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INTEGRATED SOLID WASTE MANAGEMENT: A FRAMEWORK FOR ANALYSIS

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ABSTRACT

Owing to the number of potential impacts and the vast heterogeneity of state and local solid waste management programs, any careful attempt to assess the benefits and costs of solid waste management practices must begin with a fairly comprehensive organizational framework, one that is applicable to a wide range of available waste management options and that accounts for all possible impacts while taking care to avoid potential double-counting. This paper provides such a comprehensive framework by combining the traditional economic method of benefit-cost analysis with the more recent life-cycle approach found in systems analysis, resulting in a framework based on the flow of waste materials through generation, collection, processing, recovery, and/or disposal. The framework presented in this article is valuable to researchers, decision makers, and others who are interested in identifying and analyzing the large number and types of benefits and costs associated with integrated solid waste management systems.

INTRODUCTION

Managing municipal solid waste is an endeavor associated with a bewildering number of economic, environmental, and societal impacts. Several participants are involved (local, regional, and federal governments, private firms, nonprofit organizations, and individuals), and each participant is potentially immersed in a myriad of waste management activities (product selection and other waste reduction efforts, recycling activities such as cleaning, sorting, storing, transporting, and processing of materials, landfill operation, and closure maintenance). Moreover, the impacts of solid waste management activities vary among the numerous types of waste materials (paper, yard waste, plastic, glass, food waste). Thus, owing to the number of potential impacts and the vast heterogeneity of state and local solid waste management programs, any careful attempt to assess the benefits and costs of solid waste management practices must begin with a fairly comprehensive organizational framework, one that is applicable to a wide range of available waste management options and that accounts for all possible impacts while taking care to avoid potential double-counting.

This article provides such a comprehensive framework by combining the traditional economic method of benefit-cost analysis with the more recent life-cycle approach found in systems analysis, resulting in a framework based on the flow of waste materials through generation, collection, processing, recovery, and/or disposal. Thus, by grounding benefit-cost analyses of solid waste programs on the life-cycle approach, we are assured that all benefits and costs are identified a priori and that none are double counted. The framework presented in this article is valuable to researchers, decision makers, and others who are interested in identifying and analyzing the large numbers and types of benefits and costs associated with integrated solid waste management systems.

BRIEF OVERVIEW OF LIFE-CYCLE ANALYSIS

This section provides a very brief overview of life-cycle analysis and how it is used in this article. For a more complete discussion of the life-cycle methodology and its applications, two particularly good sources are [1] and [2].

In general, life-cycle analysis (LCA) is a systematic tool used to assess the impacts of specific products, services, or activities. It is comprised of four major phases: 1) goal and scope definition; 2) life-cycle inventory analysis; 3) impact assessment; and 4) valuation and/or interpretation of the impacts. In the first phase, the goal of the project is explicitly stated, including a definition of what is to be studied and the intended use of the results. The inventory analysis phase consists of an accounting—initially qualitative, but eventually quantitative—of all potential inputs and outputs at each stage in the life cycle. The inventory analysis takes a systems approach, where the definition of system boundaries (what is included in the study and what is omitted) is a crucial step. The impact assessment phase entails determining the economic, environmental, and/or social impacts associated with each input and output item in the life-cycle inventory. To date, most LCA studies have focused on environmental impacts and to a lesser extent on economic impacts; social impacts have been virtually ignored. Finally, the valuation phase involves ascertaining as accurately as possible the value of the impacts and, where the impacts cannot be valued, explaining their relative importance in relation to the goal and scope of project. Any assumptions and underlying uncertainties must be made explicit in all phases of the LCA. The life cycle methodology is valuable because its "cradle-to-grave" approach is intended to ensure that all direct and indirect impacts are accounted for and that none are double counted, even in extremely complex systems such as the many types of integrated solid waste management. This term is here taken to refer to a solid waste management system that incorporates two or more waste management strategies (recycling, composting, waste-to-energy, landfilling, etc.).

While there have been hundreds of practical applications of LCA, most can be categorized according to their purpose and level of sophistication. Some examples of LCA applications include, first, internal uses by private firms such as product development and improvement [3, 4] and strategic planning [5, 6]. A second type of application involves external uses by private firms such as the marketing of "green" products [7, 8]. A third category of applications includes public policy uses such as setting ecolabeling requirements [7, 9], "green" procurement decisions [9, 10], and, as in the present case, waste management choices [11, 12].

