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STATE UNIVERSITY of NEW YORK
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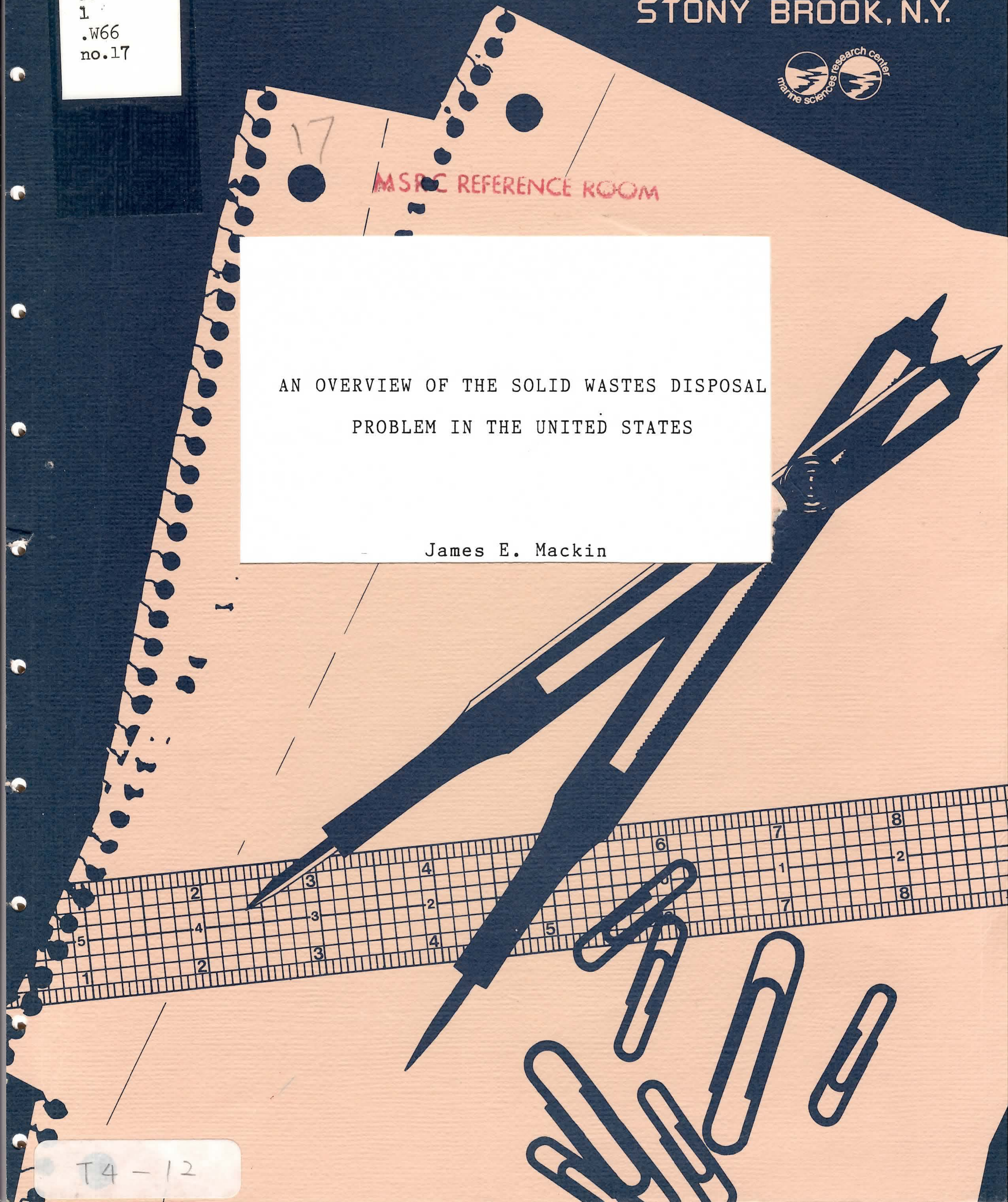

AN OVERVIEW OF THE SOLID WASTES DISPOSAL PROBLEM IN THE UNITED STATES

James E. Mackin

Marine Sciences Research Center
State University of New York
Stony Brook, New York 11794-5000

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J.R. Schubel

J. R. Schubel

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Municipal solid waste includes refuse produced as a result of residential, commercial, industrial, construction and demolition activities. Each American will generate an average of more than one and one half tons of this unwanted material this year, of which nearly 1 ton/person must be disposed of or recycled by organized agencies. The present per capita refuse collection rate translates into nearly 200 million tons of material for which organized disposal and recycling will be necessary in the United States this year. The disposal and reuse capacity must rise in the future due to projected increases in both population and per capita refuse generation (Doggett et al., 1980). At present only about 8% of collected solid waste is reused by materials and energy recovery, leaving the remaining 92% for disposal. Landfilling has been the preferred mechanism for disposing of solid waste in the past. Landfills are, however, rapidly filling to capacity, and suitable new landfill sites are lacking in many areas of the country.

Increasing federal, state and municipal regulation of solid waste disposal techniques as a result of concern over the potential associated environmental and health hazards has magnified the waste disposal problem in the United States. Permissable disposal options have decreased in number in the face of ever increasing waste generation. Many cities are now approaching a crisis situation of having no place to put the wastes accumulated in their communities. For example, in New York City roughly 17,000 residential incinerators, 22 municipal incinerators, and 89 landfills were available for solid waste disposal in 1934, whereas today only 2 landfills (Fresh Kills on Staten Island and the Fountain Avenue facility in Brooklyn) handle the majority (75%) of the more than 26,000 tons of refuse generated by New Yorkers per day (NYCDOS, 1984). Fountain Avenue is due to cease operations at the end of 1985. Fresh Kills has a "life expectancy" of about 16 years at the current rate of filling, after which landfill space in New York will, for all intents and purposes, be used up. The New York City situation is not unusual and by no means extreme by comparison with other large cities in the United States. Seattle, Washington is expected to run out of waste disposal sites at current usage rates within about 3-5 years (Public Works, 1984a). The purpose of this report is to review the solid wastes disposal problem in the United States and evaluate available options and future research directions so that crisis situations can be avoided.

Figure 1 shows a flow diagram (modified from Young, 1972) which indicates the pathways of waste generation and disposal that are discussed in this report. This figure shows the various options that are either available now or are being considered for the future to deal with treatment, transport and final disposal and/or reuse of solid wastes. For most consumers, the waste disposal problem ends at the "transport options" stage of the diagram. This stage represents the curb in front of homes where waste pickup normally occurs. Municipal officials usually decide how the collected waste will be dealt with. This decision represents the disposal

