations, with each site estimated as requiring between $500,000 and $20 million for adequate clean up or reclamation.

- **Discharge into Waters and Air** Discharging is the cheapest and most simple method of disposing of waste. Discharge of certain treated and untreated wastes into rivers and the air may be safe up to certain levels of concentrations. However, cumulative effects need to be considered, as well as possible interactions with other discharges. An example of a "safe in small quantities" discharge is vehicle emissions, which in some developed and developing country cities have reached alarming levels and are recognized to have a cumulative effect on the global level of atmospheric pollution. Efficient technical solutions to vehicle emission pollution are available at a cost, but are generally in use only in those locations where abatement is required by local legislation. Emission of toxic gases are already addressed far more widely through regulatory control of fuel additives, mostly in developed countries.

- **Dumping at Sea** Dumping at sea is another inexpensive and simple way to get rid of waste. Dumping hazardous wastes at sea is highly restricted or banned from most geographical locations. However, the dumping of certain non-toxic wastes continues to be allowed under the assumption that the dilution effect of the high volume of sea water will render this practice acceptable up to certain concentration levels. However, safe levels of discharge can be exceeded, and full

assessment of the likely long-term effects must be calculated to prevent what could become major ecological damage.

- **Burial** Burial is a widely used method of waste disposal, or, in cases where the waste is not fully degraded to a harmless form, a way of storing waste. Burying hazardous or non-hazardous industrial or domestic wastes in man-made or natural holes in the ground was, for a long time, considered to be an effective means of waste disposal in industrial countries, with little thought given to the possible environmental consequences.

Most industrial sites and cities were initially surrounded by cheap and convenient land that can be used for dumping and burying industrial and municipal waste. However, industrial and urban development generates pressure on land-use, creating a gradual trend towards disposing at more remote sites often with prohibitive charges for continued disposal. Due to the high costs of burial and the even higher costs of other disposal and treatment techniques, regulations designed to maintain the safety of landfill sites have been widely abused in developed and developing countries alike.

However, a properly managed landfill site accepting known, treated wastes, with plastic linings to prevent leaching of toxic chemicals to groundwater, is still a viable

means of waste disposal. In addition, methane, a common gas produced at landfill sites as decomposition of waste occurs, can be utilized as an energy resource, thereby providing a good opportunity for some return on investment.

The convenience, low cost and low technology requirements of burial render it the most attractive of options for waste disposal in those developing countries where land is not at a premium. However, it is important to recognize the lessons learned in developed countries, in terms of ensuring the safety of sites to prevent leaching, and acknowledgement that burial is a short-term rather than long-term solution to waste disposal.

- **Incineration** Incineration has emerged as an alternative to disposing of hazardous wastes and domestic waste by landfill. In some cases, the incineration plant is designed to deal specifically with a single pollutant such as PCBs (polychlorinated biphenyls -- used as an inert, electrically insulating medium for cooling and isolation of electrical power components, before it was banned in the late 1970s) that cannot be safely disposed of by other procedures.

Incineration involves considerable capital investment, and comprises a variety of incineration technologies aiming at convert solid, liquid and gas wastes physically to a safer

end-product through high temperatures (often exceeding 1200 °C). The resulting gases created during incineration still require treatment and disposal, and flue gas cleaning systems such as filtration, and gas scrubbing procedures are an integral part of the plants. Similarly, ashes and the liquid solvents from scrubbers must be chemically neutralized and suitably disposed.

Rotary kilns are considered to be the most versatile type of incinerator currently available, as they are able to destroy a full range of wastes that might be presented from contaminated soil through solids and liquids wastes. The competing technology, incineration by fluidised bed technology, makes use of a turbulent hot sandlike medium rather than the hot kiln chamber. Relatively new to incineration technology is plasma arc torch incineration that can completely destroy liquid organic waste at temperatures up to 5000 °C. Plasma arc torch incineration is still undergoing further development, but is believed to be a highly effective means of destroying organic waste.

In spite of the costs involved in building and running the plants, incineration is the most environmentally effective and versatile means currently available to dispose of wastes. Incineration plants can be mobile or located at the sites of waste production. There are opportunities for improving the

existing systems and developing new incineration techniques. Opportunities also exist to take advantage of the excess heat generated produced by incineration, which can be used to drive turbines or provide direct heating for industrial plants or municipal consumption.

