RESIDENTIAL AND INDUSTRIAL (SOLID) WASTE DISPOSAL SUPPORT PACKAGE

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This document is one of five Technical Support Documents that have been developed to accompany international training workshops on the Principles of Environmental Enforcement. They were developed as resource documents for government officials and others who are motivated to try to reduce the adverse environmental impacts from activities described in the case studies used for the course. The five case study areas include:

- Mining (Metallic ores and Minerals),
- Petroleum Refining and Petrochemicals,
- Residential and Industrial (Solid) Waste Disposal
- Tourism, and
- Deforestation.

The documents provide an overview of the environmental impacts, pollution prevention and control opportunities, range of institutional mechanisms to control adverse impacts, and an annotated bibliography of selected reference materials. They do not address institutional and program development issues surrounding regulatory and enforcement programs. These topics, as well as country specific program examples are developed in the Proceedings of the International Conferences on environmental compliance and enforcement, UNEP institution-building workshop materials and new capacity building documents under development for the Fourth International Conference scheduled to be held in April, 1996 in Thailand.

International workshops on the Principles of Environmental Enforcement provide an opportunity for governmental and non-governmental officials to discover and apply the definitions, frameworks and principles to develop a successful management approach, compliance strategy and enforcement program for any environmental problem in any cultural or legal setting and to explore negotiated resolution of enforcement problems. The Principles of Environmental Enforcement text and training was developed by the U.S. Environmental Protection Agency in collaboration with the government of Poland and in cooperation with the government of the Netherlands. It was adopted as a basis for international exchange after having been successfully presented with this purpose in mind at the Second International Conference on Environmental Enforcement held in Budapest, Hungary, September 1992.

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This Technical Support Document is intended to accompany the Principles of Environmental Enforcement Text, U.S. EPA, which describes the basic elements and approaches for establishing effective compliance strategies and enforcement programs. As a supplement to international efforts to advance effective environmental compliance and enforcement programs, the readers are referred as well to the UNEP IE training manual on Institution Building for Industrial Compliance and Proceedings of the series of International Conferences on Environmental Compliance and Enforcement for further discussion of these programs.

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1. INTRODUCTION AND SUMMARY

Population growth, rising standards of living increasing urbanization, and industrialization

all have contributed to increased solid waste generation in both industrialized and developing countries. Solid wastes pose significant threats to public health and the environment if they are not stored, collected, and disposed of properly. The most serious effects of improper solid waste management include air pollution, contamination of drinking water supplies, and the spread of human disease. These problems suggest the need for government policy-makers to explore pollution prevention options and to consider regulatory and enforcement strategies to minimize the harmful environmental impacts of improper solid waste management practices, especially those used in landfilling, the main method of waste disposal in the world.

1.1 Purpose and Overview of the Solid Waste Support Package

This document is a general resource for governments and others about environmental effects of solid waste. It introduces some of the methods available to prevent, control and mitigate these impacts. More detailed sources of information are cited in the *Annotated Bibliography of Additional Sources* section in the Appendix for those seeking more in-depth technical or regulatory information.

The focus of this report is on solid waste landfilling, the most common method of solid waste disposal worldwide. Since it is the most prevalent management option, land disposal presents the greatest environmental challenges internationally. Other solid waste management practices such as source reduction, collection, recycling, composting, and incineration are discussed, but in considerably less detail. Of the remaining options, incineration can be most harmful to the environment and public health when it is poorly controlled. Incineration, however, is practiced only infrequently in developing countries since the technology is expensive and waste streams in developing countries tend to have little heat content (i.e. in low-income countries, waste contains only 2% paper compared to 31% paper in waste streams in industrialized nations). Less sophisticated waste burning in open dumps, which is more characteristic of many low-income and developing nations, is addressed in this support package.

Industrial hazardous waste -- solids, sludges, and liquids that contain toxic levels of metals, solvents, or organic or inorganic chemicals -- also are not considered in this support package. In most low-income countries, hazardous waste flows contribute only small percentages of the total industrial and household solid waste stream. As industrialization escalates, of course, these wastes can become a much more important problem. Several documents cited in the *Annotated Bibliography of Additional Sources* (see the Appendix to this package) address alternatives to prevent, controll, or remediate impacts from industrial hazardous waste.

For purposes of this document, solid waste is defined as:

> *"Material for which the user (or generator) of the material abandoning the material requires no compensation upon abandonment. This material is considered within the responsibility of the government to ensure the proper collection and disposal of this material."*

Solid wastes are generated by residential, commercial, and industrial establishments. Industrial wastes fall within the responsibility of the municipal government even though they are often collected and disposed by private companies. All industrial and household hazardous wastes which are disposed with non-hazardous solid wastes are considered within this definition.

Because solid waste is such a broad and complex topic, this package includes an extensive bibliography of resources providing greater detail on issues that are only briefly discussed in this document.

1.2 Solid Waste Management and the Environment

Solid waste management techniques vary from country to country depending upon physical geography, demographics, and level of economic development. Most industrialized countries have regular solid waste collection and disposal services. Most waste disposal sites are required by law to have at least some environmental prevention and control technologies. In contrast, most developing countries provide formal waste collection and disposal services to only a portion of the population -- the urban poor as well as residents of rural areas often have no formal collection services or designated dumping areas. Even when areas are designated as disposal sites, often they are open dumps that pose serious threats to public health and the surrounding environment.

1.3 Toward Sustainable Development: Pollution Prevention and Control

The environmental effects of improperly disposed solid wastes can be controlled through public education; economic incentives; careful planning; monitoring of waste flows; and enforcement of clear, well-defined solid waste management regulations. Approaches must cover all phases of solid waste management including storage of wastes at the point of generation, waste collection, and waste disposal. Examples include:

- public education that demonstrates the linkages between poorly controlled solid waste and environmental contamination or health risks;
- provision of containers or regulations that require controlled storage of solid waste so that every generator has an adequate number of containers to store waste between times of collection;
- education, public programs, or private contracts that assure reliable central or curbside collection consistent with storage requirements;
- regulations to control the construction and operation of collection and transport vehicles to minimize odors, leakage, and litter; and
- education, incentives, or regulations that eliminate littering and the indiscriminate disposal of solid waste - especially burning and open dumping.

The choice of management approach ultimately will depend on waste volume, waste composition, local social and economic conditions, and the technological capabilities of local communities. Waste flows per person in low-income countries, for example, typically are 1-3 times lower than in industrialized countries (see table 2a). Waste streams in low-income countries also tend to be dense, wet, and dominated by vegetable matter. Recycling makes little sense since few materials in this waste stream have residual value. Composting, on the other hand, may be well-suited to the typical waste stream and socio-economics of low-income countries. In industrialized countries, in contrast, waste has a much higher percentage of paper, glass, and metal; it is not

nearly as dense and much drier. Source separation, recycling, and incineration of high-heat content residuals may make more sense for these countries. Mechanisms to effect waste management options for each of these situations are likely to be somewhat different. **2. PROFILE OF THE SOLID WASTE MANAGEMENT INDUSTRY**

This section describes the characteristics and scope of the solid waste industry in low-income, middle-income, and industrialized countries. Topics discussed include: waste stream characteristics; and collection; transfer; and disposal practices.

2.1 Waste Stream Characteristics

How a country chooses to manage solid wastes depends upon the type and amount of waste that it produces. Table 2(a) below describes the characteristics of urban wastes in low-income, medium-income, and industrialized countries. Countries are categorized according to their mean annual income per capita: low income countries less than US$360, middle income between US$360 and US$3,500, and industrialized greater than US$3,500.

Table 2(a): Characteristics and Composition of Urban Solid Wastes[1]

Parameter	**Low-Income Country**	**Medium-Income Country**	**Industrialized Country**
Waste Generation Rate at Source of Generation (kg/capita/day)	0.4 - 0.6	0.5 - 0.9	0.7 - 1.8
Composition			
Paper	2 %	7 %	14 %
Metal	2 %	60 %	2 %
Plastics	2 %	22 %	11 %
Glass	4 %		2 %
Textiles, rubber, leather, wood			
Vegetable			
Other			14 %

47 %
10 %

31 %
8 %
8 %
10 %

5 %
25 %
13 %

Density (wet density per kg/m^3)	250 - 500	170 - 330	100 - 170
Moisture (percentage)	40 - 80	40 - 60	20 - 30

2.1.1 Waste Generation

Comparisons of waste generation rates are inevitably crude because few governments know how much waste is made and there is no consistent definition of what constitutes municipal solid waste and hazardous wastes. For example, some countries consider construction and demolition debris as part of the municipal waste stream, while others do not.

Despite these difficulties, there is general agreement that residents of industrialized countries dispose of much more waste than residents of developing countries. A recent World Bank study found that urban areas in industrialized countries generate 2 to 3 times more waste per capita than low income nations (see Table 2(a)). In developing countries, waste is a luxury available to only the wealthy minority. Most wastes are recycled or reused by residents who scavenge through the waste stream for valuable materials.

Industrialized countries generate fewer wastes as their economy grows and a greater proportion of income is spent on services, such as education and health, which generate less waste per dollar spent. For example, between 1980 and 1990, per capita municipal waste generation in the United States grew by only 0.5 percent a year compared with an increase in the size of the U.S. economy per capita of 1.9 percent per year. Section 2.5.1 below discusses the importance of efforts to reduce waste generation through source reduction and reuse of materials.