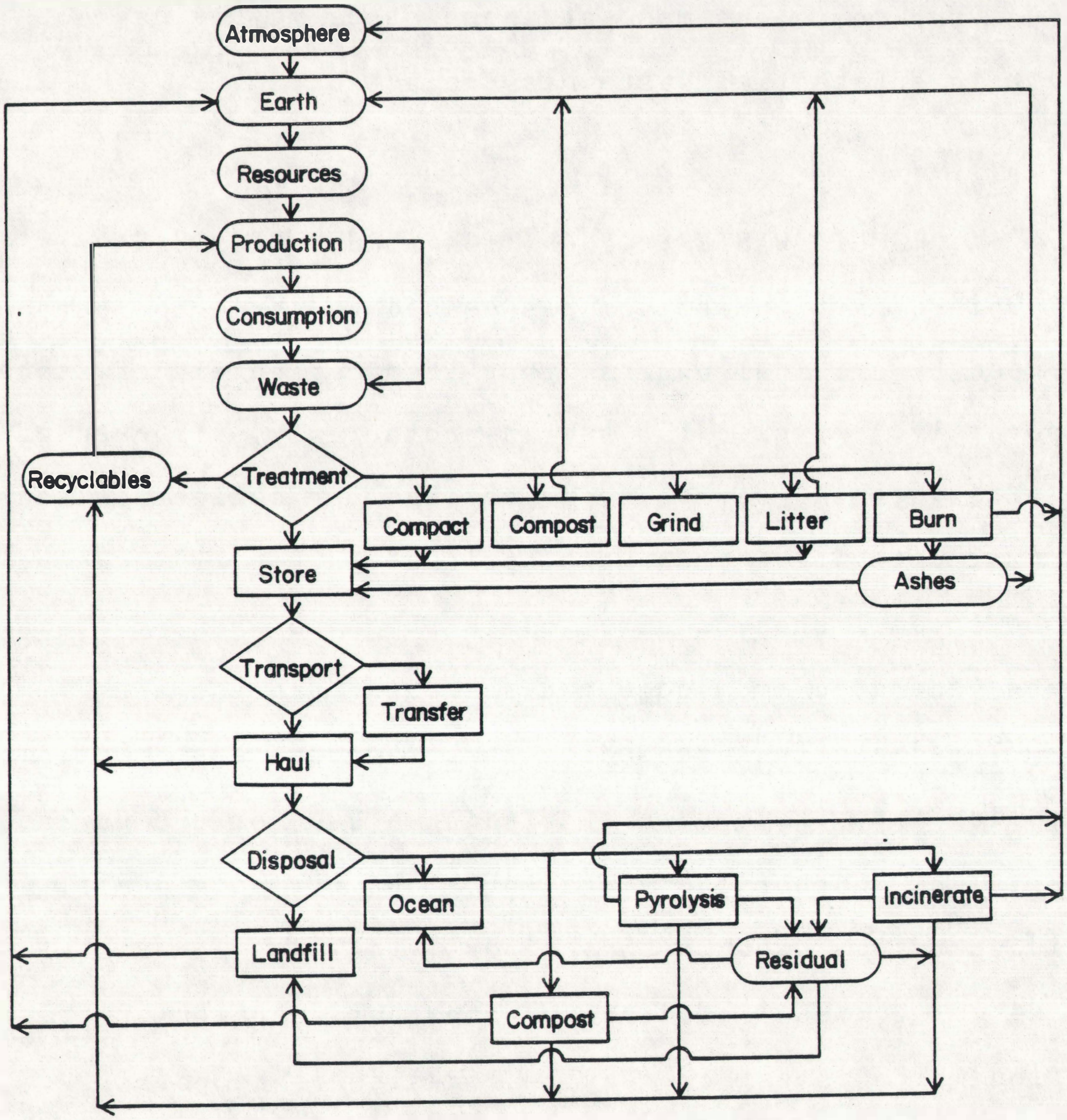

Figure 1. Flow diagram for solid wastes generation, transport and dispsoal (modified from Young, 1972).

options stage in figure 1. The production, consumption and recycling stages in figure 1 have relevance to wastes disposal because the decisions made at these steps may or may not result in substantial waste mass reduction.

SOLID WASTES: GENERATION VERSUS DISPOSAL

Once a particular item has ceased to serve the purposes intended by original owners, that item may be either stored temporarily, recycled for use in another way, disposed of at the site where it was used, or set out for collection and disposal off-site ("Treatment options" in Fig. 1). Recycling may be accomplished on-site, as is the case when, for example, scraps generated from some manufacturing process are accumulated and then reused in that same process. Off-site recycling puts the burden of finding a use for the unwanted material on another individual or group of individuals. Total solid waste, as used in this report, includes material in all of the categories listed above with the exception of that portion which is either recycled on-site or temporarily stored. The amount of this material which is generated tells community officials the potential total amount of space and recycling effort that may be necessary to deal with wastes. The amount of waste set out for collection and disposal at an off-site location (exclusive of the recycled portion) gives a measure of the immediate need for wastes disposal space. The difference between these two quantities depends in part upon the sources of wastes in a community.

Wastes Sources in a Community-

The major wastes sources normally present in a community that require separate disposal or recycling plans can be categorized as follows (after Haggerty et al., 1973; Doggett et al., 1980):

Residential: Product wastes originating in private households, including food and yard wastes, packaging, and used appliances, among others.

Commercial: Wastes from office buildings, restaurants, hospitals, schools and all other commercial trade and service establishments.

Transportation: Waste products resulting from cars, trucks, ships, airplanes, railroads and other transport equipment. The waste may be in the form of whole vehicles or vehicle parts. This category is distinguished from the others due to special procedures and equipment that may be necessary for recycling and disposal.

Industrial: This category consists of obsolete machinery previously used in product manufacture, as well as scrap material, sludge and ash that are byproducts of the manufacturing process. Agricultural and mining wastes are included here, although not explicitly discussed in this report (for a discussion, see Brunner, 1985).

Construction-Demolition: Wastes such as concrete, masonry, wood, etc. that are due to construction and/or demolition of buildings.

In the case of the construction-demolition category, a large amount of waste is generated each year (discussed below), whereas only a small fraction is set out for collection due to on-site disposal (or burial). On-site recycling is common in industrial sectors, as implied previously. Residential and commercial wastes have a high probability of being set out for collection, either at the curbside or through street sweeping of litter. A small fraction of residential waste may be burned or used for home compost heaps (Fig. 1).

Quantifying Wastes Generation and Disposal-

Estimates of the quantity and composition of wastes generated and collected in any particular community are necessary for planning disposal options because the success of any method is directly dependent upon these variables. One possible way to estimate the amount of solid waste that is set out for collection and disposal in any region of the country is to conduct a survey of relevant collection services. These surveys have proven very useful on both regional and nationwide scales. They show that the quantity and composition of collected solid wastes vary considerably between different regions of the country and may vary seasonally within any given region (American Public Works Association - APWA, 1966; Malina and Smith, 1971; Haggerty et al., 1973; Kemper and Quigley, 1976; Even et al., 1981). Surveys have the drawback that direct measurements on the wastes collected are often not available, such that only estimates can be provided. These estimates can give misleading results. For example, the 1968 nationwide survey by the American Public Works Association (APWA, 1968; see Haggerty et al., 1973 for a summary) gave a total paper disposal rate for the United States that was greater than the paper production rate. This was apparently caused by overestimates of paper disposal rates by a large proportion of the survey respondents (Doggett et al., 1980). Another drawback of surveys is that total wastes generation cannot be estimated, because not all of the waste is set out for collection, as implied previously. Also, it is difficult to compare results from year to year, because of differences in the types and number of survey respondents.

A method that has been used to quantify total wastes generation in the United States utilizes an input-output model, where it is assumed that product purchase must translate into waste output when appropriate corrections are applied for product lifetime, on-site recycling, and, particularly in the case of yard and food wastes, volume reduction (Doggett et al., 1980). Although these types of models can be criticized on several grounds (see Doggett et al., 1980 for details), they yield an internally consistent set of data for year by year comparisons and can be used to project trends in solid waste composition based upon production trends. The projections are somewhat dependent upon technology and recycling trends assumed in models. Qualitative results are not strongly model-dependent, and data discussed here are taken from the reference scenario calculations of Doggett et al. (1980) for illustration.

Figure 2A shows the estimated average composition of total solid wastes generated in the United States in terms of %paper, %plastics, %ferrous metal, %non-ferrous metals, %food and yard wastes, %concrete and masonry, %wood and %residual (textiles, glass, rubber, and leather) for the time period of 1971-1990, calculated from the data of Doggett et al. (1980). Figure 2B is a similar plot, but with the construction-demolition sector neglected and with appropriate corrections applied for recycling, in order to estimate the amount of each