The organizational properties of life-cycle analysis provide a valuable foundation for benefit-cost analyses of solid waste management. As Gramlich [18] points out, a careful benefit-cost analysis makes explicit all underlying assumptions and measurement uncertainties:

> For any real world choice, there will always be some considerations that cannot easily be enumerated or valued, and where the analysis becomes quite conjectural. Benefit-cost analysis does not, and should not try to hide this uncertainty.

Moreover, opponents of benefit-cost analysis have often argued that, beyond the issue concerning the ease of measurement, there are often items that simply cannot, or *should not* be valued in any monetary sense. The approach for dealing with the inherent uncertainties and unknowns in a benefit-cost analysis is to value those items that can be accurately valued and explicitly described within the study all items that cannot be valued or are chosen not to be valued. This requires beginning with a consistent theoretical framework that allows for all possible types of benefits and costs, whether they can be valued or not. The life-cycle approach developed in this article provides just such a framework.

LCA AND INTEGRATED SOLID WASTE MANAGEMENT

Figure 1 illustrates a complete life-cycle flow of materials from the natural environment through the human system and back to the natural environment. The journey begins with the extraction/harvest of raw materials and ends with the management of solid wastes either through recovery or disposal. Managing solid waste includes monitoring and maintenance activities that occur long after landfill closure. An important step in LCA is defining what is to be included in the study and what is to be left out. This is done through the use of system boundaries. Since most applications of LCA do not require analyzing the complete life cycle, systems are typically streamlined by choosing boundaries that are consistent with the overall scope and goal of the project. For example, Figure 2 depicts the boundary for an integrated solid waste management system which includes recycling, combustion, landfilling, and illegal disposal components or paths. Each individual path in an integrated solid waste management system involves many potential participants, or agents, which can be categorized as waste generators, waste processors, brokers, and end users of recovered materials or energy. Waste generators include households, firms, and governments. Waste processors and brokers are primarily firms and governments. And end users of recycled materials or recovered energy are typically only firms and governments. Each type of agent potentially engages in several solid waste management activities, e.g., cleaning, sorting, storing, transportation, processing, and use/maintenance. The general framework developed in this paper considers all potential activities of each agent in each solid waste management path, though in practice some activities may not occur depending on the location or type of solid waste management system analyzed.

Compiling a life-cycle inventory (LCI) entails systematically accounting for all input and output flows associated with every activity in every stage in the life cycle. Figure 3 illustrates typical inputs (materials, labor, energy, water, and land and capital) and outputs (products, air pollutants, water pollutants, solid wastes, and other outputs) associated with a given activity.

From a broad social perspective, the types of benefits and costs associated with integrated solid waste management can be grouped into three categories: economic, environmental, and societal. Economic costs are items such as labor,

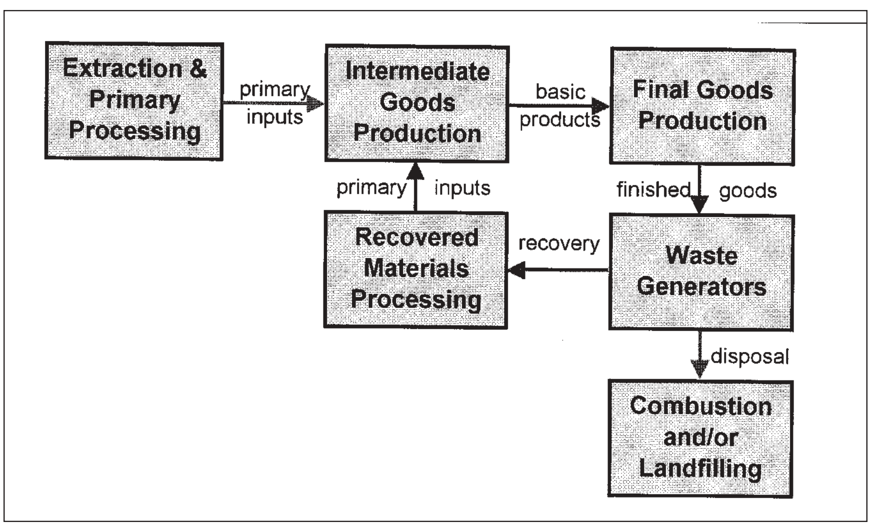

Figure 1. Life-cycle flow of materials.