2.1.2 Waste Density

The density of waste is inversely related to the amount of waste generated. In other words, countries with high per capita waste generation rates (i.e. industrialized countries) produce waste that is of a lower density than waste produced by countries with low per capita waste generation (i.e. developing countries). Waste densities are between 2 and 5 times higher in low income countries (see Table 2(a)). Industrialized countries produce lower density waste because they generate a higher percentage of paper, plastic, glass, and metals which are often used as packaging materials for consumer goods. These materials have large open spaces (i.e. an uncompacted tin can) and a low moisture content. In contrast, developing countries produce a higher percentage of food wastes, which has less open spaces and a high moisture content. The moisture content of wastes in developing countries is higher because it has a higher percentage of food (vegetable) wastes and the waste is often stored on the open ground awaiting collection.

2.1.3 Waste Composition

Waste from low- and middle- income countries contains fewer paper products and non-food items than waste from industrialized countries. The composition of solid waste is a key determinant in decisions concerning types of vehicles needed for collection and transfer, requirements for final disposal, and resource recovery alternatives.

In both developing and industrialized countries, the waste stream may become contaminated by human and hazardous wastes. In developing countries human wastes are mixed into the waste stream when there are inadequacies with the sewage system. In more industrialized countries, most of the human wastes comes from disposal diapers.

Hazardous wastes are generated by residents and industry. Residents dispose of household hazardous wastes such as batteries, used motor oil, and cleaning solutions. Industry can generate substantial amounts of hazardous wastes such as industrial solvents. While the degree of industrialization in developed countries is much greater than in developing countries, the ratio of industrial hazardous wastes to total industrial wastes is similar. In the United States, approximately 10 to 15 percent of all industrial wastes are classified as hazardous.[2]

2.2 Provision of Solid Waste Management Services

Most countries place the responsibility for collection and disposal of solid wastes on the local municipal government. In some cases, the local government provides collection and disposal services directly while in others, the local government contracts these services out to the private sector. Contracting waste management services to the private sector is becoming an increasingly popular way of providing waste services at lower cost in many industrialized countries. In the United States, more than 80 percent of the nation's municipal solid waste is collected by private firms and 7 percent of the landfills and 73 percent of the resource recovery facilities are operated by private contractors. The costs for providing solid waste management service in Sao Paulo using private contractors is less than half that in Rio de Janeiro which uses a publicly run system. Privatization in lower-income countries is somewhat limited as few companies have expertise in solid waste management and foreign investment is not encouraged.

2.3 Solid Waste Collection

This section describes solid waste collection practices in low-income, middle-income, and industrialized countries. Three main issue areas are discussed: provision of collection services; waste storage, and collection vehicles. Where possible, comparisons are made between collection practices in developing versus industrialized countries.

2.3.1 Provision of Collection Services

Although most urban areas in developing countries have waste collection services, this service is usually not available to all sectors of the population. Waste is usually collected from the high and middle income areas of the city but not in the lower-income areas. Lower-income areas have poor roads making it difficult for waste collection vehicles to assess the area, and generate

fewer recyclables making it less profitable to recover materials from the waste stream. In Latin American countries, the average service coverage for cities in the region is about 70 percent -- ranging from 50-70 percent in smaller cities to 85-90 percent in larger ones. Thus, about 30 percent of the garbage in the region, or some 20 - 25 million tons a year, is not collected at all.[3] Frequent collection services are needed to prevent health problems, especially in regions with high temperatures and humidity where solid wastes decompose and decay rapidly. For example, in Colombia, uncollected refuse can cause malaria. The uncollected refuse blocks storm drains and creates stagnant pools of water where malaria-carrying mosquitoes breed.

In areas which have waste collection, other problems occur such as residential cooperation and frequent collection vehicle breakdowns. Residents put their garbage out on the wrong days or in open piles or inappropriate containers. These inappropriate collection practices not only increase litter and threaten public health but also increase the cost of collection. Many developing countries are trying to improve collection practices through education programs. Another problem is the frequency in which collection vehicles breakdown. This is common in developing countries where insufficient budgets make it impossible to provide adequate maintenance. Downtimes of 40 to 60 percent are common for collection vehicles in developing countries compared with 5 to 15 percent downtimes in industrialized countries.[4] Development of preventive maintenance programs and educational efforts may very helpful in certain locations.

2.3.2 Storage of Waste at the Source of Generation

Waste can be stored at the source of generation in a variety of containers including household storage bins and communal storage bins. Household storage bins are used to store waste generated from a single household or business and are either provided by the collection agency or the waste generator. Communal storage bins are usually used to provide service to neighborhoods or apartment complexes. The type of storage container dictates how the waste is collected and the efficiency of the collection process. Improper storage methods increase litter, threaten public health, and increase the cost of collection.

2.3.3 Collection Vehicles

There are basically three types of waste collection vehicles: those that are human-powered, animal-powered, and engine-powered. Each of these vehicles give different levels of service and require different levels of skills to operate. Human-powered equipment includes pushcarts, pedal tricycles, and wheelbarrows. This equipment is commonly used in collection areas with limited access, such as narrow streets. Animal-powered equipment includes carts drawn by animals or animals that are saddled with collection containers. Animal-powered equipment is often used on hilly, unpaved, and/or narrow streets. Engine-powered collection equipment includes tractors that pull wheeled containers (tractor trailers), flat bed trucks, and trucks with mechanized compaction equipment. In general, compaction trucks are not needed in developing countries because of the higher density of waste. (Compaction trucks achieve a compaction ratio of 4:1 in industrialized countries and only a 1.5:1 ratio in developing countries.) Table 2(b) below summarizes the characteristics of these collection vehicles.

Table 2(b): Solid Waste Collection Options[5]

Parameter	Manual Handcart	Pedal Tricycle	Animal Cart	Tractor Trailers	Flat Bed Trucks	Compactor Trucks
Distance Traveled	<2 Km	<10 Km	<10 Km	<15 Km	Unlimited	Unlimited
Speed	Very slow	Slow	Slow	Relatively slow	Fast	Fast
Applicable width of street	Narrow	Narrow	Moderate		Moderate	Wide	Wide
Volume per vehicle	0.5-1 m^3	2-3 m^3	4 m^3	4 m^3	8 m^3	12 m^3	
Labor Requirement	1 Collector	1 Driver	1 Driver	2 Loaders	1 Driver		
				2 Loaders	1 Driver		
				3 Loaders	1 Driver		
				3 Loaders			
Purchase Cost	Very Low	Low	Low	Relatively Low	Moderately High	Very High	
Maintenance Requirement		Very Low	Low	Low	Low	Moderately High	High

2.4 Solid Waste Transfer

Solid waste that is collected from an area may either be hauled directly to the disposal site by the collection equipment or it may be transferred to another size or type of equipment for hauling. In general, waste transfer is economical when the disposal site is located sufficiently far from the collection area. Transferring waste to a larger or more efficient hauling vehicle allows the collection vehicle to maximize its time on its collection route and for the collection crew to maximize its time collecting wastes. Typically, waste is transferred at a transfer station where waste is dumped onto a platform and then pushed (or dumped) into the larger collection vehicle. In many cities, waste is transferred into rail cars or barges for transport to the disposal site.

2.5 Solid Waste Disposal and Management Techniques

Landfilling is by far the most common method of waste management in both industrialized and developing countries because it is generally less expensive than the alternatives of incinerating, composting or recycling. In the lower-income countries, waste is most often disposed in open dumps with few, if any environmental controls. Some recycling is done by scavengers and other resource recovery options such as composting and incineration are not widely used.

In industrialized countries, landfills are usually required to install some types of pollution prevention and environmental controls. Even with these more stringent control requirements, landfilling is still often the least cost method of disposal. For example, when compared with per ton incineration costs, landfilling in Germany is $70 per ton cheaper and $20 per ton cheaper in the United States.[6] Table 2(c) below presents the percentage of waste landfilled in numerous industrialized countries. **Table 2(c): Estimates of the Percentage (by weight) of Post-Recycling Municipal Solid Waste Landfilled in the United States, Japan, Europe**[7]

Country	Percent Landfilled	Year
Denmark	44	1985
France	54	1983
Greece	100	1983

Ireland	100	1985
Italy	85	1983
Japan	33	1987
Netherlands	56-61	1985
Sweden	35-49	1985, 1987
Switzerland	22-25	1985
United Kingdom	90	1983
United States	90	1986
West Germany	66-74	1985, 1986

Industrialized countries are becoming aware of the environmental problems caused by waste generation and disposal and many use more environmentally friendly methods of waste management such as waste composting and recycling. In support of this movement, the United Nations Environment Programme has endorsed a common approach to waste management -- the waste management hierarchy. This hierarchy lists waste management alternatives in order of priority: source reduction (decreasing waste generation), direct reuse of products, recycling and composting, incineration with energy recovery, and as the last resort -- landfilling. This hierarchy is primarily used as a planning tool and to date, waste management options have not been applied in this order. For example, in 1992, the United States generated approximately 292 million tons of solid waste, of which approximately 72 percent was landfilled, 17 was recycled or composted, and 11 percent incinerated.[8]

Table 2(d) below compares the solid waste management practices in low-income, middle-income and industrialized countries. It should be noted that some nations have much higher recycling rates or more materials reuse than others, partly because of governmental efforts to encourage recycling and reuse as a means of waste management. Reusable beverage containers, for example, are very common in certain European nations.