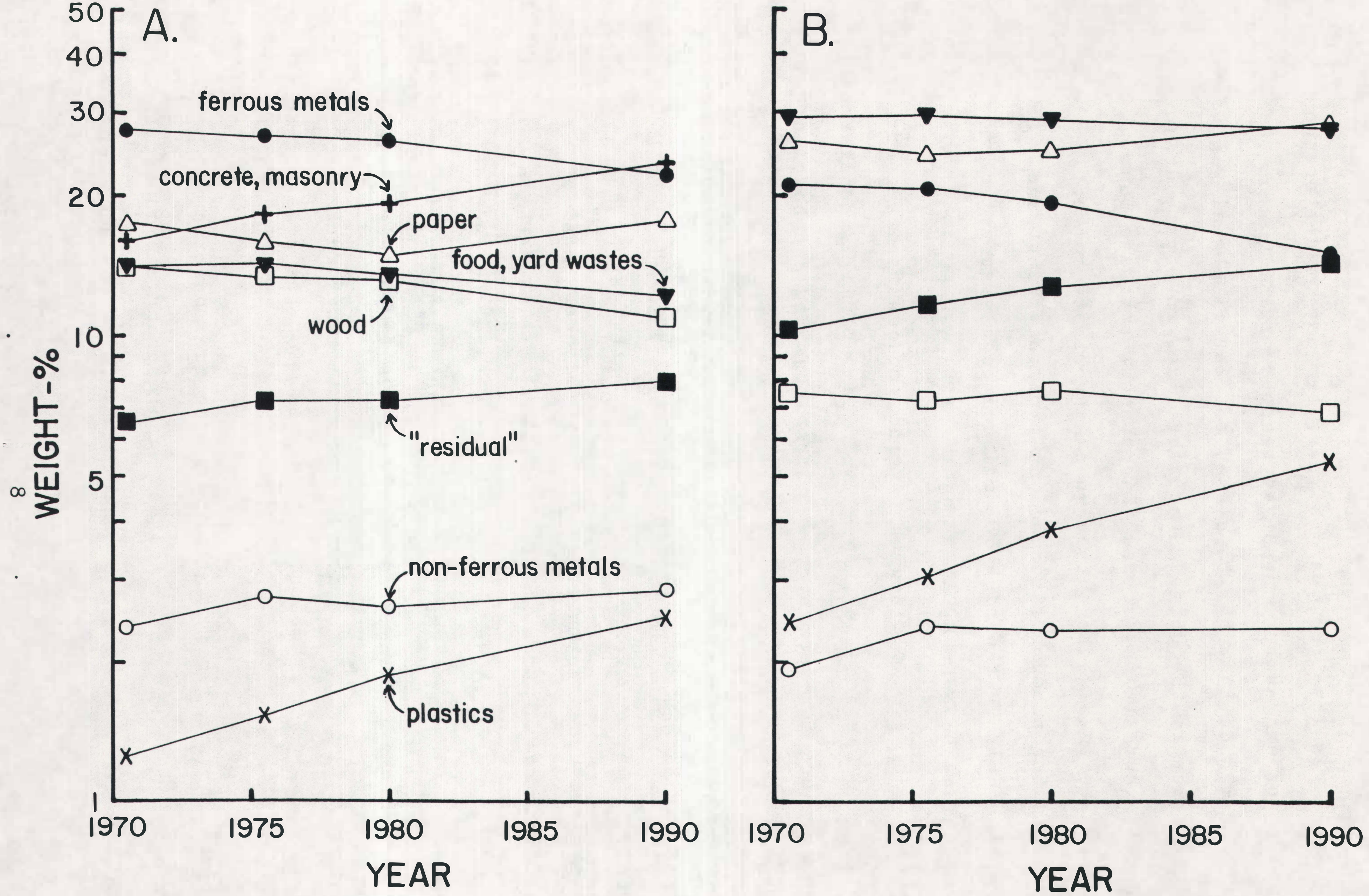

Figure 2. The percentage by weight of different constituents in solid wastes in the United States; A.) Total wastes generated; B.) Estimated wastes set out for disposal.

waste component that is set out for collection and disposal only. This data is plotted to give an indication of the composition of waste generated that actually requires off-site disposal (discussed below). The total of the components in figure 2B is plotted over the relevant time period in figure 3 for disposal rate (mass/time) and average per capita disposal rate (mass/person/time).

Data in figure 2A indicate that a large fraction of total wastes generated in the United States consists of concrete, masonry and wood, constituents which are almost exclusively attributable to the construction-demolition sector. The concrete and masonry waste generation rate for 1971 corresponds to approximately 1.75 pounds/day on a per capita basis, whereas the 1968 APWA survey mentioned before gave a total collection rate for wastes in the construction-demolition sector of only 0.2 pounds/person/day. This discrepancy is far outside the errors associated with both types of wastes generation estimates, and indicates that a very large fraction of the construction-demolition wastes are disposed of on-site. When total wastes generation is corrected for the component derived from the construction-demolition sector, residential and commercial wastes constitute from 87 to 88% of the total, which agrees very well with the APWA survey results.

The data in figure 2 suggest a trend of increasing paper, plastics and non-ferrous metals (mainly aluminum) relative to ferrous metals, food and yard wastes and other components of wastes generated and collected. All of these trends are also observed in historical records of regional and nationwide wastes generation (APWA, 1966; Haggerty et al., 1973; McIntire and Papic, 1974; Mantell, 1975; Kemper and Quigley, 1976; Henstock, 1980). The increasing paper, plastics, and aluminum contribution to total wastes is largely due to increased use of packaging in the United States through time. Factors responsible for this rise include self-service merchandizing, personal affluence, public desire for convenience, and the persuasive nature of packaging (Mantell, 1975).

The combustible fraction (paper, plastics, textiles, leather, wood, food and yard wastes) of the wastes set out for collection calculated from the data plotted in figure 2B increases from approximately 67% in 1971 to 71% in 1990. Substantial increases in the combustible fraction of solid wastes have also occurred in the United States prior to 1971, due largely to the packaging increase mentioned before (see, e.g., APWA, 1966; Kemper and Quigley, 1976). The high combustible fraction of solid wastes has important consequences for use of incineration in wastes management, because this technique is advantageous only when combustion can result in significant wastes volume reduction. Composting, on the other hand, relies on a large biodegradable fraction in wastes (i.e., food and yard wastes), and this fraction has been declining through the last century, due partly to the increasing fraction of packaging materials. Garbage disposal units in homes ("grinding" in Fig. 1) have also contributed to the decrease in the fraction of municipal solid waste consisting of food waste.

Wastes disposal rates shown in figure 3 illustrate the problem faced by wastes management agencies today. Future actions in this area must deal with ever-increasing total and per capita wastes production in the United States. Federal intervention into the solid wastes management field has been such that environmental and health issues can no longer be ignored, which greatly restricts the options that are available. Use of a wide variety of wastes volume reduction and disposal techniques, each with specific applications, may eventually be necessary to reduce all of the various threats posed by solid wastes to tolerable levels.

FEDERAL REGULATION OF WASTES DISPOSAL

The options indicated in figure 1 are subject to and modified by Federal, State and Municipal laws, which have evolved considerably over the last 50, and particularly the last 20 years. The major concerns with respect to solid waste disposal in the United States originally were aesthetics and economics. A wide variety of inexpensive disposal techniques were in use prior to about 1970, having the primary purpose of displacing wastes from the view of the general public; open dumps were common, ocean disposal of raw waste was acceptable and solid waste incineration was essentially unregulated.

Although there was some regulation of waste disposal practices imposed on the City or State level, such as the banning of ocean disposal of raw municipal waste in July of 1934 by New York City, only very minor Federal intervention occurred until the Solid Waste Disposal Act of 1965 was passed by Congress.

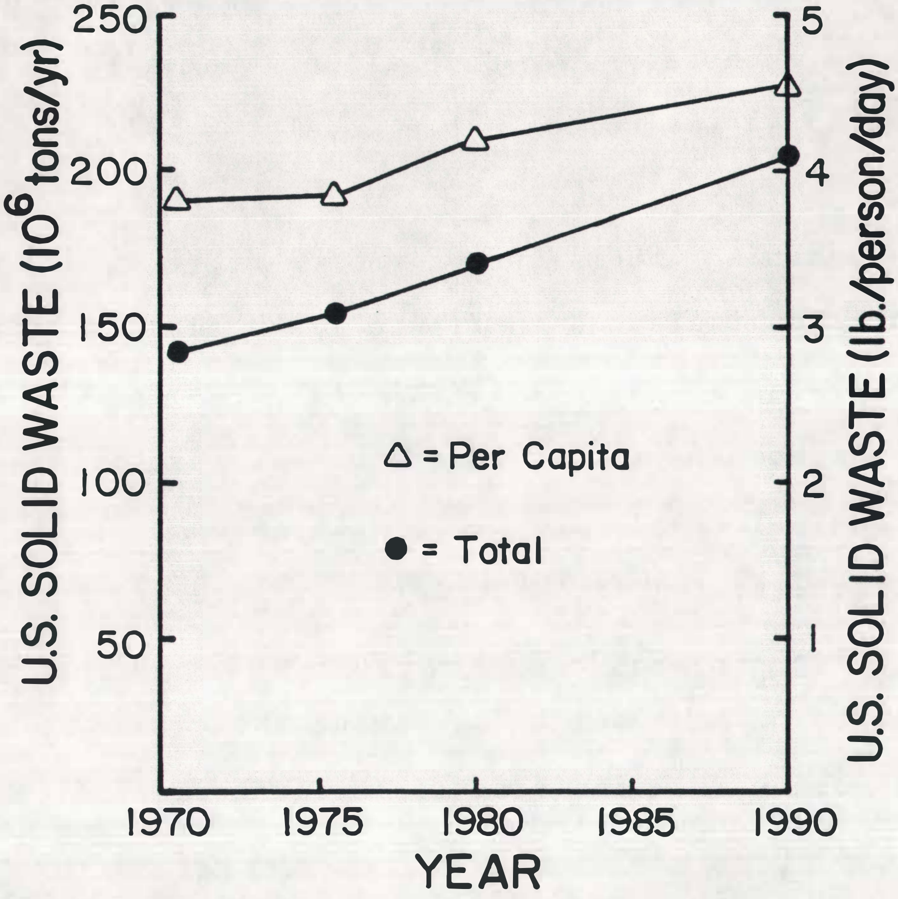

Figure 3. Net solid waste disposal rates for the United States expressed in terms of total amount per year (closed circles) and amount per person per day (open triangles).