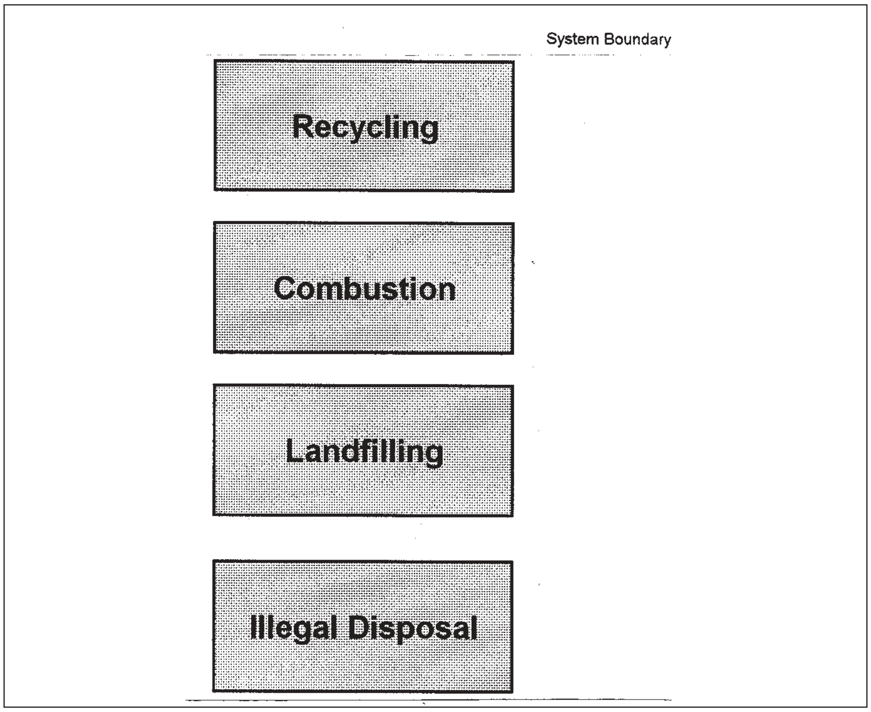

Figure 2. Integrated solid waste management.

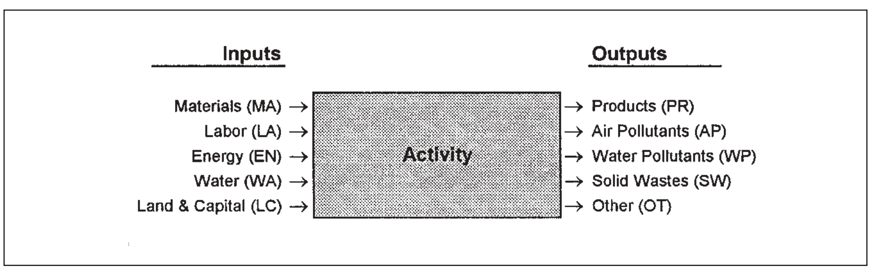

Figure 3. Inputs and outputs associated with an activity.

materials, energy, and equipment costs, while economic benefits include waste removal, avoided economic costs of landfill disposal, and virgin resource use. Environmental costs include the values of air and water pollution damages, visual disamenities, odor, congestion, and insect- and rodent-related problems. Environmental benefits are the reduced environmental costs of disposal and of virgin resource use. The societal benefits and costs include several "warm glow" items that are very difficult, if not impossible, to value monetarily. Such benefits include the building of individual self-esteem and collective community values, a heightened awareness of environmental issues, and improved citizenship. Costs might include the spillover of disposable attitudes that lead to diminished values of human life, and/or personal relationships, or that contribute to deviant behavior.

BENEFITS AND COSTS OF INDIVIDUAL SWM PATHS

Integrated solid waste management systems can be viewed from the perspective of the activities involved, such as collection, processing, and transport, or from a functional path perspective such as recycling and landfilling. The framework in this article takes the functional path perspective.