Table 2(d): Comparison of Solid Waste Management Practices: Low Income, Middle Income, and Industrialized Countries

	Source Reduction	Recycling	Composting	Incineration	Landfilling
Low Income Country	No organized programs, but reuse and low waste generation per capita are common.	Most recycling performed by scavengers.	Rarely undertaken although high percentage of compostable materials.	Infrequent. Expensive technology and high moisture content and high percentage of inert materials.	Low-technology sites, usually open dumping.
Middle Income Country	Some discussion of source reduction, but rarely taught in any organized programs.	Some high technology sorting and processing facilities.	Some, mostly small-scale, composting projects.	Operate, but not as common as in industrialized countries.	Contained landfills with some environmental controls.
Industrialized Country	Organized education programs are beginning to emphasize source reduction and reuse of materials.	Dedicated collection services and high technology sorting and processing facilities.	Gaining popularity at both backyard and large-scale facilities. Fewer compostables generated than in low-income countries.	Prevalent in areas with high land costs. Most incinerators have some type of energy recovery (i.e. steam) system.	Sanitary landfills. U.S. landfills have liners, leak detection and leachate collection systems, and energy (methane gas) recovery systems.

2.5.1 Source Reduction and Reuse

Although pollution control through technology has historically received much attention, pollution prevention is in many cases a less expensive method of managing wastes, and can be particularly helpful in nations with limited financial resources. One means of pollution prevention is source reduction. Source reduction is the most basic and sometimes the least costly method of waste

management. Source reduction involves the management of materials before end disposal to reduce the volume or toxicity of materials. Source reduction extends the useful life of landfills as well as reduces the toxicity of the waste stream that is landfilled or incinerated. Many nations apply financial incentives or requirements so that companies or households will produce less hazardous waste.

The reuse of materials is another important form of pollution prevention. Some countries encourage the production of goods that can be easily reused, such as refillable bottles, or products with longer useful lives. These changes reduce the amount of waste generated per year.

Source reduction and reuse are regularly undertaken in developing countries (although primarily for economic, rather than environmental, reasons), while these are only beginning to be practiced widely in industrialized countries. Several obstacles have precluded waste prevention efforts including manufacturing decision and consumer buying patterns. For example, manufacturers have little incentive to consider the cost of waste collection and disposal when designing a product because consumers do not take these factors into consideration when making purchasing decisions. Likewise, consumers demand more convenient and disposal products which contain higher amounts of packaging material.

2.5.2 Composting

Composting involves separating organic materials such as paper and food wastes from solid wastes and allowing the material to decompose into an organic end-product. Composting is most common in industrialized countries even though, on average, 60 percent of the solid waste produced in low-income countries is compostable compared with less than 35 percent of the waste produced in industrialized countries (See Table 2(a)). Composting is more widely used in developing countries where the climate is arid and the soil needs organic supplements. Composting is becoming more widespread in industrialized nations, especially to manage leaf and yard wastes. The major obstacles to composting are the limited markets for compost use and environmental concerns about industrial or toxic wastes that may enter the waste stream and end up in the compost.

2.5.3 Recycling

Recycling involves separating reusable materials such as metals, glass, and paper from solid waste. The recyclable materials are then processed and returned to the economy as parts of other products. Recycling offers many benefits including:

- reduced environmental impacts because of reduced waste disposal;
- improvement in the cost effectiveness of waste-handling and disposal by providing income from recycled materials and products;
- extension of landfill life and improvement of landfill management;
- conservation of natural resources and energy savings in production of new materials (e.g. using scrap aluminum saves energy over using virgin ore);

- generation of economic activity and employment opportunities;
- reduction of dependence on imported goods and raw materials.[9]

Recycling has become increasingly popular in industrialized countries given the high costs and environmental concerns associated with incineration and landfilling. Some nations promote recycling through various types of financial incentives, active development and support of markets for used goods, government purchases of materials made from recycled substances, or requirements that consumers recycle certain materials. Support for the development of markets for secondary materials (e.g. scrap paper) has been particularly important in the success of efforts to increase recycling rates.

Recyclables are usually separated at the point of generation and sent to a materials recovery facility for processing. In industrialized countries, the largest hurdle to recycling is developing sufficient demand for recycled products to make it cost-effective. For example, demand for recycled plastic is limited since it can not be used to make food containers because of the danger of contamination. In addition, many consumers have reservations as to the consistent quality and dependable supply of products made from recycled materials.

Recycling is also common in developing countries. Most of the recycling is performed by scavengers who pick through the waste stream (either at the point of collection, transfer or disposal) to recover high value materials. In some low-income countries, scavengers recycle as much as 10 percent of the waste stream, and sometimes these activities are encouraged as a source of income and an effective means of waste reduction. However, scavenging may pose health and safety problems for the people (often children) sorting through wastes at landfills. Segregation of materials before they are disposed of by households, using separate bins at the curb for different materials, or separation at a special facility, can be safer than scavenging at landfills.

2.5.4 Incineration

Another method of solid waste disposal is incineration. In the incineration process, wastes are burned at very high temperatures and by-products are released into the atmosphere and concentrated into incineration ash. The by-products which are released into the atmosphere contain dust, acidic gases, vaporized metals, toxic chemicals such as dioxin, all of which have been linked to public health and environmental degradation. These by-products can be reduced with a variety of air pollution technologies such as scrubbers which remove particulates before they are released into the atmosphere. The incinerator ash is highly toxic as it contains a high concentration of heavy metals, which stay in the incinerator while other wastes are burned, from batteries and other waste products. Products such as batteries may be banned from or removed from the waste stream and recycled before incineration. Because ash is highly toxic, many industrial countries limit ash disposal to landfills which have extensive leachate control systems. Recently, new technologies have made it possible to incinerate wastes while at the same time recovering steam, electricity, or industrial heat. Energy recovery is widely used in the United States and Canada.

Even with energy recovery, incineration is more expensive than landfilling in most developing countries, and as such, incineration is rarely undertaken in developing countries without assistance from regional or international aid organizations. Waste from low-income countries is less suitable for incineration than waste from higher income countries because it has a higher percentage of moisture and non-burnable inert materials such as ash and sand. It requires more energy and is therefore more expensive to burn waste with a high moisture content.

2.5.5 Landfill

Landfilling is the main method of disposal of municipal solid wastes in most countries. Unlike composting and incineration, landfilling is not capital intensive and does not require skilled laborers. Landfills dispose of municipal solid wastes directly, as well as the residues that remain after recycling, composting, and incineration. Regardless of the level of technology used, landfilling is a very simple process -- waste is dumped into a disposal area where, depending upon the type of landfill, the material may be compacted, and covered with a layer of soil. Over time, organic wastes such as paper and food wastes decompose to produce methane, carbon dioxide, water, organic acids, and other chemicals. The rate of decomposition depends upon many factors including moisture content, pH, temperature, degree of compaction, and waste age and composition. When degradation occurs, the volume of the original waste is reduced, providing additional landfill capacity. Strong odors are emitted as the organic wastes decompose. Inorganic wastes such as metals and glass do not decompose, and remain essentially unchanged over time.

There are three types of landfills, each defined by the extent to which they use environmental and public health and safety controls: low, medium, and high technology landfills. In general, most landfills in industrialized countries have environmental control technologies and are classified as medium and high technology sites. Developing countries have landfills that have few if any environmental controls and are classified as open dumps or low technology landfills. There are major exceptions, however, as high-technology landfills have been built in developing countries, including a large landfill in Monterey, Mexico. Most high-technology landfills that are properly operated can safely handle both municipal solid and industrial hazardous waste.

3. PRINCIPAL CONTROL AND PREVENTION OPTIONS TO MINIMIZE ENVIRONMENTAL IMPACTS OF LANDFILLING

Whether a landfill causes environmental problems depends upon a number of factors including: the composition of the waste, the rate of decomposition, the hydrogeology of the site, rainfall, distance to aquifers, types of liners and covers, runoff controls, and the ability to collect leachate and gas. This section describes the most common environmental problems associated with solid waste landfilling and possible environmental controls. Each environmental control is discussed separately below, but in practice they should be considered as integrated elements in a single system.

3.1 Summary of Landfill-Related Pollution Prevention and Control Options

Landfilling can pose significant public health hazards and environmental degradation. The most

effective way to prevent this degradation is to limit where landfills can be located and to control the disposal of toxic and hazardous wastes at the site. If prevention techniques are not effective, control technologies must be utilized to address three environmental problems: groundwater contamination, surface water contamination, and air pollution. These problems as well as possible environmental controls are described below.