This Act was the result of growing concern over potential adverse effects of imprudent waste disposal practices on public health and the environment. The Act was ammended in 1970, 1971, 1972 and finally in 1976, when the Resource Conservation and Recovery Act (RCRA) was passed.

The Environmental Protection Agency (EPA) was created in 1970 to develop and promulgate Federal regulations, programs, and plans as mandated by the Solid Waste Disposal Act and subsequent ammendments. Specifically, the comprehensive RCRA required development of (1) a federally-controlled program for the management of hazardous wastes, (2) guidelines for solid waste disposal sites, (3) establishment of state and regional solid waste plans, (4) a program to assist in the development of markets for resources recovered from wastes, and (5) comprehensive training, public education and judicial review procedures in the area of solid wastes management. The EPA published suggested criteria for decisions in solid wastes management in November of 1979. Although these criteria will not become Federal law until 1987, they have already had a major impact on waste disposal practices. The criteria are the basis for regulations that have been passed into law in all States. These State regulations are dispersed and enforced by agencies like the New York State Department of Environmental Conservation (NYSDEC), which were created specifically to implement RCRA. The EPA criteria and New York State regulations for solid waste management are discussed briefly below in relation to effects on specific waste disposal and transport options.

The Clean Air Act of 1970 represents another major effort by the U.S. government to control the impacts of man on the environment. The Act identified certain "criteria" pollutants for which National Ambient Air Quality Standards (NAAQS) were set for purposes of identifying air pollution hazards in all States. Specific NAAQS have been established by the EPA for sulfur dioxide, nitrogen oxides, total hydrocarbons, carbon monoxide, ozone and lead.

The original Clean Air Act required adoption by all States of federally-approved plans and permitting programs for air pollution control. Nationwide pollutant emissions standards were set as a result of the Clean Air Act, but planning for reduction of air pollution to NAAQS levels was left largely to individual States. Emissions regulations were established that distinguish between moving sources, including cars and trucks, and stationary sources, like incinerators. The 1977 amendments to the Clean Air Act identified 29 states, including New York, as non-attainment areas. These states, where some or all of the NAAQS are exceeded, are now required to (1) implement mandatory emissions inspections for moving sources and (2) follow plans submitted individually in 1979 to reduce pollutants to NAAQS levels by 1987. Although the EPA sets nationwide New Source Performance Standards (NSPS) for minimum control of "criteria" pollutant emissions from stationary sources, the exact emissions level for these and other "noncriteria" pollutants is handled on a regional basis, depending on the local nature and severity of air pollution problems (see Muskie and Snyder, 1981 for details).

The Clean Air Act was to have a major impact on solid wastes management. Many, if not most, incinerators in operation before 1970 had to be either closed or substantially modified because of emissions violations. The 1977 amendments to the Clean Air Act called for new strict emissions regulations on heavy-duty trucks, including refuse collection vehicles. These regulations will be effective in 1988 (U.S. EPA, 1985) and will undoubtedly have a major effect on the costs of wastes collection. The regulations will necessitate addition of more sophisticated pollution control systems to collection vehicles, in addition to more frequent vehicle maintenance scheduling.

Other Acts that have had important impacts on waste collection and disposal include the Water Resources Planning Act of 1965, the Federal Water Pollution Control Act, the Fish and Wildlife Act, the Noise Pollution and Abatement Act of 1970, and the Ocean Disposal Act of 1972. The first three were initiated to control pollution of waterways in the United States. As a result of these Acts, any process water used in incinerators, pyrolysis plants and composting operations must be cleaned of pollutants before being discharged into natural waterways. The Acts also placed limits, in addition to those established by RCRA, on the locations that may used for waste disposal facilities, such that any possibility of water pollution is eliminated. The Noise Pollution and Abatement Act led to development of specific criteria for reducing noise problems in the United States. This Act is pertinent to solid wastes management because of high noise levels that may be generated both during collection and disposal of wastes. The Act, therefore, places limitations on the design of refuse collection vehicles and disposal facilities. Regulations contained within the Ocean Disposal Act of 1972 have essentially eliminated ocean dumping of processed and unprocessed solid wastes. This means that, at the present time, landfilling is the only legal method for disposing of either raw municipal solid wastes or the residual component generated by other disposal options (see Fig. 1 and below).

WASTE DISPOSAL

In this section the disposal options of landfilling and ocean disposal are briefly defined and described. These are the only "ultimate" disposal methods. The other disposal options shown in figure 1 are not 100% efficient and residue generated requires landfilling or ocean disposal.

Sanitary Landfills-

The practice of burying solid wastes on land, or landfilling, dates back to Biblical times. Landfilling was the preferred method of disposing of municipal solid wastes in the United States until very recently because it was convenient and inexpensive. An estimated 8700 landfills are in operation in the United States today (NYCDOS, 1984). The term "landfilling" can take on many possible meanings to different people. These range from the "garbage dump", where refuse is deposited in an open pit with little regard to aesthetics, safety or environmental and health hazards, to the "sanitary landfill", with connotations described below.

Regulations resulting from RCRA require that all landfills conform to the definition of a sanitary landfill, which implies: (1) daily soil cover, (2) no open burning, and (3) air and water pollution controls. In 1968 only about 6% of the landfills in the United States met all of these requirements, and only 14% received daily cover (Haggerty et al., 1973). These percentages are likely to be much higher now due to Federal, State and public pressures on wastes management practices.

Efforts to control water pollution problems caused by landfills, as mandated by RCRA, have had significant effects on both economic and logistical aspects of landfilling. Water pollution is mainly caused by leachate production in landfills. Briefly, leachate results when water draining through landfills becomes contaminated with the decomposition products of the waste. This water can drain into groundwater, rivers, and streams and may pollute drinking water supplies. Filling of wetlands such as marshes and creation of landfill extensions into water bodies, which were at one time common practices in coastal cities like New York, are now virtually prohibited because of the possibility of surface water contamination. This and other logistical considerations necessary for sanitary landfilling have severely restricted the sites available for waste disposal on land. Also, pollution abatement and monitoring equipment required for sanitary landfills have caused capital and operations costs to skyrocket such that other disposal options have become economically competitive and, in some cases, preferrable.

The control of air pollution from sanitary landfills is necessary because, during the decomposition of organic materials in refuse, potentially explosive gases like methane and other low molecular weight hydrocarbons are produced. These gases can be captured by Landfill Gas (LFG) collection devices, which have been installed in many landfills across the United States. These devices are increasing in popularity because they reduce air pollution problems associated with landfilling and the collected gases are of economic value. The LFG collection system used in the Fresh Kills landfill on Staten Island is the largest such operation in the world. The LFG from this facility provides heating gases for some 10,000 homes in the surrounding area and generates more than $6,000,000 annually for New York City.

Ocean Disposal-

Ocean disposal of both raw municipal waste and ashes from incinerators have been outlawed for the past 11 years, as discussed previously, and very little use of this disposal method has been implemented since about 1950. Research is, however, being conducted to determine the feasibility of dumping raw municipal wastes and incinerator ashes into the oceans in the future. Potential environmental impacts may be due to bottom morphology alteration and toxic leachate production from ashes as well as beach fouling by floatable raw waste.

If deposited in a stabilized form, problems associated with ash and raw waste disposal in the oceans may be minimized. Stabilization of raw municipal wastes can be accomplished by baling prior to disposal. Baling is done by compacting wastes into high-density blocks and applying a strapping material. Baling may reduce problems caused by floatables (e.g. wood, plastics) that would be present in solid wastes deposited in the oceans. The technology of baling is already available because the technique has been widely used to treat wastes prior to landfilling. In that case, the goal of baling is to increase the initial density of deposited wastes to lengthen the useful lifetime of the fill.