- **Bioremediation** Bioremediation, the use of bacterial digestion, is receiving increasing attention as a means of waste treatment. The concept is not new, as bacteria have always been actively involved with the selective decomposition of different various substances. With better understanding of metabolic pathways and improved biotechnical means to identify, isolate, clone, manipulate, and clone bacteria with the ability to metabolize specific toxic wastes, an arsenal of bacteria is now made available to treat wastes.

  Although the bioremediation can be used to remove pollutants from waste streams and solids, it strength lies with its ability in cleaning polluted soils, where a cocktail of suitable bacteria can selectively and efficiently remove particular wastes without further damaging the local environment. To its added advantage, bioremediation is a much cheaper method than say, chemical treatment, of cleaning up contaminated sites or removing soils for dumping or incineration. The one area of concern is monitoring environmental conditions following the release of a cast

amount of bacteria. However, the same safeguards used in the application of biological pest controls and release of genetically modified organisms are sufficient to ensure adequate protection from having "runaway bacteria" damaging the environment.

The bulk of experience in applying bioremediation effectively has been with polluted soil. Recent bioremediation treatment of oil spill have indicated another potential area of successful application. Following some major demonstrated successful applications over recent years, industry confidence has grown considerably in the ability of bioremediation to be an effective player in waste treatment.

There exist hundreds of different types of bacteria equipped with the ability to metabolize different chemicals. As a larger number of bacteria is identified and isolated for the task of metabolizing specific target pollutants, the use of bioremediation becomes increasingly attractive. Skilled knowledge is required to formulate the correct mix of bacteria needed to treat a specific site, depending on the nature and concentration of the pollutants present. Bioremediation has a lot of potential in developing countries because of its moderate cost compared to other means of waste disposal, and its relatively low-tech application that does not require a large number of technically-skilled personnel.

Table 3
Cost Comparison for Different Methods of Waste Disposal

Method	Estimated Treatment Cost per cubic yard
On-site bioremediation for contaminated soil	$50 - $100
Excavation with off-site landfill	$200 - $400
Excavation with off-site incineration	$300 - $1000

- **Other Disposal Technologies** Disposal technologies still under development include microwave treatment of wastes, and enhanced oxidation of organic waste, making use of water in its super-critical state to dissolve normally insoluble organic.

Waste Storage

Where suitable technologies do not exist for effective or immediate waste disposal, or when the available techniques are prohibitively expensive, storage may be an option on both a temporary and permanent basis. Wastes that can be stored range from volatile liquid wastes awaiting incineration, to highly toxic wastes that need to be immobilized before disposal by landfill, to the long-term storage of radioactive materials. The prime consideration of all storage techniques is to contain the waste in a receptacle that minimizes the possibility of leakage into the surrounding environment. Selection of the appropriate materials for building the containment tank and effective subsequent

monitoring of leakage is key to this technique. Various storage techniques will be described below.

- **Deepwell Injection** Deepwell injection is specifically targeted towards hazardous liquids. It involves pumping the liquid into a permeable earth stratum below water levels (to eliminate groundwater contamination), and between impervious shale, clay or granite layers. For most wastes this is very much a "let's-bury-it-and-forget-it" solution, since the environmental impact of these facilities is rarely known. This method of storing waste is not very technically complex, but would involve high costs of capital expenditure.

- **Storage Tanks** Storage tanks both above and below ground can be more closely monitored. Storage tanks can be used to contain hazardous materials until they are transferred for final disposal or treatment. With the appropriate materials for building storage tanks, accurate estimate of their lives before disintegration, and effective monitoring devices to detect leakages, storage tanks have their role to play in waste management options. Storage tanks are only moderately costly and technically very simple. However, they are seldom regarded as a long-term solution because the tanks will only have an finite life-span.

- **Solidification** Solidification comprises a variety of treatment techniques designed to entrap wastes within a solid matrix having high structural integrity to minimize the risk of leaching during long-term storage, providing appropriate safeguards in burial sites for waste storage. Typical wastes handled this way are pesticides, heavy metals and cyanide.