3.2 **Pollution Prevention Options** Specific to Landfills

3.2.1 Avoiding Toxic and Hazardous Waste Contamination

Perhaps the largest single factor in determining whether or not a landfill poses significant threats to public health and the environmental is the amount of toxic materials disposed at the site. While pollution prevention is discussed in section 2.5, one sort of "prevention" that applies specifically to landfills is to prevent hazardous wastes from entering solid waste landfills. Although this is not true pollution prevention, it does keep hazardous wastes from being disposed of in landfills not designed for such waste. Many industrialized countries have imposed regulations which ban industrial hazardous wastes from municipal solid waste landfills, where environmental controls are typically less effective than at true hazardous waste landfills.

3.2.2 Siting Landfills Away from Sensitive Areas

An important factor in determining whether or not a landfill poses significant threats to public health and the environment is location. Groundwater contamination is less likely at a site that has clay soils and a groundwater table far below the disposal area while surface water contamination is less likely at sites distant from lakes and rivers. Air pollution is less of a threat to public health if the landfill is located far from human settlements. Furthermore, siting in wetlands or other sensitive areas can cause significant damage to local plant and animal species. Of course, siting in any natural habitat causes loss or disruption of habitat and associated plants and animals. Siting in floodplains can cause a loss of floodwater retention capacity, resulting in higher flood levels and causing flood damage in the area.

Many countries control where landfills are located by requiring that all facilities obtain a siting permit. Compared to costly high-technology solutions, proper siting can be an inexpensive means of preventing environmental health problems, particularly well suited to nations with limited financial resources. Of course, it cannot be seen as a complete solution, since other types of pollution prevention or control technologies will be necessary.

In some developed nations, the legal costs of obtaining a permit to develop a landfill can be quite high, especially when the proposed site is near a community which opposes the facility. In the United States, the cost of getting a permit to develop a landfill site can cost $500,000 or more even before the expense of buying land. Most of the money goes toward convincing the public that it is acceptable to site a facility in their community. Because of these high costs, much of the new landfill capacity comes from expansion of existing landfills rather than siting new ones.

3.3 **Environmental Controls: Water Pollution**

3.3.1 Groundwater Contamination

Groundwater contamination is the most common means of environmental degradation associated with solid waste landfilling. Groundwater contamination occurs when liquids from rainfall, moisture in the waste itself, or decomposition, percolate through the landfill and carry chemicals through the landfill and soil to the groundwater. This liquid, or leachate, is generally toxic and may become more toxic if it becomes mixed with hazardous wastes such as household cleaners or industrial solvents. The extent of groundwater contamination depends upon the amount of contaminants in the leachate, the ability of the soils under the landfill to absorb or filter water contaminants, and the depth of the groundwater table. Groundwater contamination is, for the most part, not a problem in very dry climates where rainfall is limited and where the groundwater table is located far below the disposal area.

The most effective way of eliminating the threat of groundwater contamination is to exclude the disposal of hazardous wastes at the site and ensure that the landfill is sited properly (i.e. not located where groundwater contamination can easily occur). A more expensive method of control, used in high-technology landfills, is to install either a plastic liner or a layer of clay soil along the bottom of the landfill to reduce the migration of leachate to groundwater beneath the site. No liner is guaranteed to be a permanent solution, but can very significantly delay or mitigate environmental contamination.

Some modern landfills use cellular construction, a system where a section of the landfill perhaps 4 to 40 hectares in size -- one cell -- is separated from other parts of the landfill with a liner. Keeping cells insulated from each other allows better control of leakage, allowing detection of leakage from a single cell and remediation of that one cell.

Leachate may be collected, either through simple ditches or a more complex system including pipes. Various methods are used to manage collected leachate, including transport to a sewage treatment plant, on-site chemical or biological treatment, or recirculation through the landfill. In order to detect any possible leakage, additional pipes are sometimes placed underneath liners, where groundwater may be monitored for signs of leakage.

Finally, cells or entire landfills may be covered, or “capped”, once full, as described in section 3.6 below.

3.3.2 Surface Water Contamination

Surface waters such as streams and lakes may also become polluted from landfill operations. Rain water flows across the landfill, and into surrounding surface waters (i.e. lakes, rivers). This rain water picks up and carries with it, depending upon the level of rainfall, a portion of the landfill cover material, solid waste, and percolating leachate.

As with groundwater contamination, the most effective way to control surface water contamination is proper siting and then to ensure that hazardous wastes are not disposed of in landfills designed to manage only normal, solid wastes. If a special hazardous waste landfill is not available, a solid waste landfill may be modified to provide at least some temporary control of hazardous wastes.

The most common way to reduce surface water contamination is to build drainage canals around the perimeter of the site to prevent surface waters from entering the site. In more inexpensive, low-technology landfills these drainage canals are unlined. In more costly, high-technology landfills, which provide much more effective control of leachate, these canals are lined with either plastic or cement. In either case, contaminated surface waters may be captured in canals and diverted into a holding pond. The run-off accumulates in the holding pond and is either treated on-site or off-site or left to percolate into the soil and underlying groundwater table. As described in section 3.6, landfills may be covered once full, providing further control of water pollution.

3.4 Environmental Controls: Air Pollution

Municipal solid waste landfills generate several gases that pose risks to the environment and public health. The primary gases are methane and carbon dioxide. A number of factors influence the composition and amount of gas produced including: the amount and composition of the degradable waste and leachate, the type and thickness of soil covering, and waste placement techniques and site tipping history.

There are two causes of air pollution at solid waste landfills: waste burning and waste decomposition. Waste fires are common at open landfills in developing countries. Many fires are set intentionally to reduce the volume of waste at the site. Other fires occur when organic wastes that are exposed to the sunlight spontaneously combust. Waste burning is controlled by enacting regulations which prohibit open burning and require that a layer of cover material be placed over the fill area each day.

The second cause of air pollution, waste decomposition, causes pollution when methane and other gases are released into the atmosphere as organic wastes anaerobically (i.e. without oxygen) decompose in the landfill. It is estimated that 7 per cent of the total methane emissions in the world come from landfill sites.[110] These gases may explode under certain conditions if not managed correctly. Methane and other gas releases are controlled by diverting the gas into a pipe where the gas can be monitored and in some instances, burned. This gas is sometimes collected at the site and sold as methane fuel or used to generate power on-site. Landfill gas exploitation is common in the United States and is becoming more popular in some parts of Western Europe such as Britain, France and Germany.

3.5 Environmental Controls: Public Health and Safety

A landfill has many potential public health and safety problems if it is not properly engineered and operated:

- Waste disposal, especially in open areas, attracts rodents, insects, and birds which can spread disease;

- Pathogens can be directly inhaled as wind transports fine-grained waste contaminants; and

- Children playing at the dump as well as human scavengers are exposed to disease or toxic chemicals and injure themselves on sharp objects in and around the landfill.

The most effective way to address these concerns is to: compact the waste, apply daily cover material, and limit access to the disposal site. Waste should be compacted once it is placed in the fill area to decrease the amount of standing water where insects can proliferate. In developing countries, waste is commonly compacted with hand tools, while in industrialized countries bulldozers or other types of heavy machinery is used. Installing fencing around the site decreases the number of children and scavengers at the dump site.

3.6 Environmental Controls: Landfill Closure and Reclamation

When a landfill closes, measures are often taken to minimize the future environmental impact of the abandoned landfill site, as well as to ensure the safety of surrounding residents. Often efforts are made to make the site into a area that can be used by the entire community such as a playground or park. Reclamation activity is often aimed at establishing a permanently-stable landscape that is environmentally compatible with the surrounding ecosystem.

Landfill closure typically involves covering or “capping” the landfill area, and reclaiming and revegetating the land disturbed during site operations. Often these closure activities are less expensive and more effective if they are planned for early in the life of a site. Many governments therefore require that plans for landfill closure be included in official plans (i.e., environmental impact assessments required in the U.S.) developed before operations begin.

Without appropriate action, surface water and groundwater contamination may continue for many years after operations cease. Cover systems for landfill areas are used to minimize these lingering effects. Cover systems generally include some area cap overlaid with a material capable of supporting vegetation. Capping entails the placement of a layer of material composed of natural soils and rock, clays, and/or synthetic liners over the landfill. Multilayered caps consisting of a layer of plant growth, a layer of loose soil that allows drainage, and a hard layer that prevent exposure of fill materials are the most common. In addition, surface water and groundwater runoff from sites can still be monitored, and contaminated water treated using the techniques described above.

After the fill area is capped, the landfill site can be reclaimed through restoration of the area and revegetation of the land. Revegetation minimizes erosion at landfill sites, reduces wind-blown litter, absorbs contaminants harmful to humans, and helps reestablish natural ecosystems in the surrounding area. The ability of post-landfill area to support plant life is determined by the properties of the soil in the area where plants lay down their roots. Successful revegetation may not be possible in some cases, and it may be very difficult to restore completely the original, natural environment. Generally, plant materials must be limited to shallow-rooted grasses and forbs that will not penetrate the landfill cap.