It may be possible to incorporate ash resulting from incineration of municipal solid wastes into concrete blocks to minimize leachate production in the environment of the oceans. This stabilization technique has been demonstrated successfully for the case of coal fly ash disposal, and is being investigated for possible use with solid waste incineration ashes. Further research will be necessary to determine the impact of both stabilized ash and baled solid wastes on the ecology and aesthetics of the oceans. This research is critical, because disposal sites for wastes and ashes on land are rapidly becoming depleted, and the ocean may provide a valuable alternative sink for properly treated material.

RESOURCE RECOVERY

Modern uses of incineration, pyrolysis and composting all involve resource recovery by energy production and/or materials recycling. Because of high costs that are mainly attributable to pollution control equipment required in disposal facilities, the revenue generated by resource recovery is necessary to make the disposal options economically viable (see Albert, 1983 for a complete review).

Separation of Waste Components-

Whenever a wastes disposal option involves materials recycling, separation of the waste components will be necessary to remove the recyclable components. Separation techniques vary in complexity depending upon the heterogeneity of the waste and the degree of purity necessary for the recyclables (see, e.g., Haggerty et al., 1973; Golueke, 1977 for detailed discussion).

Manual separation is often used in composting operations, where relatively low volumes of waste are processed. This technique is also used at community recycling centers, where much of the sorting has already been done by the customers that supply recyclables. It is generally required for removing aluminum from wastes and for separating plastic film from paper, because satisfactory mechanical or electronic separation techniques to deal with these specific cases have not been developed.

In its most primitive form, manual separation can simply involve spreading the bulk materials onto a floor and picking the materials of interest out of the rubbish. For composting operations, materials are usually placed on a conveyor belt, and personnel working the belt are assigned specific tasks, such as paper, aluminum, plastics, rubber or textiles removal. This technique involves high labor costs, but is probably the most efficient of all separation techniques in terms of product purity.

A simple technique that is very commonly used to remove ferrous metals from unprocessed as well as processed (e.g. combusted) waste is magnetic separation. Again, the bulk materials are moved along a conveyor belt under a large electromagnet, which efficiently removes only the materials containing a high percentage of iron. This technique receives wide application in refuse derived fuel preparation and composting and often accompanies manual separation operations.

The inertial methods for separating materials in the waste stream rely on differences in density and elasticity between the different components. These methods are usually used on materials that have been shredded (discussed below) previously so that bulky materials will not foul or damage the equipment. In ballistic separation, materials are poured onto a mechanical rotor, which propells the components into a series of bins. The lighter, organic fraction of the waste travels the shortest distance and is deposited in bins closest to the rotor. Heavier materials settle into bins located at the farthest distance from the rotor.

A second inertial separation method uses the "Secator" system. Materials are projected from a conveyor belt toward a vertically oriented metal plate. The materials drop from the plate onto a rotating drum and then into a series of containers below the drum. Inelastic materials will be propelled the shortest distance from the metal plate, and when they drop onto the drum, will tend to be carried in the direction of rotation and drop into appropriately located containers. Heavier and less elastic materials will be dropped into containers on the opposite side of the drum.

The third inertial separation technique uses the "Inclined-Conveyor Separator". This is very similar to the Secator method except that the rotating drum is replaced by an inclined conveyor belt and the metal plate is not used. The rotation of the belt is in the opposite direction of inclination. Heavy and elastic components are propelled down the belt inclination whereas light and inelastic materials travel in the direction of belt rotation to achieve separation.

Three other commonly used mechanical separation techniques, which do not require prior shredding of material, are air classification, fluidized bed separation, and screening (trommel and vibrating). These techniques rely on size and density differences between the components of refuse to achieve separation. In the "zigzag" air classifier, for example, refuse is poured into a channel having an air source at the bottom. The air pushes lighter components upward through an outlet at the top of the channel, whereas the larger and heavier components drop unimpeded to the bottom. The channel has several bends in it (zigzags) so that particles are passed through the air stream many times to increase the efficiency of separation. This particular air classification technique has been shown to be very valuable for removing glass and other contaminants from compost, which substantially increases the economic value of the product (Stone and Wiles, 1975). The major disadvantage, from an environmental standpoint, is that large amounts of dust may be produced during air classification.

In the fluidized bed technique, refuse is poured into a water resevoir having a conveyor belt at the bottom. Air is bubbled up through the water to cause flotation of the lighter materials. These light components are carried with the flowing water into a collection bin, whereas the heavier materials drop onto the conveyor belt and are transported to a bin at the opposite end of the water reservoir. The disadvantage of this technique is that the water becomes heavily contaminated with pollutants and must be treated before being ejected into natural waterways.

The trommel screen consists of a rotating drum having numerous screen-covered outlets. As the drum rotates, heavier and smaller particles pass through the screens, while the lighter and larger materials like plastics and newspaper are retained inside the drum. A vibrating screen accomplishes much the same task, but in this case the refuse is placed on a combination conveyor belt and screen that is vibrated.

Screening, like air classification, is a commonly used method for treating compost to remove glass and other contaminants.

Several other techniques used to separate the components of refuse use fairly sophisticated electronic systems. These techniques involve photometric, X-ray attenuation, conductivity, and radiometric measurements on the components of the waste stream. Because each component must be analyzed separately, these techniques are usually very time consuming and, for this reason, not often used. The photometric method has been used fairly extensively to separate colored and clear glass from cullet, which is otherwise very difficult to accomplish.

Shredding-

Solid waste is often shredded for ease of handling and so that any mechanical equipment used for separation and disposal of waste components are not fouled and damaged by bulky items. It is also used for shredfills, where materials are shredded prior to landfilling. Shredding can reduce vectors associated with landfills and increase the density and, therefore, useful lifetime of the fill. Shredding usually reduces the size of materials to about 1-2 inches in diameter. The most common shredding techniques are: hammermilling, drum pulverizing, crushing, and wet pulverizing.

In a hammermill, material is passed into a shaft that is either vertically or horizontally oriented. Hammers, rotating inside the shaft, impact the refuse and break it up into small pieces. Hammermills are not appropriate for very large or dense materials like trees and engine blocks, which damage the hammers.

Drum pulverizers are used to shred the light organic fraction of wastes. Material is passed into an inclined and wetted cylinder having low baffles. Interaction of the wetted organic components with the baffles when the cylinder is rotated causes them to be torn into small fragments.

Grinders are characterized by a verticle shaft in a funnel-shaped housing. Rings attached to the shaft are forced outward upon rotation, which causes material to be ground against the sides of the housing. The utility of grinders is comparable to that of hammermills.

Wet pulverizers are essentially large garbage disposal units that, like drum pulverizers, are used primarily for the light, organic fraction, of refuse. Wastes are poured into water in a cylinder, where rotating blades grind the material to a small size. The final size of the material is determined by the size of the openings in a screen that is placed at the bottom of the water reservoir.

Environmental hazards associated with shredding of solid wastes include dust generation, high noise levels, and exhaust gases produced by machinery. Perhaps the major concern regarding shredding operations is related to operator safety. Many potentially explosive materials (e.g., gasoline cans) are present in municipal solid wastes and the action of shredding may promote explosions. This can be avoided by prior separation of explosive materials out of the bulk wastes.

Waste Volume Reduction Techniques: Incineration-

Although burning of refuse to reduce wastes volume has been practiced for as long as landfilling, controlled high temperature (>600°C) combustion of wastes to service the disposal needs of entire communities is a comparatively recent innovation. The first of these so-called central incinerators were built in Europe and the United States in the late 19th century. Pollution abatement laws discussed previously, which necessitate use of sophisticated air pollution control devices in incinerators, have caused the costs of operation to rise to the point that incineration alone is not economically feasible in most cases. Many wastes management programs in the United States are therefore turning to incineration with an energy conversion system to partially offset high operation costs. In some cases, incineration alone is still practiced because of a lack of available markets for the energy produced (e.g., Norton, 1984; discussed below).

Two basic types of incineration - resource recovery facilities are in use today. These are the mass-burning and refuse derived fuel (RDF) incinerators. A total of about 350 incinerators of these types are in operation in the world today (NYCDOS, 1985). Mass burning incinerators are further divided into field erected and modular combustion units. The latter are small scale (<100 tons per day - TPD - refuse capacity) units which are designed to be set up in preexisting structures and are also referred to as starved-air incinerators. The former large scale (up to 3000 TPD) incinerators require construction of a new structure to house the components.