There are several means of solidification. Portland cement is the most popular solidification agent for inorganic wastes. Lime-based pozzolana has advantages in restricting the leaching potential of metals. Thermoplastic resins are another useful material (the most used is bitumen), having application in immobilizing arsenic and other heavy metals, PCBs, and dioxin. However, it is mainly used with radioactive wastes, as have organic polymers.

Another form of solidification techniques is glassification (or vitrification), through which wastes are mixed with molten borosilicate glass which solidifies to give a structure with high tensile and compressive strengths. Glassification is used almost exclusively with radioactive wastes because of its high cost.

The cost of solidification vary with the substance being treated, but is in general lower than deepwell injection and higher than using storage tanks. It is, however, a quite

effective means of preventing leakage of hazardous materials during storage.

- **Encapsulation** Similar to solidification, the waste material is coated with a polyethylene or polybutadiene insoluble jacket. Encapsulation isolates the wastes without the need for secondary containment, such as in drums. The process is expensive, due to high material costs, energy requirements, and the need for skilled labor.

Waste Recycling and Materials Reclamation

Waste recycling is an effective means of reducing the amount of wastes that need to be treated or stored. It reduces the cumulative effects of pollution from poorly disposed waste, or the cost of effective disposal. It also lowers the demands on materials resources. From water (recycled through organic solvents, metals and minerals) to plastics and paper, there exists considerable opportunity for developing techniques that help to isolate and prepare materials for recycling.

Many materials are suitable for recycling, but each has different purity requirements and varying degrees of contamination problems. A major differentiation exists between waste such as offcuts and spillages in process plants, where the material remains on site and is relatively pure liquid and solid wastes (or even gas) containing a mixture of materials, and the recycling of

manufactured products, such as metals and plastics in vehicles. The major technical hurdle is to collect and isolate the material for it to be reintroduced into a production cycle.

However, the environmental advantages of recycling materials may not exist in some cases. For example, where the extraction and purification processes consume large amounts of energy, tolerating waste production may be environmentally superior to using excess energy for recycling. Collection and sorting of mixed materials in municipal wastes, for example, calls for either highly developed technology or intensive labor levels. Moreover, for recycling to be attractive to industries, the collection and isolation of wastes for recycling must be financially beneficial relative to other options of waste disposal. Of course, strict environmental legislation may leave industries with no choice, and drive research further into improving recycling systems.

It would be futile to focus on the technical details of the various recycling technologies for the purpose of this study, as they are very much materials-specific. The success of any recycling programme will not be driven by technology alone, but rather by the resource constraints, the relative replacement and disposal costs, and legislated requirements. Recycling of certain materials is likely to be more appropriate in developing countries than in industrially developed countries due to the scarcity or high cost of both materials and energy, and low labor costs.

Variations of the above will change the cost-benefit equation for recycling.

Alternative Materials and Processes

Avoiding the generation of particular wastes, whether they cause pollution or are a valuable, or nonrenewable resource is another technological solution to environmental protection. Here, a wide variety of environmental technologies exists, ranging from straight forward substitution of one material for another (in order to remove a pollutant directly from the environment), to the use of alternative, renewable or non-carbon fuel sources, to techniques and processes designed to conserve energy and heat (to protect traditional energy resources). Detailing the list of available techniques would not meaningful within the context of this study. It is more important to appreciate the rationale behind these options, and to identify those options that are both environmentally sound and appropriate for application in developing countries.

- **Materials Substitution** The most straight forward option is materials substitution, which in some cases requires considerable R&D, in other cases consumer education. In industries, replacement of asbestos, PCBs and chlorofluorocarbons (CFCs) by substitutes are the key examples where recognition of environmental damage led to a rapid search for alternative materials. Legislation is vital for

such a fast industry response. However, substitution does not have to be applied globally to be useful. Local environmental problems may be better solved through substitution rather than improved waste disposal and treatment. Substitution has the potential of being technically, economically and environmentally beneficial to developing countries. For example, manufacture of one product instead of another may require less energy, or use more readily available materials.

- **Process Modification** Process modification is closely associated with materials substitution in many instances. Modification of production processes such as chemical reactions may result in less harmful byproducts, or reduced energy use. Research on the possibilities of process modifications are in the interests of all manufacturers and has been frequently applied in the normal cycle of process improvements. Emerging legislation on environmental protection would provide the additional incentive to industries to examine their production processes.