3.7 Summary Matrix of Environmental Control and Pollution Prevention Technologies

Table 3(a) below summarizes the environmental control technologies most often installed at low, medium, and high technology landfills.**Table 3(a): Matrix of Environmental Control and Pollution Prevention Technologies at Low, Medium, and High Technology Landfills**

Environmental or Public Health/Safety Issue	Low Technology Controls

Medium Technology Controls High Technology Controls

Surface Water Contamination None (Proper siting can reduce potential for surface water contamination.) Perimeter drainage canals Perimeter drainage canals with on-site or off-site treatment

Groundwater Contamination None (Proper siting can reduce potential for groundwater contamination.) Clay liner Double liner, leachate collection and treatment

Odors, Litter Waste compaction and sporadic application of cover material Waste compaction and daily cover Waste compaction and daily cover (more than 10 centimeters of cover)

Air Pollution None Gas venting (rock chimney) Gas venting (gas collection is some areas)

Disease Vectors Cover material Daily cover and perhaps application of certain insecticides only if absolutely necessary. Daily cover and perhaps application of certain insecticides only if absolutely necessary.

Public Access None Perimeter fence Perimeter fence

4. PLANNING, MONITORING, ENFORCEMENT AND COMPLIANCE APPROACHES

4.1 Level of Implementation

Compliance promotion activities can be undertaken at the federal, state, regional, and local levels. Some countries, such as the United States and Germany, are moving in the direction of developing more regulations at the national level for the design and operation of sanitary landfills. The *Sample Landfill Regulations* section in the Appendix contains a brief description of the national landfill policies recently passed in the United States.

4.2 Monitoring

Company-managed environmental monitoring and reporting systems can supplement government enforcement effort. Of course, the government will have to enforce any requirements to ensure that companies conduct monitoring and reporting correctly. It may be useful to monitor some or all of the following at a landfill:

- surface water quality at or near the site;
- groundwater quality;
- air quality;
- samples of waste entering the landfill;
- extent of soil erosion; and
- extent of trespassing on site.

Important water quality parameters to monitor include: pH; biological oxygen demand; chemical oxygen demand; nitrates; sulfates; fecal coliform levels; and various levels of toxic chemicals. Such monitoring programs can improve cooperation between government and industry, reduce costs, and still provide adequate environmental protection in some instances.

4.3 Regulatory Approaches

In most countries, solid waste management, like other government and private sector activities, is subject to laws, regulations, and standards in many areas of operation. Environmental requirements such as control of water contamination are sometimes incorporated into these laws. Although solid waste landfill laws are rarely specific and extensive enough to be considered a complete environmental control program, they often draw upon laws in related areas (e.g. general environmental legislation, and/or legislation on health, safety, and chemicals) to provide a legal framework for environmental protection. Some environmental issues that solid waste landfill laws can incorporate into specific regulations include:

- Groundwater monitoring;
- Establishment of wastewater retention and treatment techniques, and safe management of contaminated runoff;
- Monitoring and control of on-site toxic and hazardous waste disposal;
- Soil erosion control and revegetation procedures during operation and after closure;

In addition, related legislation may cover aspects of environmental regulation of direct concern to the solid waste industry, including:

- Laws governing land use and the impact of development on endangered species, tropical forests, and flora and fauna;
- Laws governing the impact of development on indigenous cultures;
- Water quality laws that limit discharges into streams or rivers;
- "Clean Air" laws that govern emissions of toxins in gases or dust; and
- Controls for soil contamination by wastes and chemicals.

These environmental regulations can be packaged in a number of ways, depending in part on the existence of an environmental legal framework apart from laws governing landfilling. New laws can be crafted to build on, and be consistent with the existing legal structure. The appendix at the end of this document shows excerpts from environmental landfill laws and regulations in Italy, Poland, the United States, Denmark, Columbia, and Mexico.

4.4 Compliance Promotion

Government should be aware that requiring environmental control technologies increases the cost of waste disposal, which in turn, creates incentives for non-compliance and illegal dumping.

In general, problems with solid waste enforcement are common in developing countries. In Santiago, Chile, substantial portions of many municipalities are exempted from property tax, thus placing the burden of cost recovery on a minority of lower- and middle-income residents. In most

cities, enforcement is weak, and non-paying customers, who are denied service, dump their waste illegally. To avoid non-payment of waste collection fees, some institutions have entrusted their billing and collection to a water or power utility[111]

Many developing countries have laws which prohibit littering and open dumping, although these laws are seldom seriously enforced.[112]

There are six approaches to compliance promotion:

- Providing education and technical assistance to the regulated community;
- Building public support;
- Publicizing success stories;
- Creative financial arrangements;
- Providing economic incentives; and
- Building environmental management capability within the regulated community.

Actual examples of two of these methods of compliance promotion are described below.

4.4.1 Providing Education and Technical Assistance to the Regulated Community

By law, commercial establishments in the Netherlands are required to dispose of their hazardous wastes through permitted processors. However, getting the waste to the processor has been a problem for small businesses. The processors are often unwilling to pick up small amounts of wastes, and transporting small quantities of waste long distances to a processor places an economic burden on small businesses. Small companies were therefore often out of compliance with the hazardous waste rules. The Dutch government helped to solve this problem by establishing a collection depot in nearly every town. Both private citizens and small companies may discard their waste at these depots at regular times. This government-facilitated cooperative arrangement was instrumental in helping solve this compliance problem.[113]

4.4.2 Building Public Support

New York State recently passed legislation requiring all municipalities to reduce waste streams. In order to comply with this regulation, the New York City Department of Sanitation undertook an extensive public education campaign to teach people to how to generate less waste and how to recycle. The Department of Sanitation, in conjunction with various non-profit organizations, successfully built public support by developing and distributing information about environmental problems, the importance of compliance, program activities and successes, and ways the public can support the program.

4.5 Compliance and Enforcement Programs

This Technical Support Document is intended to accompany the Principles of Environmental Enforcement Text, U.S. EPA, which describes the basic elements and approaches for establishing effective compliance strategies and enforcement programs. As a supplement to international efforts to advance effective environmental compliance and enforcement programs, the readers are referred as well to the UNEP IE training manual on Institution Building for Industrial Compliance and Proceedings of the series of International Conferences on Environmental Compliance and Enforcement for further discussion of these programs.

5. APPENDICES

5.1 APPENDIX 1: Sample Landfill Regulations

The references in the bibliography can direct the reader to many examples of regulations, but some excerpts are provided here as illustrations.

5.1.1 Defining Waste: Milan, Italy

The Italian law defines wastes as "any substance or object derived from human activities or natural causes that is abandoned or destined to be abandoned." The disposal of wastes, including its storage, treatment to facilitate partial or complete reuse, landfill, etc. is undertaken observing the following principles:

- avoidance of the risk of damage or deterioration in the well-being or health of one or more individuals;
- guarantee that every precaution is taken to avoid pollution of the air, water, soil or subsoil and that unacceptable noise and odor pollution are not caused;
- protect flora and fauna and prevent deterioration of the countryside;
- respect economic and land planning; and
- use disposal methods which maximize the reuse or recovery of resources contained in the waste.[114]

5.1.2 Siting: Poland

In 1973, Poland's Ministry of Land Management and Environmental Protection, adopted the *Code of Practice*, issued by the World Health Organization, as a guideline for landfill design. According to these guidelines, the following criteria must be met in siting a new landfill:

- suitable geological and hydrological conditions including low permeability/filtration coefficient of the soil;
- natural or artificial re-entrants, e.g. clay headings, located a suitable distance from the building site, guaranteeing a proper sanitary protection zone;
- soil of low productivity class at the area covered by the new landfill; and

- good connection to the existing road networks.

5.1.3 Siting, Operation and Closure: United States

In 1994, new landfill regulations that are part of the federal Resource Conservation and Recovery Act (RCRA) went into effect. These rules set minimum criteria for where landfills can be located, how they're designed, and how they must be operated and eventually shut down. State government must implement programs for assessing whether or not landfills comply with the new regulations before granting waste disposal permits. These new landfill regulations are summarized below.

1) Location. Landfills cannot be sited on wetland, floodplains, earthquake-prone areas, unstable geological formations, or property close to airports. Existing areas near airports, floodplains or other unstable areas must be closed by a certain deadline unless engineering measures can be used to ensure that they operate safely.

2) Linings. The bottom and side of a landfill must be lined with a plastic liner beneath which there must be at least two feet of clay.

3) Leachate. To keep contaminants from leaking, landfills must capture leachate fluids in drainage layers, remove them through a system of pipes and pumps, and treat the leachate before releasing it into streams or the land surface.

4) Gas Control. To prevent explosions, landfill operators must monitor the gases that landfills give off as waste decays. If concentrations of gas are too high, landfills will have to install pipes to collect the gas. Air pollution regulations may require the methane and other landfill gases be collected in order to control odors, protect public health and combat global warming.

5) Groundwater. All landfills must install perimeter wells to monitor and detect contamination in nearby groundwater. If contaminants are found, environmental threats must be assessed and corrected.

6) Toxics. Operators must check for and remove regulated hazardous wastes and PCBs from garbage loads before they are deposited in solid waste landfills. Bulk liquid wastes that are not held in containers cannot be dumped. Operators are to screen waste deliveries at random to search for unacceptable materials.

7) Cover Soil. At the end of each day, the garbage must be covered with 6 inches (15.2 centimeters) of earthen material. When a landfill reaches capacity, operators must apply 19 inches (48.3 centimeters) of earthen material to keep moisture out of the disposal area, below 6 inches of additional cover material to support natural vegetation and prevent erosion of the cover material. States with their own EPA-approved regulations can allow operators to use plastic covers, foam sprays and other materials that take up less air space than soil.