The major difference between mass burning and RDF incinerator applications is that for RDF, shredding and separation steps precede refuse combustion. This is done to remove some or all of the inorganic, noncombustible materials from the refuse. In mass-burning facilities, all of the refuse is passed directly into the combustion chamber, and any noncombustible materials must be disposed of by landfilling. In both cases the heat derived from the burning refuse can be used to generate steam or electricity or both (so-called cogenerators). The steam and electricity are potentially available for heating and powering the incineration facility as well as other buildings.

Although very few incineration - resource recovery facilities are in operation in the United States today, many others are under construction or in the planning stages. Because initial capital costs for building a resource recovery incinerator are essentially fixed, whereas the costs of energy are expected to rise in the future, these operations have the potential for generating net revenue. For this reason, incineration with resouce recovery is considered by many to be the wave of the future in the field of wastes management (e.g. Public Works, 1984a). Concern has, however, arisen over the environmental impact of incineration. Although pollution control devices are required for such operations, these devices may not satisfactorily control emissions of some materials, such as dioxins, furans, and heavy metals. Dioxins and furans are chlorinated hydrocarbons which are among the most toxic substances known to man and are produced during the refuse combustion process (e.g., Commoner et al., 1984). A mass burning facility built in Hempstead, New York has been closed indefinitely and plans to construct eight resource recovery plants in New York City have encountered considerable opposition because of concern over dioxins and furans. Future research will be necessary to resolve the dioxin-furan and other environmental questions and determine the fate of incineration with resource recovery as a wastes disposal option.

Pyrolysis-

Pyrolysis is a solid wastes volume reduction technique that is very similar to incineration, and has been introduced in the United States within the last 20 years. The major difference between incineration and pyrolysis is that, whereas oxygen is purposely admitted into the combustion chamber during incineration, it is specifically excluded or limited during pyrolysis. The advantage of the latter is that because gas volumes are considerably less than those produced when oxygen is introduced during combustion, air pollution control is less costly. Exclusion of air from the combustion chamber means that an outside fuel source is necessary for combustion, and the costs of these fuels may offset the advantage of low air pollution control costs. Gases produced during pyrolysis can, however, be used as fuel for combustion such that pyrolysis systems are potentially self-sustaining. Other advantages of pyrolysis discussed below may eventually make this solid wastes disposal technique preferrable for at least some applications.

Many different pyrolysis systems have been tested on a pilot scale for use with materials such as forestry and agricultural residues, paper, tires, sewage sludge, and municipal solid wastes (see Sunavala, 1981 for a summary). These pilot operations show that pyrolysis can be accompanied by both energy and materials recovery, similar to incineration of RDF. Additional byproducts of the pyrolysis process include oil and tar, which are potentially useful as fuels, and "char", which is an organic residue with properties similar to carbon black. When a separation procedure does not precede pyrolysis the process also produces an inorganic ash, which must be disposed of.

Only one full-scale municipal solid wastes pyrolysis plant (1000 TPD) has been constructed in the United States. This plant, built in Baltimore, eventually failed and was converted to a mass incineration facility. Technological problems associated with scaling up of previous pilot studies to the full-scale operation were primarily responsible for failure of the pyrolysis facility. A full-scale pyrolysis plant for municipal solid wastes disposal was constructed in Japan in 1981. Technological problems were also encountered in that case for the first year, after which the plant has operated successfully, processing a capacity of 500 TPD of municipal solid wastes. The success of this plant as well as the pilot studies mentioned before suggests that pyrolysis with energy and possibly materials recovery may be a reasonable alternative to other wastes disposal methods in the future.

Composting-

Composting is probably best known for applications using yard wastes, where leaves and other litter are allowed to decompose by bacterial action to form a humus-like material that can be used as a soil conditioner. Possible use of composting as a means of solid wastes disposal has been investigated intensely in the United States since the early 1950's (see Golueke, 1977 for a summary). The major goal of composting, in this case, is to optimize conditions such that natural bacterial activity in refuse will rapidly convert biodegradable components into materials that are safely applied to land for soil conditioning. Various combinations of sewage sludge and solid wastes have been studied as possible composting material. Full-scale municipal solid wastes composting plants have been in operation in Europe since 1932.

Material like food and yard wastes, that are easily degraded by bacteria and fungi, are the principle components of solid wastes used to form compost. Paper and wood may be slowly decomposed by bacteria, but other nonbiodegradable materials must be removed for recycling and/or landfilling in order to yield a compost of satisfactory quality. Separation and shredding of wastes are necessary for a composting operation and can be accomplished in several different ways, which were discussed previously. In practice, as much as 50% initial solid wastes will be present in the final compost product due to difficulties in completely separating out the nonbiodegradable component (Stone and Wiles, 1975). Sewage sludge is usually added to the separated and treated waste to increase the nitrogen and water content as well as the bacterial population. All of these factors increase the rate of organic matter decomposition in the waste and therefore speed the composting process. Addition of nitrogen also increases the market value of the compost product because nitrogen is a vital nutrient for vegetation. Properly prepared compost from municipal solid wastes has been shown to increase the yield of a variety of crops for many years after being mixed into soils because of favorable changes in both the chemical and physical properties of the soil (e.g., Stone and Wiles, 1975; Golueke, 1977; Colacicco, 1982).

Composting is accomplished by two general categories of techniques: (1) windrow and (2) mechanical. In both methods, constant aeration is essential to promote growth of thermophilic bacteria, which thrive only under oxygenated conditions, and limit odor production, which occurs under anoxia. Temperatures rise to 50-60°C in the waste within a few days as a result of bacterial activity. These high temperatures are necessary to promote rapid organic matter decomposition and to kill disease-causing pathogens in the waste and sewage sludge. A decrease of temperatures in a compost heap down to ambient levels is usually a good indicator that composting is complete.

Windrow composting is accomplished by laying material down in rows in a field and providing intermittent turning or constant aeration. The constant aeration method is sometimes referred to as static pile composting. Mechanical composting is accomplished in-doors, usually by placing material into large containers, to which aeration and sometimes agitation are applied. There are numerous designs now available for both windrow and mechanical composting operations (see Sanitation Industry Yearbook, 1983a for a summary). In some cases a combination of the two methods may be most advantageous because rain inhibits compost formation in the windrow method, but costs are comparatively high for a full-scale mechanical operation (e.g. Haug and Davis, 1981).

The composting step may require only about six days of waste storage, but subsequent curing to increase compost quality usually extends the entire operation to 4-6 weeks. After the curing step, several final preparations, such as screening and/or air classification will usually be necessary to increase the market price of the compost, as was mentioned before. The long residence time of material in a composting facility means that extensive land space for the windrow method or high capital costs for the mechanical method are necessary to process large amounts of wastes. For this reason, composting is usually limited to small scale (<500 TPD and more often <100 TPD) wastes disposal requirements.

Compost from solid wastes has been used in roadside stabilization, horticultural growth media, landscaping, golf courses, and public parks. While this list of compost markets is impressive, one of the major drawbacks of composting has, until recently, been the low market demand for compost. As the public has become more informed as to the potential value of compost, particularly in agricultural applications, and composting techniques have become refined such that environmental hazards, such as pathogen production, odors, and vectors have been substantially reduced, the marketability of compost from municipal wastes has increased significantly over the past ten years. Composting will probably remain a viable wastes disposal alternative mainly in rural areas, where relatively low waste disposal capacity (<500 TPD) is required and markets for compost are readily available.

WASTE TRANSPORTATION SYSTEMS

The major mode of transportation used to bring wastes to disposal sites has been and will probably continue to be refuse collection trucks. Rail transport of wastes has been used extensively in Europe and has been studied at various times in the United States (Wolf and Sosnovsky, 1969; Pollock, 1980). No rail transport system is presently being run for wastes disposal in this country, although one such system is due to begin operations in southeastern Massachussetts in 1987 (Public Works, 1984b). Objections to the use of railhauling include litter, odors and vectors eminating from the moving trains. These problems can be overcome with proper management and planning (see Pollock, 1980) and railhauling may become a viable alternative to truck transport of solid wastes in the future, particularly as disposal sites become more remote from sites of wastes generation in large cities.