Recycling

Traditionally, the term recycling has referred to the reprocessing of inorganic materials such as aluminum, paper, and glass, and the term composting has referred to reprocessing organic matter such as yard and food wastes. In this article, recycling and composting activities are combined so that the recycling system refers to both inorganic *and* organic recycling activity. The recycling life-cycle path is illustrated in Figure 4a. The agents involved include waste generators, processors, brokers, and end users of recycled materials. Waste generators engage in cleaning and sorting, storage, and/or delivery activities. Processors are involved in collection, operation and maintenance (cleaning and sorting, processing, and storage), and delivery activities. Brokers are associated with administrative activities. Finally, the activities of end users include transport and use/processing of recycled materials. Based on the life-cycle path in Figure 4a, Figure 4b presents all of the economic, environmental, and societal types of benefits and costs associated with recycling.

Combustion

Combustion of solid waste occurs for two reasons: to recover stored energy and to reduce the volume of waste before landfilling. Figure 5a presents the combustion system path. The agents involved in combustion are waste generators and processors. Waste generators engage in storage and/or delivery activities, while processors are involved in collection, operation and maintenance (cleaning and sorting, storage, processing), and delivery activities. Figure 5b presents the economic, environmental, and societal benefits and costs associated with the combustion path.

Landfilling

Figure 6a illustrates the landfill life-cycle path. The agents involved in landfilling are waste generators and processors. The activities of waste generators include storing and delivering waste materials, and the activities of processors include collection, operation, and maintenance, which includes monitoring and maintaining landfills during and after their closure. Figure 6b presents the economic, environmental, and societal benefits and costs associated with the landfill path.

Illegal Disposal

While illegal disposal is not usually considered among the alternatives available to decision makers for dealing with solid waste, it is nonetheless an alternative. Decisions concerning solid waste management indirectly affect the extent of illegal disposal by setting levels of enforcement and by influencing the relative costs of legal waste removal options. We can expect the amount of illegal disposal to rise with lower levels of enforcement of littering laws and higher prices for legal disposal options. The illegal disposal system is depicted in Figure 7a. The only agents involved in illegal disposal are waste generators, which include households, firms, and governments. These agents engage in storage, transportation, and open dumping activities. Figure 7b presents the economic, environmental, and societal benefits and costs associated with the illegal disposal path.

SUMMARY

This article does not address the problems in measuring, comparing, and aggregating the many kinds of inputs, outputs, costs, and benefits associated with paths and activities. However, the organizational properties inherent in the life-cycle approach provide an effective basis for identifying the multitude of benefits and costs associated with solid waste management paths—such as recycling, combustion, landfill, and illegal disposal—without risk of double-counting. This article combines the traditional economic method of benefit-cost analysis with the life-cycle approach to describe a comprehensive analytical framework that is based on the flow of waste materials through generation, collection, processing, recovery, and/or disposal. This framework is an invaluable tool for researchers, decisions makers, and others who are interested in identifying and analyzing the extremely large number and types of benefits and costs associated with integrated solid waste management systems.