8) Closure. Before a landfill opens, operators must have plans in place for closing it. Owners must submit plans for monitoring gas, collecting leachate and preventing the cover from being disturbed for 30 years after the last waste is dumped. Even before a landfill is opened, owners have to prove they have the financial capacity to keep the site safe after it is closed. The regulations require operators to set up a trust fund or arrange some other mechanism as financial assurance of payment of the post-closure costs.

The cost of complying with these new landfill standards is estimated to be between $20 and $40 per ton, and will more than double the cost of landfilling in the United States.[115]

5.1.4 Technical Guidelines: Denmark

The "Guideline for Landfilling" issued by the National Agency for Environmental Protection is the prime basis for landfilling in Denmark. This guideline outlines all of the major issues of landfilling in terms of items to consider. Very few specific rules are presented in the document and the intention is to allow for (and encourage) technical developments in meeting specified criteria. Topics included in this guideline are as follows:

1) Laws, related laws and authorities involved.
2) Definition of waste types, typical densities, definition of landfill types, and waste types accepted on three types of landfills.
3) Siting criteria for landfills.
4) Preliminary site investigations: geology, groundwater, surface run-off, noise, traffic, future use of the completed landfill.
5) Liners (clay, plastic) including criteria, installment and quality control.
6) Leachate collection including expected amounts of leachate, drainage systems, pipelines and leachate storage. No guidance is given on leachate treatment
7) Gas controls including typical amounts of gas, gas composition and gas venting. No guidance is given on gas extraction and utilization.
8) Final use including topography, top layer size and quality, planting and maintenance.
9) Landfill operation covering working instructions, public service and safety instructions.
10) 10 Environmental monitoring and controls including control of arriving waste, leachate monitoring, groundwater quality monitoring, surface water monitoring, noise monitoring, reports to the environmental authorities, inspections and monitoring after completion of the site.[116]**5.2**

APPENDIX 2: Environmental Control Costs at High Technology Landfills

Below are the estimated costs for environmental control technologies for a 5,000 ton per day municipal solid waste landfill. This landfill operates 302 days per year and complies with all U.S. regulations. All costs are in 1990 dollars.[17]

	Total Cost	**Percentage of Total**
Capital Costs		
Capital Costs*		
Surface Water Control		
Stormwater Management	$2,000,000	1.8%
Sedimentation Ponds	$1,500,000	1.3%
Monitoring		

Groundwater Monitoring	$110,000	.1%
Gas Monitoring Wells	$55,000	.05%
Containment		
80 mil HDPE Liner	$13,200,000	11.5%
Sand	$12,400,000	10.8%
Clay	$48,000,000	41.7%
Leachate Collection		
6" collection pipes	$5,400,000	4.7%
Geonet drain layer	$6,600,000	5.7%
Miscellaneous		
Fencing and Security	$352,000	.3%
TOTAL ENVIRONMENTAL CONTROL CAPITAL COSTS	$89,617,000	78%

	Total Cost	**Percentage of Total Operating Costs**
Operating Costs**		
Soil Cover	$2,400,000	26.7%
Environmental Monitoring and Testing		
Groundwater Monitoring	$2,500	.03%
Gas Monitoring	$200	.002%
Sampling	$280,000	3.1%
Leachate Testing	$292,000	3.2%
Leachate Treatment / Disposal	$548,000	6.1%
TOTAL ENVIRONMENTAL CONTROL CAPITAL COSTS	$3,522,700	39.1%

	Cost Per Year
Closure Costs (Capital and Operating Costs Per Year)	
Engineering Inspections	$3,000
Vegetation Maintenance	$39,000
Drainage Maintenance	$64,000
Groundwater Monitoring	$149,000
Gas Monitoring	$31,000
Leachate Monitoring	$3,000
Leachate Treatment	$66,000
Cap Maintenance	$30,000
Replace Monitoring Wells	$11,000
TOTAL CLOSURE COSTS	$396,000

* Total capital costs are $115,000,000. This does not include land costs.

** Total operating costs are $9,000,000 per year.

5.3 APPENDIX 3: Annotated Bibliography of Additional Sources

James G. Abert, *Municipal Waste Processing in Europe: A Status Report on Selected Materials and Energy Recovery Projects*. World Bank Technical Paper Number 37, April 1985.

This report deals with municipal waste processing in Europe. It is a status report on selected material and energy recovery projects. It is intended for those readers, primarily from developing countries, interested in the potential application of industrial country techniques for reuse and recycling of solid wastes.

Contact: Publication Sales Unit, Department T, The World Bank, 1818 H Street N.W., Washington D.C. 20433. Tel: (202) 473-1155

R. Barnard and G. Olivetti, "Limiting Environmental Impact by Waste Management" in *Resource, Conservation and Recycling*, Vol. 4, No. 1,2, August 1990. ISSN 0921-3449.

This paper describes a data base that has been developed to allow developing countries to predict the amount of industrial waste generation. These predictions are based on waste production per employee in other locations.

Contact: Elsevier Science Publishers B.V., Journals Department, P.O. Box 211, 1000 AE Amsterdam, The Netherlands, Tel: 5803 911, Telex: 18582 ESPA NL.

Carl Bartone and Janis Bernstein, "Improving Municipal Solid Waste Management in Third World Countries," in Resource, Conservation and Recycling, Vol. 8, 1993, p. 43-54.

This paper describes recent World Bank efforts to improve municipal solid waste management practices in developing countries.

Contact: Elsevier Science Publishers B.V., Journals Department, P.O. Box 211, 1000 AE Amsterdam, The Netherlands, Tel: 5803 911, Telex: 18582 ESPA NL.

Carl Bartone and C. Haley, "Economic and Policy Issues in Resource Recovery from Municipal Solid Wastes" in *Resource, Conservation and Recycling*, Vol. 4, No. 1,2, August 1990. ISSN 0921-3449.

This paper reviews resource recovery policies and practices in Japan and the United States, examines the economic basis for resource recovery, and discusses an array of policy instruments that can be used to encourage resource recovery.

Contact: Elsevier Science Publishers B.V., Journals Department, P.O. Box 211, 1000 AE Amsterdam, The Netherlands, Tel: 5803 911, Telex: 18582 ESPA NL.

Carl Bartone, "Institutional and Management Approaches to Solid Waste Disposal in Large Metropolitan Areas," in the journal entitled *Waste Management and Research* (1991), number 9, pages 525-236.

> *This paper examines a model of decentralized solid waste collection and centralized transfer and disposal that is in place in Norfolk, Virginia U.S.A. and which is being applied in the Federal District of Mexico City. Lessons are drawn for the application of such a model to metropolitan areas in other developing countries.*

Carl Bartone, "Keys to Success: Private Delivery of Municipal Solid Waste Services," in *Infrastructure Notes*, a publication of the Infrastructure and Urban Development Department in the World Bank, August 1991, Urban No. UE-3.

> *Evidence in Latin American cities demonstrates that private delivery of municipal solid waste services can be successful in terms of efficiency and quality of service. Keys to success include creating contestable markets, establishing appropriate regulations and standards for contractors, and strengthening local government capacity to negotiate contracts and monitor performance.*
>
> *Contact: Publication Sales Unit, Department T, The World Bank, 1818 H Street N.W., Washington D.C. 20433. Tel: (202) 473-1155.*

Carl Bartone, Luiz Leite, Thelma Triches and Roland Schertenleib, "Private Sector Participation in Municipal Solid Waste Service: Experiences in Latin America," in *Waste Management and Research* (1991) 9, 495-509.

> *This article summarizes four cases studies on the private provision of municipal solid waste services in four large Latin American cities (Buenos Aires, Caracas, Santiago, and Sao Paula). This research supports the authors thesis that private service provision can be successful in terms of cost containment and quality of service as long as the service contracts are awarded through a competitive bidding process. These and other studies in the region suggest that local authorities should establish operational and environmental regulations and standards to guide private contractors, and have the capacity to oversee these activities. Supervision and payment should be based on specific performance measures.*

Anu Bose and Ian Blore, "Public Waste and Private Property: an Enquiry into the Economics of Solid Waste in Calcutta," *Public Administration and Development*, vol. 13, no. 1, pp. 1-15, U.K., World Bank Joint Library, February 1993.

> *This paper examines both formal and informal sector waste management operations in Calcutta. It is hypothesized that there may not be measurable economies of scale in waste collection, transfer, and disposal and therefore, it may be worthwhile to improve and expand the informal system of waste management.*

Sandra J. Cointreau, *Environmental Management of Urban Solid Wastes in Developing*

Countries: A Project Guide, The World Bank, Urban Development Department, Technical Paper No. 5.

This project guide provides information and procedures for planning and implementation of solid waste collection and disposal improvements in developing countries. Information on solid waste generation rates and composition for countries of various levels of economic development is provided as well as case study information on the formal and informal sector refuse collection and disposal activities prevalent in cities of developing countries.

Contact: Publication Sales Unit, Department T, The World Bank, 1818 H Street N.W., Washington D.C. 20433. Tel: (202) 473-1155.