Truck Transport of Solid Wastes-

Over the last few years many changes have taken place in the wastes collection industry. Whereas traditional rearloading type trucks once dominated refuse collection vehicle fleets, the sideloading trucks have become increasingly popular (see Wolpin, 1984). This is due in part to the inherent ease of loading these vehicles, but is primarily caused by the attention paid by sideloader manufacturers to the needs of modern refuse collection agencies. Sideloaders have been constructed for ease of maintenance, driver comfort, mobility and safety, and maneuverability. Some of these trucks are fully automated so that only a driver is necessary for operations, whereas the traditional rear loader generally requires one driver and two helpers. The high costs of labor have led many cities to move toward automated sideloading trucks for routine residential refuse collection (see Maxfield et al., 1983; Sanitation Industry Yearbook, 1983b).

Most recent changes that have taken place in the refuse collection industry have been necessitated by economic considerations. Environmental consequences of the changes are generally good, with a few exceptions. Many costs reduction efforts have focused on keeping trucks on the road for the minimum possible time period necessary to pick up a given amount of refuse. Fuel consumption, labor costs, and truck maintenance are all reduced by these efforts. Exhaust emissions reductions will occur through any effort that keeps trucks on the road for the minimum possible time period, such that costs and environmental impacts should generally be directly related to one another.

Computerization of truck routing has helped reduce both refuse collection costs and total truck emissions by aiding refuse collection management in determining the most efficient routes for trucks. Transfer stations, which are sites intermediate in distance between collection routes and disposal sites where refuse is transferred to large transfer trailers, have also helped to reduce total truck emissions. The transfer trailers are capable of carrying 10-15 compacted collection vehicle loads, so that total truck traffic may be substantially reduced by operation of a transfer facility. Transfer facilities may also double as recycling centers, where recyclable components are removed from the waste stream (discussed below). The resulting reduction in waste flow to the disposal site can give added benefits of lowering disposal operation costs and lengthening the useful lifetimes of landfills. The recent popularity of transfer facilities is due, in large part, to increasing difficulties in finding suitable landfill sites in the immediate vicinity of collection routes. It is expected that transfer facilities will double in abundance in the United States in the next ten years (World Wastes, 1984).

Recent broad-scale conversion of refuse collection vehicles from gasoline to diesel powered engines (see Wolpin, 1984) is attributable to better fuel efficiency of the latter engines. Diesel engines produce about fifty times more particulate matter in exhaust emissions (U.S. EPA, 1979). Since these particulates can promote various respiratory diseases and contain carcinogens such as dioxins (Bumb et al., 1980), this conversion to diesel power has potentially adverse health effects. Recent regulations imposed on diesel engine particulate matter emissions (U.S. EPA, 1985) are designed to minimize the environmental problems caused by increased popularity of diesel engines in all areas of transportation.

SOURCE REDUCTION AND RECYCLING

Source reduction refers to any change in consumer or corporate habits which causes a reduction in the solid wastes load. Use of home compaction units can be a source reduction technique if the viability of the disposal method (i.e. landfilling or ocean disposal) being used is in some way limited by the volume, rather than mass, of waste generated. Source reduction usually results from lowered use of a particular product, a lengthening of the time that a product is used for the purposes originally intended, or a decrease in the production of waste during manufacture of the product. When the product ceases to serve its original purpose, the component parts can then be recycled for use in either the same or another way.

Source Reduction-

Considerable attention has been given to the topic of source reduction in the area of hazardous wastes. So-called Pollution Payoff Programs have been implemented in some States to educate the producers of hazardous wastes regarding the economic merits of source reduction (Tapscott, 1983, 1984). While no such organized effort has been implemented in the area of nonhazardous wastes, on-site recycling of scrap materials resulting in source reduction is fairly widely practiced, as discussed previously.

Source reduction through lowered use of a product or an increase in the effective lifetime of the product in it's original intended use are methods that will probably be very difficult to implement. For example, lowered use of packaging could result in a substantial reduction in the solid wastes flow in the United States. Because of economic and other advantages of using large amounts of packaging mentioned before, it would be very difficult to convince industry and commerce to practice this type of source reduction.

The tactic of lengthening effective lifetimes of most products in their originally intended uses as a method of source reduction would be difficult to pursue for several reasons. Progress is one deterrent in this regard, because a product may be discarded for the simple reason that it has become obsolete and will be replaced by a more modern version.

The reasons that any given person may choose to discard a particular product are not easily defined. It might be argued that by increasing the durability of purchased products, substantial increases in products' useful lifetimes should result. Conn and Warren (1979) found that, in addition to product durability, factors such as preconceived expectations for a product's useful lifetime, satisfaction with the performance of a product, sentimental value of a product, and the original price of the product all effect consumers' choices and timing regarding decisions of whether to discard, repair, store, or sell a particular product. Thus, increasing the durability of a product may have only a minimal effect on the product's useful lifetime. Further research is necessary to define feasible mechanisms for using source reduction to slow the rate of wastes generation in the United States.

Recycling-

Recycling was, at one time, thought to be the single solution to most wastes disposal problems. The harsh realities of supply and demand have caused recycling to take on a role that is currently of much lesser importance for reducing solid wastes flow than was orginally envisioned (see Henstock, 1980 for a review).

Recycling can be occur at several places on the flow diagram shown in figure 1. Recycling at the point of generation of wastes, or on-site recycling, has been discussed as a potential source reduction technique. This section deals with recycling that is done at some point outside of the wastes generation site. This type of recycling can be accomplished through the use of bottle deposit laws like that implemented in New York as of 1982, community recycling programs, or resource recovery operations associated with RDF or mass-burning incineration, pyrolysis and composting. The term "recyclable" usually refers to waste components that fall into the categories of ferrous metals, non-ferrous metals, paper, and glass. Energy obtained from RDF and mass-burning incinerators is an example where the combustible fraction of waste is the recyclable material, and energy generation is a result of the recycling operation. For RDF incineration, materials and energy are recovered from waste.

The components common to all recycling programs include: (1) a supplier of recyclables, (2) a dealer that collects and disperses the recyclables, and (3) a buyer (see Henstock, 1980 for a detailed discussion of these components). A successful recycling program must, in most cases, deal with the problems of generating enough supply and finding sufficient demand for the recycled materials to justify the existence of the program on economic grounds. In considerations of economic aspects of recycling, the reduction in waste flow to disposal sites must be included. Waste flow reduction will lower the operation costs and, in the case of landfilling, increase the lifetime of the disposal method. Also, Federal, and in some cases, State, County or City financial assistance can be obtained for recycling operations.

The bottle deposit law of New York represents an example of how a recycling program can successfully deal with the problems of supply and demand. In that case, beverage consumers are the suppliers of recyclables, the commercial operation that sells the beverage containers and accepts returns is the dealer, and container manufacturers are the buyers of the recyclables. Supply of recyclable materials (the containers) is virtually guaranteed by use of a monetary incentive, the container deposit. Demand for the recycled containers is guaranteed by State laws governing container manufacturers. The success documented for this type of program suggests that it might readily be adapted for use in recycling of other types of products. The New York bottle law is expected to eventually reduce the flow of solid wastes in New York City by about 5.5% of the total (NYCDOS, 1984).

For community recycling programs, the keys to ensuring sufficient supply of recyclables are that the recycling operation involve: (1) minimal inconvenience to customers, (2) incentives for participation, and (3) systems for informing the public about the existence and benefits of the program (see Jacobs and Bailey, 1982 for a case study). In the case of resource recovery operations involving RDF and mass incineration, pyrolysis and composting, the supply of recyclables is determined by the volume of wastes brought to the facility. Usually, wastes volume will be planned according to the total costs of operating the facility and will be controlled through contractual arrangements between facility owners and the municipality involved if the municipality is not the owner (see Nesheim and Theisen, 1983 for details). If landfilling is a viable alternative to resource recovery in a particular area, then tipping fees for disposal at the resource recovery facility must be competitive with those at the landfill, or the resource recovery operation may fail due to low supply of materials (Albrecht et al., 1981).

Community recycling programs usually require that participants bear at least some of the burden of materials separation. They may also require that participants transport materials to a collection center. In cases where the collection center is a transfer station, materials separation may or may not be accomplished by station operators (see Roth, 1983; Bracken et al., 1981). In "buy-back" operations, the inconvenience of the requirement that participants transport recyclables to recycling centers is partially offset by a cash incentive. Because curbside collection involves the least inconvenience to customers, many communities are turning to this type of operation to increase participation in recycling programs (e.g., Blanker, 1983; Grogan, 1983; Larkey, 1984; Public Works, 1984a). Participant inconvenience can be further reduced by offering back-of-the-yard collection or by providing separate containers specifically for recyclables to each customer (Tchobanoglous et al., 1977; Larkey, 1984).