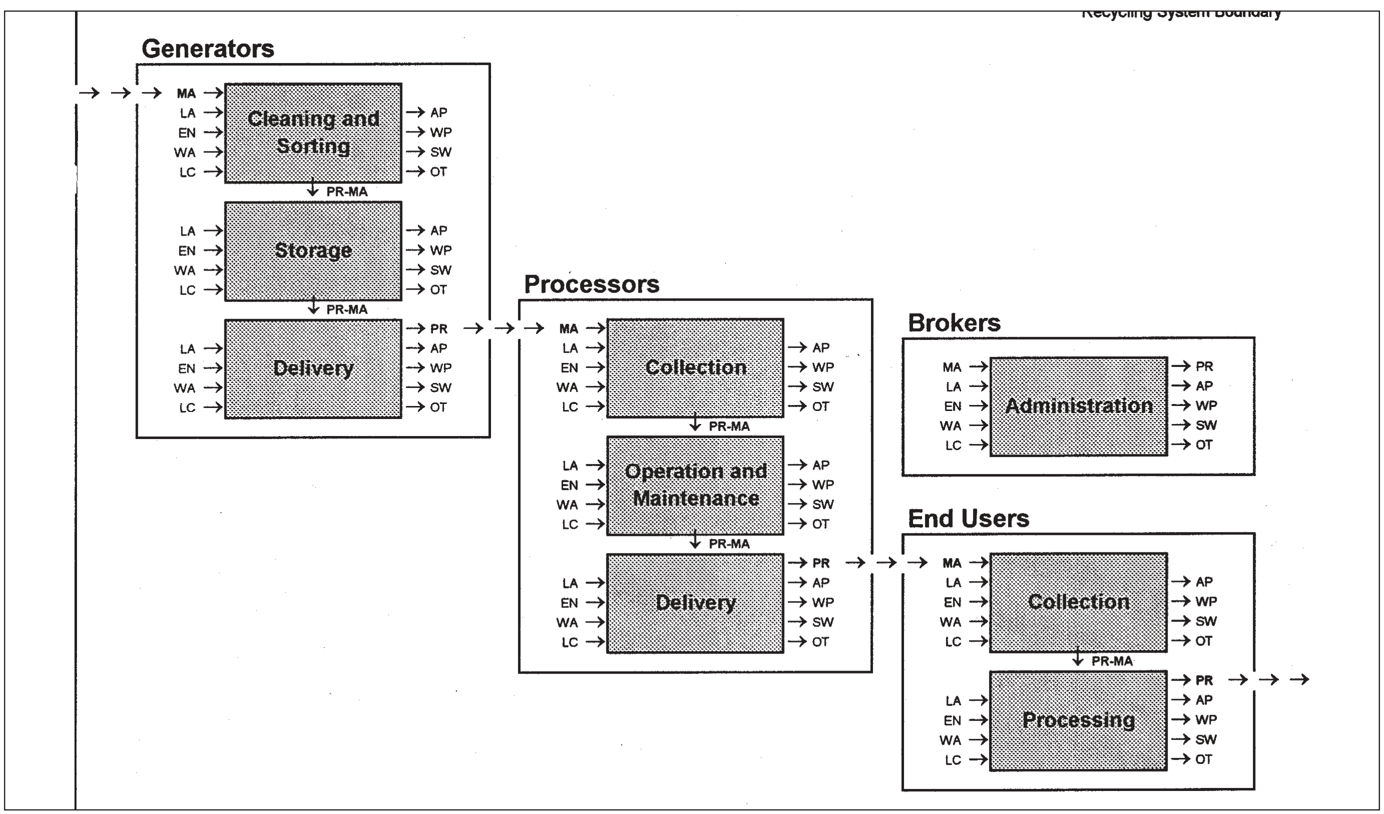

Figure 4a. Recycling path agents and activities.

		ECONOMIC		ENVIRONMENTAL		SOCIETAL	
Agents	Activities	Benefits	Costs	Benefits	Costs	Benefits	Costs
Generators (households, firms, governments)	Cleaning and Sorting	waste relocation; reduced economic costs of disposal; reduced economic costs of virgin resource use; revenues from sales of recycled materials; possible net job creation	chemicals, labor, energy, water, capital	reduced environmental costs of disposal; reduced environmental costs of virgin resource use	water pollution, solid waste	self-esteem, community building, heightened environmental awareness, improved citizenship, and other warm glows	na
	Storage		land, capital		visual disamenity, odor, insects, rodents		
	Delivery		labor, energy, capital		air/noise pollution, congestion		
Processors (firms, governments)	Collection		labor, energy, capital		air/noise pollution, congestion, litter		
	Operation and Maintenance		chemicals, labor, energy, water, land, capital		water/noise pollution, solid waste, visual disamenity, odor		
	Delivery		labor, energy, capital		air/noise pollution, congestion, litter		
Brokers (firms, governments)	Operation and Maintenance		materials, labor, energy, capital		solid waste		
End Users (firms)	Collection		labor, energy, capital		air/noise pollution, congestion, litter		
	Processing		materials, labor, energy, water, capital		air/water pollution		

Figure 4b. Life-cycle inventory of the recycling path benefits and costs.