Sandra J. Cointreau, "Improving Solid Waste Management," *National Development*, vol. 31, no. 5, pp. 30-33 and 12, World Bank Joint Library, Sept./Oct. 1990.

This article explains how better management, closer supervision, and support from both the central government and the community can improve municipal solid waste services in developing countries.

Sandra J. Cointreau, Charles C. Gunnerson, John M. Huls, and Neil N. Seldman, *Recycling from Municipal Refuse: A State-of-the-Art Review and Annotated Bibliography*, Washington, DC: World Bank, 1984.

This report is in two parts: a concise state-of-the-art overview of recycling from municipal refuse, focusing on techniques and conditions germane to developing countries; and an annotated bibliography with abstracts of more than 200 published references on recycling.

Contact: World Bank Publications, P.O. Box 37525, Washington D.C. 20013.
Tel: (202) 473-1155.
$12.95

Sandra Cointreau-Levine, "Private Sector Participation in Municipal Solid Waste Services in Developing Countries," report for the World Bank Infrastructure and Urban Development Department, August 14, 1992.

This report provides a review of issues which need to be considered when determining whether to involve the private sector in solid waste management services. It provides a review of privatization approaches which are currently used in developing countries.

Contact: World Bank Publications, P.O. Box 37525, Washington D.C. 20013.
Tel: (202) 473-1155.

Republica de Columbia, Gobernacion de Antioquia, Departamento Administrativo de Planeacion, *Guia Para el Diseno, Construccion y Operacion de un Relleno Sanitario Manual*, April 1988. (Guidance for the Design, Construction, and Operation of a Sanitary Landfill,

Republic of Columbia, Medellin, April 1988, Department of Administration and Planning, Antioquia.

This document is a very thorough manual on landfills, and includes extensive technical details on many aspects of design, construction, and operation of a relatively affordable landfill (i.e. one with controls that might be appropriate to a smaller city with a limited budget). It also includes an appendix with some information on water quality monitoring.

Contact: Republic of Columbia, Medellin, Department of Administration and Planning, Antioquia.

P.C. Comolli, A. Mauri, and G.C. Olivetti, "Incineration of Domestic Refuse with Energy Recovery - the Milan Experience," in *Resources, Conservation and Recycling*, 4 (1990) p. 161-172.

This report describes the organization of the Milan Environmental Service Department, which is responsible for collection, recovery and disposal of urban solid wastes. Statistics relating to the quantity and composition of wastes, during the last 25 years, are presented. Disposal of wastes is achieved by two incinerators and two landfills. Technical details of the second incinerator and its economic aspects are presented and discussed.

The Congress of the United States, Office of Technology Assessment, *Facing America's Trash: What's Next for Municipal Solid Waste?* OTA-O-424, Washington, DC: U.S. Government Printing Office, October 1989.

This report, commissioned by the U.S. Congress, discusses options for a national policy based on the dual strategies of municipal solid waste prevention and better management. It also presents options to address immediate problems such as increased interstate shipments of municipal solid waste and unfinished Federal guidelines for landfills and incinerators.

Contact: Superintendent of Documents, Government Printing Office, Washington D.C. U.S.A. 20402-9325. Tel: (202) 783-3238.
G.P.O. stack number 052-003-01168-9.

L.F. Diaz and C.G. Golueke, "Solid Waste Management in Developing Countries," in the journal entitled *Biocycle*, Volume 26, Issue 1, Page 46, 1985.

This article includes a summary of practices commonly followed in waste management and offers a few suggestions and "solutions" whereby the pollution and environmental problems associated with waste management in less developed countries can be somewhat alleviated.

Contact: Biocycle, 419 State Avenue, Emmaus Pennsylvania, U.S.A..
Tel: (215) 967-4135.

1993 Directory of Country Environmental Studies, edited by Daniel B. Tunstall and Mieke van der Wansem, World Resources Institute, 1992.

This directory contains information on solid waste management practices in countries throughout the world.

Contact: WRI Publications, P.O. Box 4852, Hampden Station, Baltimore MD 21211. Tel: (800) 822-0504 or (410) 516-6963.

Charles T. DuMars and Salvador Beltran Del Rio M., "A Survey of the Air and Water Quality Laws of Mexico," *Natural Resources Journal*, vol. 28, pp. 787-813, Fall 1988.

This article provides in the English language full citations to the air and water pollution laws of Mexico, and it places those laws in the perspective of Mexican political and legislative history of the time.

Environment Bulletin: A Newsletter of the World Bank Environment Community, World Bank publications.

This is a quarterly newsletter published by the World Bank Environment Department. It contains articles on numerous environmental issues including solid waste management.

Contact: Publication Sales Unit, Department T, The World Bank, 1818 H Street N.W., Washington D.C. 20433.

Environmental Action Foundation, *Legislative Summary: Statewide Recycling Laws*, October 1988.

A concise summary of laws in ten states (Oregon, Wisconsin, Rhode Island, New Jersey, Connecticut, Massachusetts, New York, Maryland, Florida and Pennsylvania) that demand some type of mandatory recycling is provided in this paper. The following information is included for each state program: key recycling legislation, major components of the recycling program, materials targeted, recycling goal, funding mechanism, State procurement program, and other market development activities.

Contact: Environmental Action Foundation, 1525 New Hampshire Avenue, N.W., Washington, D.C. 20036. Tel: (202) 745-4870.
$6.00 donation.

Environmental Liabilities and Regulation in Europe, edited by Mark Brealey, International Business Publishers Limited: Netherlands.

This reference guide to liability and compliance contains information on environmental laws and regulations in 21 European jurisdictions. Waste disposal issues in each country are discussed.

Contact: Bureau of National Affairs, Inc., BNA Books, P.O. Box 6036, Rockville, Maryland. Tel: 1-800-372-1033.
$120.00.

Federal Register, *Part II: Environmental Protection Agency, 40 CFR Parts 257 and 258 Solid Waste Disposal Facility Criteria; Final Rule*, vol. 56, no. 196, October 9, 1991.

This document contains revisions to existing municipal solid waste landfill regulations promulgated by the U.S. Environmental Protection Agency in the fall of 1991 in response to the 1984 Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act. These revisions set forth minimum federal criteria for municipal solid waste landfills including location restrictions, facility design and operating criteria, groundwater monitoring requirements, corrective action requirements, financial assurance requirements, and closure and post-closure care requirements.

Contact: Superintendent of Documents, Government Printing Office, Washington D.C. U.S.A. 20402-9325. Tel: (202) 783-3238.

Christine Furedy, "Solid Waste Management: Exploring Non-Conventional Options in Asian Cities," Urban Studies Programme, York University, July 1992.

This paper describes small-scale, community based waste management projects in Bangalore, Manila, Madras, Jakarta and Kathmandu. Its main concern is to assess the potential to change the simple, and increasingly ineffectual, conventional organization of residential solid waste services in Asian cities. Two case studies are included: the first on street pickers in Calcutta slums, the second on a programme to support the renovation and sale of second-hand shoes in Delhi.

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This article describes the waste management system in China. China is the only country with an extensive state-controlled waste recovery system. Nevertheless, there is an informal economy of solid waste collection and disposal which has become more important as administrative and economic changes have eroded the base of the state system.

Contact: Biocycle, 419 State Avenue, Emmaus Pennsylvania, U.S.A..
Tel: (215) 967-4135.
$6.00 per issue.

Christine Furedy, "Working with the Waste Pickers: Asian Approaches to Urban Solid Waste Management," *Alternatives*, V. 19, No. 2, pp. 18-23, 1993.

Street children, who lack access to schooling since they have no permanent home, pick waste for a living. Community-based projects in Asian cities strive to improve pickers' earnings, health, living conditions and security.

Christine Furedy and Mohammed Alamgir, "Case Study 1: Street Pickers in Calcutta slums," *Environment and Urbanization*, V.4, No.2, October 1992.

This case study examines the role of street pickers in Calcutta. Included is a description of this work, and the street pickers relations with dealers, awareness of health risks and their perceptions of status and acceptance in the neighborhood.

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This article describes the recovery of recyclable materials in Beijing. Both the formal and the informal system are described as well as environmental benefits and current policy dilemmas.

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Contact: Waste Quality Division, Municipality of Metropolitan Seattle, Exchange Building, 821 Second Avenue, Seattle, WA 98104. Tel: (206) 684-1233.

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This article summarizes the new recycling and landfill regulations which will be required by the U.S. Environmental Protection Agency in the spring of 1994.

Contact: Congressional Quarterly, 2300 N Street N.W., Suite 760
Washington DC 20037. Tel: 202-862-8802.
$4.50 per issue.

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This article describes a composting facility in Warsaw, Poland that produces high quality compost from municipal solid waste and sludge. This facility was funded by the European Community's PHARE program.

Contact: Biocycle, 419 State Avenue, Emmaus Pennsylvania, U.S.A..
Tel: (215) 967-4135.

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Hazardous Waste Management in Manitoba, edited by Edwin Yee, Emil Kucera, J.J. Keleher for the Manitoba Environment and Workplace and Health, Hazardous and Special Waste Management Program, July 1985.