Incentives for participation in community recycling programs are usually monetary. The recycling program may be made manditory, in which case there are monetary penalties for non-participation (Larkey, 1984; Public Works, 1984c). Seattle, Washington uses a curbside refuse collection system, where customers are charged for the service according to the number of refuse containers set out for collection, to encourage recycling (Public Works, 1984a). In other cases, customers may be either paid directly for recyclables, as mentioned previously, or given a reduction in refuse collection costs for participation in recycling programs.

The dealer of recyclables is usually an organization that collects all types of materials or one specific component that will be sold to buyers. This organization may or may not be the same one that provides the collection service to individuals. Dealers operate on a local, regional, or nationwide basis. They must decide, based upon the markets available and labor costs necessary for further materials separation, the degree of purity required for supplied recyclables. Although low materials purity is advantageous for minimizing inconvenience to participants in a recycling program, high product purity is usually necessary for maximum market value. Thus, some further separation of materials (e.g., removing paper labels from glass bottles or separating aluminum and steel cans) is usually required of dealers or the organization providing the collection service to ensure success of the recycling program. Labor and equipment costs for materials separation play a major role in determining the economic viability of community recycling programs.

Dealers must be prepared to stockpile materials during periods when market demand is low. Considering the fluctuating nature of markets (discussed below), it is probably best to use dealers that operate on a regional or nationwide basis and who work with a wide range of materials.

These dealers have the greatest degree of freedom in the sense that they can compare prices offered for a particular recyclable by many different companies, and low demand for one type of material may be offset at any given time by high demand for another.

Although considerable emphasis has, in the past, been placed upon optimization of the supply side of recycling, it is probably the demand side that will determine the ultimate success of recycling for reducing the flow of wastes to disposal sites. Adjusting the collection systems to increase participation of individuals in recycling operations is simple in comparison to the adjustments that will be necessary to increase the demand for many recyclables.

Progress is one impediment to recycling. For example, although a particular metal alloy may, at one time, be used for the manufacture of a product, further refinements in the product may rapidly cause that alloy to become obsolete. Therefore, once the old product is discarded, there may be no immediate use for the metal alloy parts. Separation of different metals is usually very time-consuming and expensive, such that there may be no economic gain from acquiring the discarded metal alloy. There will, therefore, be no demand for that metal alloy, no matter the supply.

In some cases, it is clear that the industrial sector has not put recycling into proper perspective in decisions regarding future product composition. Progress in any given area of manufacturing may have only a minimal impact on the quality of a product, while having a substantial impact on the use of recyclables. For example, pulp egg cartons and meat packaging require only a very low grade of paper, and are ideal candidates for use of recycled paper. These paper packages are gradually being replaced by polymeric foam designs, resulting in a minimal improvement in the quality of packages, but entirely removing a market for recycled paper.

Another impediment to recycling of materials is that the quality of products made from recycled components may be much lower than those made from virgin materials. This may be due, in part, to the presence of contaminants in the recyclable material. In some cases contamination can be reduced by use of more efficient materials separation methods; in other cases no degree of separation will decontaminate the recycled components. For example, before newspaper can be reused, it must be de-inked. The de-inking process destroys about 10% of the original paper and reduces the quality of the final product. Recycled paper is, in general, of lower quality than that made from wood pulping, because the grinding process used in recycling shortens paper fibers. Tin cans consist of a mixture of iron and tin with lead seams, which must be melted down before reuse. Once a melt has been formed, it is virtually impossible to separate the tin and iron, which substantially reduces the usefulness of the solidified iron product. The lead contaminant also attacks and destroys furnace linings.

Logistical considerations also enter into the demand side of recycling operations. Paper mills, for example, are usually located near forests in rural areas, so that transportation costs involved with wood pulping are minimal. Because recycled paper is generated predominantly in urban areas, transportation costs to bring that paper to the mills are usually much higher. It is largely for this reason that the paper industry views recycled paper as an extra source, to be tapped only during periods of very high paper demand, rather than the principal source of new paper products (Gill and Lahiri, 1980).

Although about 25% of the waste generated in the United States is potentially recyclable, recycling rates on the order of 10% of the waste generation rate are only rarely achieved (Grogan, 1983). While low community participation in recycling programs has been one reason for the limited success of recycling in this country, it is likely that demand determines the upper limit of recycling rates. Therefore, future actions to increase recycling rates should focus on providing incentives for cooperation of industries. New attitudes toward recycling will be necessary as well as new technologies to reduce problems associated with separation of recyclables from "contaminants". Paper recycling rates could, for example, be substantially increased by bringing paper mills closer to the areas of waste paper generation and by improving paper de-inking procedures. At the present, about 10 tons of waste newspaper are generated each year in the United States, but only three tons are recycled.

CONCLUSIONS

Table 1 lists the principal advantages of each of the disposal options discussed in this report (Fig. 1), and Table 2 gives the disadvantages. Landfilling is currently the only legal "ultimate" means of waste disposal. Limitations in land space and potential problems of drinking water pollution are the major disadvantages of this disposal method. The latter may be overcome by use of pollution abatement equipment. The U.S. EPA guidelines suggest that impermeable liners be used to seal the bottoms of landfills and that leachate collection systems be installed. This pollution abatement equipment is also required by New York State Law. The effectiveness of the equipment for preventing pollution of drinking water reservoirs is still unknown, because it has been used for only a very short time.

Limitations in the number of suitable sites available for waste disposal on land may eventually force the United States to move toward ocean dumping as an alternative to landfilling. Further research will be necessary to assess the environmental impact of ocean dumping and determine appropriate waste processing techniques and disposal sites to minimize this impact.

RDF and mass-incineration have the major disadvantage of air pollution. It may be possible to reduce environmental impacts by proper siting of the facilities in non-residential areas and through further research to develop pollution control equipment for abatement of dioxin, dibenzofuran and heavy metal releases to the atmosphere. Although pyrolysis may result in lower emissions to the atmosphere, uncertainties in pyrolysis technology as it applies to full-scale operations limit the usefulness of pyrolysis as a waste volume reduction technique for the near future. Markets for the energy generated from RDF, mass incineration and pyrolysis may limit their viability as waste volume reduction techniques in rural areas. In such cases, direct landfilling of refuse may be the only reasonable waste disposal alternative. Composting can only serve low volume refuse generation needs, and markets for compost are still uncertain. Improperly prepared compost can be a source of disease-causing pathogens, while properly prepared compost is a potentially valuable agricultural tool.

It is clear that substantial future research will be necessary to assess and eliminate the harmful environmental problems associated with all waste disposal techniques. Waste collection, on the other hand, is clearly moving in a direction such that most environmental impacts will be minimized as a result of a direct coupling between economic and environmental concerns. Special problems associated with the broad-scale conversion of the refuse collection industry to diesel powered vehicles can largely be overcome through enforcement of tough Federal emissions regulations.

Although recycling has not achieved the expected results for reducing the solid waste flow in the United States, there are still measures that can be taken to increase its potential. Increasing public and corporate awareness as to the benefits of recycling will be one key to bringing about more favorable supply of and demand for recyclable materials.

Table 1. Principal advantages of disposal options.

Disposal Method	Advantages
Landfilling	1. Convenience 2. The only legal "ultimate" disposal method
Ocean Dumping	1. Infinite space available 2. Pollutants remote from man
RDF, Mass-Incineration	1. Renewable energy source 2. 90% refuse volume reduction
Pyrolysis	1. Renewable energy source 2. Low air pollution potential
Composting	1. Refuse used for agricultural benefits

Table 2. Principal disadvantages of disposal options.

Disposal Method	Disadvantages
Landfilling	1. Limited space available 2. Water pollution problems
Ocean Dumping	1. Presently illegal 2. Unknown environmental impacts
RDF, Mass-Incineration	1. Air pollution problems 2. Uncertain energy markets in some cases
Pyrolysis	1. Technological uncertainties
Composting	1. Useful only in areas with low refuse generation rates 2. Low refuse volume reduction 3. Uncertain compost markets

Incentive systems can be implemented to further increase the success rate of recycling operations. Federal, State, and City legislation could also receive wider use to promote recycling. Mandatory recycling laws and and other laws like the returnable bottle bill in New York seem to be particularly effective in this regard. The magnitude of the waste disposal problem in the United States today is such that every possible alternative to disposal must be critically examined and utilized to the fullest extent.

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