Where the gain is simply one of energy reduction, both the environmental and economic parameters have to be considered. The environmental savings are those associated with the reduction of energy requirements and the reduction of any pollution resulting from the production of that energy. Energy savings may be made in two ways. First, energy can be

saved under the different energy requirements of a new production process. Second, a conscious effort can be made to reduce energy wastage caused by insufficient insulation and inefficient power use (for example leaving plant or even lights and heating running unnecessarily) etc. In the latter case savings would be immediate, but the savings from reduced process energy requirements must be balanced with any costs incurred by adapting the process. Again, geographical location and the availability and cost of energy could be decisive.

- **Alternative Energy Sources** Industrial countries rely on three basic fuels -- coal, oil/gas, and nuclear for most of their energy needs. The environmental damage caused by continued use and the expected increase in future energy demands is well documented. It is also accepted that the carbon-based fuels have a finite life-span, and that nuclear power generation is unlikely to provide for the future global power requirements. Alternative power sources are necessary.

  For developing countries, opportunities to develop local alternative power sources is an attractive option. Many technologies are already established or being tested in these countries because of their applicability there. The selection of the most feasible technology would depend on the specific power needs of a site and its geographic location.

Table 4

RELATIVE COST COMPARISON FOR SELECTED ENVIRONMENTAL TECHNOLOGIES

Technologies	Environmental Effectiveness	Relative Costs/ Capital Requirements	Technical Complexity
Sensors			
Remote	Good	High	High
Biological	Good	Low	Low
High-tech	Good	Medium	High
Waste Water Treatment			
Physical	High	Medium	Medium
Chemical	Medium	Low	Low
Biological	High	Low	Medium
Gas Treatment			
Physical	High	High	High
Chemical	High	High	High
Waste Disposal			
Discharge	Negative	Very Low	None
Dumping at sea	Negative	Medium	None
Burial/landfill	Limited	Medium to High	Medium
Incineration	High	High to very High	High
Bioremediation	High	Medium	Low
Waste Storage			
Deepwell	Limited	High	Medium
Storage Tanks	Low	Medium	Low
Solidification	Medium	Medium to High	Medium
Encapsulation	Medium	High	Medium
Waste Recycling/Reclamation	High	Medium to High	None (payback)

Alternative energy sources that are in the advanced stages of testing and have so far proven to be promising include photovoltaic (solar), wind, biomass, hydro, tidal, and geothermal power.

CONCLUSION

The economics of waste management in developing countries is extremely complex. The cost-benefit analysis undertaken to select the efficient solution will have to take into account not only the current costs of damage and clean-up, but the future stream of benefits and costs pertaining to each alternative solution from the developing country's perspective (such as using the appropriate discount rates). USAID can play an important role in sponsoring research on the alternative methodologies that could be applied in developing countries to assess the value of natural resources and the costs of environmental damage. To assist developing countries in making informed choices, USAID can also sponsor research and disseminate information on the costs and applicability of various available environmental technologies and provide technical assistance where appropriate. This paper is an attempt to survey, classify, and assess the costs of some of the currently available technologies.

General cost comparison is possible, but other factors such as the variety and the combination of wastes and the clean-up levels sought would render such comparisons meaningless if taken

out of context. For instance, the capital costs of various gas scrubbers for reducing carbon dioxide, sulfur dioxide, and other emissions depend on specific gases involved, the quantities of gas emitted, and the abatement levels sought. Some methods are less expensive than others, but they may be less effective. The selection decision is very much governed by the abatement levels imposed by the authorities, or the nature of regulation applied (whether it is cost-based or quantity-based). The general cost comparison provided in Table 4 should only be viewed as a attempt to provide a useful perspective on environmental technology options.

The costs of solutions to environmental problems would also depend on the point at which intervention takes place. In general, prospective and preventive solutions are more flexible and less costly than retrospective solutions. Long-run, prevention technologies should be emphasized and receive high priority should USAID become more involved in sponsoring research and providing technical assistance in environmental technologies for developing countries.

SOURCES OF INFORMATION

U.S. Office of Technology Assessment.

Overseas Development Institute, London.

Review -- the United Kingdom Department of Energy Quarterly Journal of Renewable Energy

The United Nations Environment Programme (UNEP) Industry and Environment Review

The Scientific American