This report was commissioned by the Manitoba Minister of Environment for development and implementation of an appropriate management system for the handling, treatment, and ultimate disposal of hazardous and special wastes generated within the province of Manitoba. It contains: (1) an assessment of the magnitude of the problem, i.e. identification and quantification of the generated wastes; (2) results of work aimed at interim solution of the disposal problem; (3) a discussion of available technologies for handling hazardous wastes and their relevance to Manitoba's situation; and (4) an outline of the various options for dealing with the problem.

Allen Hershkowitz, *Garbage Burning -- Lessons from Europe*, 1986.

This booklet highlights safety practices and regulatory issues in waste-to-energy incineration in Europe. It provides an overview of the role incineration plays in each country's solid waste management system. Also covered are surveys of regulatory requirements, emissions, monitoring, and worker training at incineration facilities. Pollution issues and government responses are reviewed.

Contact: Inform, Inc., 381 Park Avenue S., Suite 1201, New York, NY 10016.
Tel: (212) 689-4040.
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This book describes global environmental issues and public understanding of environmental alternatives. Several chapters deal with solid waste management issues; there are relevant statistical tables on per capita municipal solid waste and hazardous waste generation in low, middle and high-income municipalities and countries.

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This report contains information on waste management policies and practices in each of the 25 member countries of the International Solid Wastes and Public Cleansing Association (ISWA). Member countries include nearly all of the European countries, American countries (Argentina, Brazil, Canada, United States of America), Israel and Japan. Each chapter, one for each member country, contains a listing of government agencies, statistical data on waste management practices, information on the most interesting implementation of technology and contact addresses, and a reference law framework.

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Contact: Pollution Engineering, 44 Cook Street, Denver CO 80206-5800.
Tel: (303) 388-5411.
$25.00 per issue.

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Contact: Massachusetts Department of Environmental Quality Engineering, 1 Winter Street, 9th Floor, Boston, MA 02108. Tel: (617) 292-5856.

Martin Medina, "Collecting Recyclables in Metro Manila," *Biocycle*, vol. 34, no. 6, pp. 51-53, June 1993.

This article explains how a new recycling program, the Linis Ganda program, has helped improve Manila's economy and environment by creating jobs and reducing the pressure on municipal waste collection.

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Contact: National Solid Wastes Management Association, 1730 Rhode Island Avenue N.W., Washington, DC 20036.
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Contact: Subscription Department, Suite 1000, 1730 Rhode Island Avenue NW, Washington DC 20036.

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This report is part of a joint global research, development, and demonstration effort of the United Nations Development Programme and the World Bank. It reviews current literature and practices on the co-composting of human waste together with the organic fraction of domestic solid waste. The report describes the composting process, reviews various co-composting systems, and discusses health aspects and key planning issues. The report also develops several cost/benefit models for economic analysis of co-composting operations and outlines the economics of the process as a whole.

Contact: Publications Sales Unit, Department F, The World Bank, 1818 H Street N.W., Washington D.C. 20433.
Tel: (202) 473-1155.

Richard Olowomeye, "The Management of Solid Waste in Nigerian Cities," in *The Environment Problems and Solutions: A Collection of New Studies and Outstanding Dissertations on Current Issues*, New York: Garland Pub., 1991.

This is a comprehensive study on solid waste management in Nigeria. Topics covered include: waste collection and disposal practices, organizational and institutional factors in solid waste management, and current solid waste regulations.

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This document presents conclusions and recommendations from conferences addressing the problems of solid waste management in Latin America. It contains profiles of typical waste management approaches used in major cities in the regio. The text, in Spanish, discusses technical, financial, political, and socio-economic aspects of the issue.

Contact: Public Health Program of the Panamerican Health Organization, Panamerican Sanitary Office, Regional Office of the World Health Organization

Panamerican Health Organization, World Health Organization, Division of Health and Environment, Hazardous Waste and Health in Latin America and the Carribean, Washington DC, 1994.

This document is intended to assist Ministries of Health and other Agencies in evaluating and strengthening their own strategies to protect human health from the adverse effects of exposure to hazardous waste. It reviews health impacts of wastes, and summarizes a survey that provides an overview of waste production and disposal in 21 countries in Latin America. It also mentions relevant legislation, institutional capacity issues, and

international agreements.

Contact: Henk DeKoning, World Health Organization, 525 Twenty Third Street, N.W., Washington, D.C. 20037 USA. (202) 861-3315.

Hasan Poerbo, "Urban Solid Waste Management in Bandung: Towards an Integrated Resource Recovery System," *Environment and Urbanization*, vol. 3, no. 1, April 1991.

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Ghani Mohd. Rais, "Solid Waste Collection, Disposal, and Cleansing Services in Kuala Lumpur, Malaysia," *Regional Development Dialogue*, vol. 10, No. 3. Autumn 1989.

This paper describes solid waste management practices in Kuala Lumpur, Malaysia.

Resource, Conservation and Recycling, Vol. 4, No. 1,2, August 1990. ISSN 0921-3449.

This journal contains the papers presented at the European Symposium on Integrated Resource Recovery from Municipal Solid Wastes, held in Bled, Yugoslavia, February 24-March 1, 1988. Most papers have been published in other journals; the most relevant papers are listed separately in this bibliography.

Contact: Elsevier Science Publishers B.V., Journals Department, P.O. Box 211, 1000 AE Amsterdam, The Netherlands, Tel: 5803 911, Telex: 18582 ESPA NL.

The Safe Disposal of Hazardous Wastes: The Special Needs and Problems of Developing Countries, edited by Roger Batstone, James E. Smith, Jr., and David Wilson, Washington, DC: The World Bank, Technical Paper No. 93, 1989.

This is the first of a three-volume manual that contains information on the classification of hazardous wastes, the effects of hazardous wastes on health and the environment, the planning and implementation of programs in hazardous waste management, and hazardous waste treatment and disposal technologies. The main emphasis of this manual is on the management aspects and on the technologies than may be appropriate for implementing a region-wide hazardous waste management program. Case studies from developing countries have been incorporated into the main test. A particularly useful section of this manual includes examples of various operating systems for hazardous waste tracking and disposal, waste survey questionnaires and techniques, and landfill design and management practices.

Contact: Publication Sales Unit, Department F, The World Bank, 1818 H Street N.W., Washington D.C. 20433. Tel: (202) 473-1155.

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This report evaluates waste scavengers in the cities of West Java, Indonesia. The report discusses various strategies for combining the formal waste management sector with the informal sector (waste scavenging).

Michael Simpson, "Lapaks and Bandars Convert MSW in Indonesia," *Biocycle*, vol. 34, no. 6, pp. 78-80, June 1993.

This article summarizes a project run by a team of specialists from Harvard University and the Indonesia Center for Policy and Implementation Studies to improve solid waste management in Jakarta. As a result of this project, the informal private sector now captures 88 to 98 percent of higher valued materials, and has become the core of an urban composting process in Jakarta.

Contact: Biocycle, 419 State Avenue, Emmaus Pennsylvania, U.S.A..
Tel: (215) 967-4135.
$6.00 per issue.

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Contact: Biocycle, 419 State Avenue, Emmaus Pennsylvania, U.S.A.
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Tel: (202) 473-1155.

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Technical Report No. 10, UNEP IE/PAC, 1991

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United States Environmental Protection Agency, *Catalogue of Hazardous and Solid Waste Publications*, sixth edition, EPA A530-B-92-001, June 1992.

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Contact: Superintendent of Documents, Government Printing Office, Washington D.C. U.S.A. 20402-9325. Tel: (202) 783-3238.

United States Environmental Protection Agency, *Interim Policy on the Inclusion of Pollution Prevention and Recycling Provisions in Enforcement Settlements*, February 25, 1991.

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Contact: Compliance and Policy Planning Branch
Office of Enforcement
U.S. Environmental Protection Agency
401 M Street, SW
Washington, DC 20460

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Contact: Superintendent of Documents, Government Printing Office, Washington D.C. U.S.A. 20402-9325. Tel: (202) 783-3238.
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This article surveys the current solid and hazardous waste practices in the World. Issues discussed include: defining waste, economic costs of waste management policies, the cost of waste recycling and disposal, the limitations of economic incentive regulations, liability issues, and waste export.

Contact: Subscription Department, P.O. Box 14, Harold Hill, Romford, Essex RM3 8EQ U.K.

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Contact: WRI Publications, P.O. Box 4852, Hampden Stations, Baltimore MD 21211.
Tel: 1-800-822-0504 or 1-410-516-6963.

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This survey of selected cities in Latin America documents solid waste practices and policy, highlighting the managerial and financial shortcomings of local governments on the one hand, on the other, the positive experiences recorded so far among private providers of service. The trend toward decentralization of responsibilities to local governments heighten these concerns. It underscores the risks of environmental damage and calls for extensive institution-building and improved regulations.

Contact: World Bank Publications, P.O. Box 37525, Washington D.C. 20013.
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John Young, “Reducing Waste, Saving Materials,” *State of the World 1991: a Worldwatch Institute Report on Progress Toward a Sustainable Society*, Lester Brown et al., New York: W.W. Norton & Company, 1991.

This report summarizes waste management policies and techniques in both developing and developed countries and argues that waste reduction is necessary to move toward a more sustainable society.

Contact: Publications, Worldwatch Institute, 1776 Massachusetts Avenue N.W., Washington D.C. 20036.

END NOTES

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