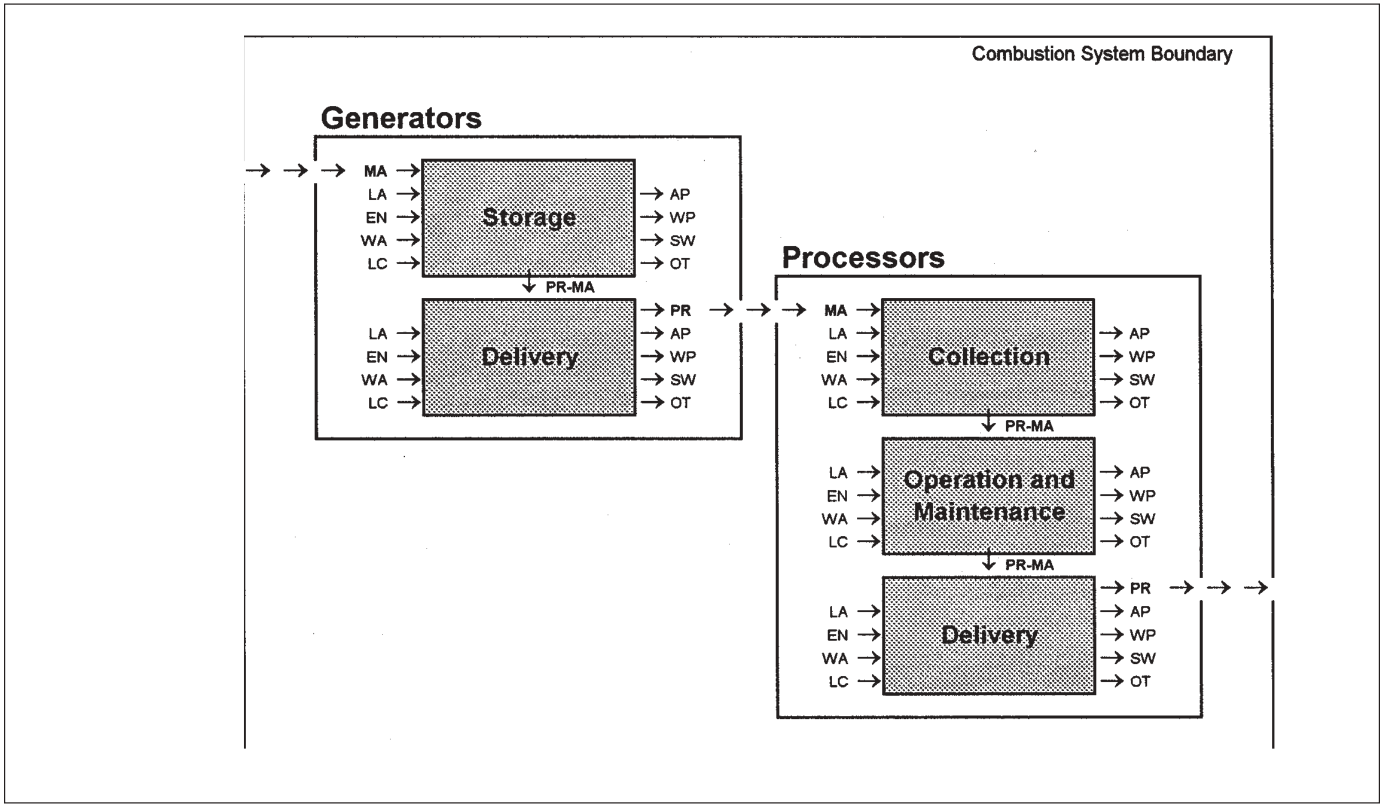

Figure 5a. Combustion path agents and activities.

		ECONOMIC		ENVIRONMENTAL		SOCIETAL	
Agents	**Activities**	**Benefits**	**Costs**	**Benefits**	**Costs**	**Benefits**	**Costs**
Generators (households, firms, governments)	**Storage**	waste relocation; reduced economic costs of disposal; reduced economic costs of virgin resource use; revenues from sales of recovered energy	land, capital	reduced environmental costs of disposal; reduced environmental cost of virgin resource use	visual disamenity, odor, insects, rodents	community building	spillover of disposable attitudes
	Delivery		labor, energy, capital equipment		air/noise pollution, congestion		
Processors (firms, governments)	**Collection**		labor, energy, capital		air/noise pollution, congestion, litter		
	Operation and Maintenance		labor, energy, water, land, capital		air/water/noise pollution, solid waste		
	Delivery		labor, energy, capital		air/noise pollution, congestion		

Figure 5b. Life-cycle inventory of the combustion path benefits and costs.

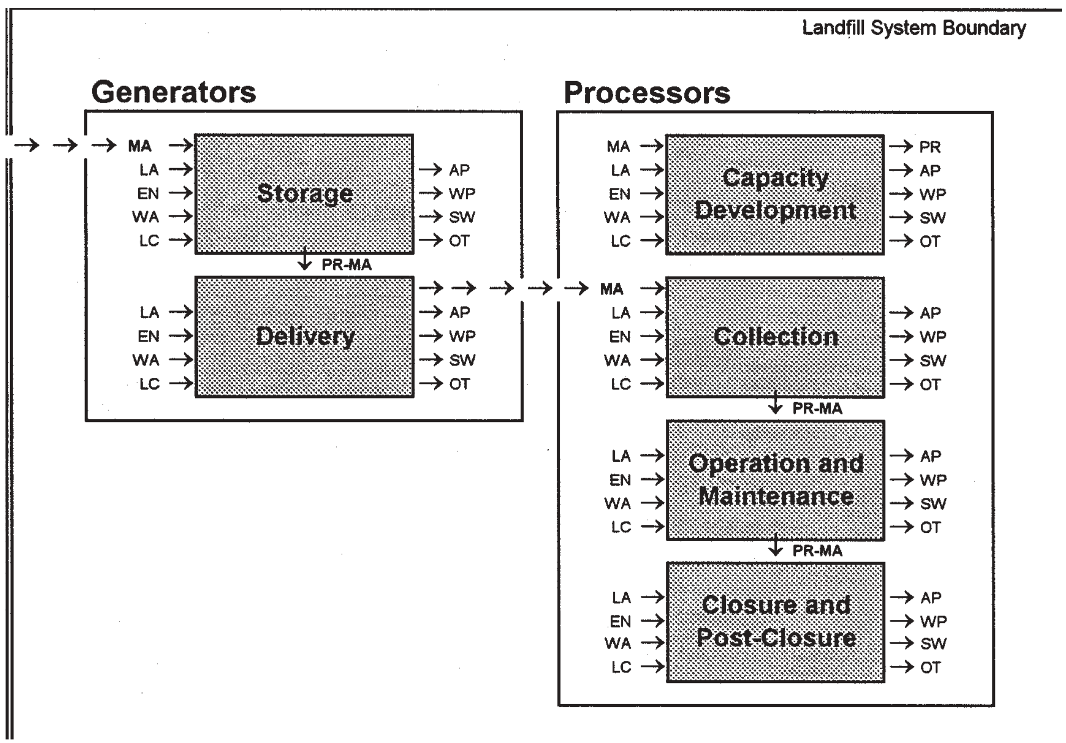

Figure 6a. Landfilling path agents and activities.

		ECONOMIC		ENVIRONMENTAL		SOCIETAL	
Agents	**Activities**	**Benefits**	**Costs**	**Benefits**	**Costs**	**Benefits**	**Costs**
Generators (households, firms, governments)	**Storage**		land, capital		visual disamenity, odor, insects, rodents		
	Delivery		labor, energy, capital		air/noise pollution, congestion		
Processors (firms, governments)	**Capacity Development**	waste relocation; revenues from sales of recovered gases	materials, labor, energy, water, land, capital	waste relocation	air/water/noise pollution, congestion	na	spillover of disposable attitude (diminished value of personal relationships, human life); community division (when siting new landfills)
	Collection		labor, energy, capital		air/noise pollution, congestion, litter		
	Operation and Maintenance		labor, energy, land, capital		air/water/noise pollution, odor, litter		
	Closure and Post-Closure		labor, energy, capital		air/water pollution		

Figure 6b. Life-cycle inventory of the landfilling path benefits and costs.

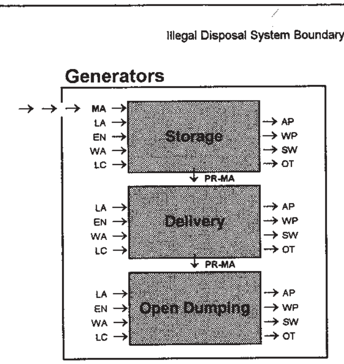

Figure 7a. Illegal disposal path agent and activities.

		ECONOMIC		ENVIRONMENTAL		SOCIETAL	
Agents	**Activities**	**Benefits**	**Costs**	**Benefits**	**Costs**	**Benefits**	**Costs**
Generators (households, firms, governments)	**Storage**	waste relocation	land, capital	na	visual disamenity, odor, insect, rodents	na	contribution to development of devian behavior
	Delivery		labor, energy, capital		air/noise pollution, congestion		
	Open Dumping		labor		water pollution, visual disamenity		

Figure 7b. Life-cycle inventory of the illegal disposal path benefits and costs.

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