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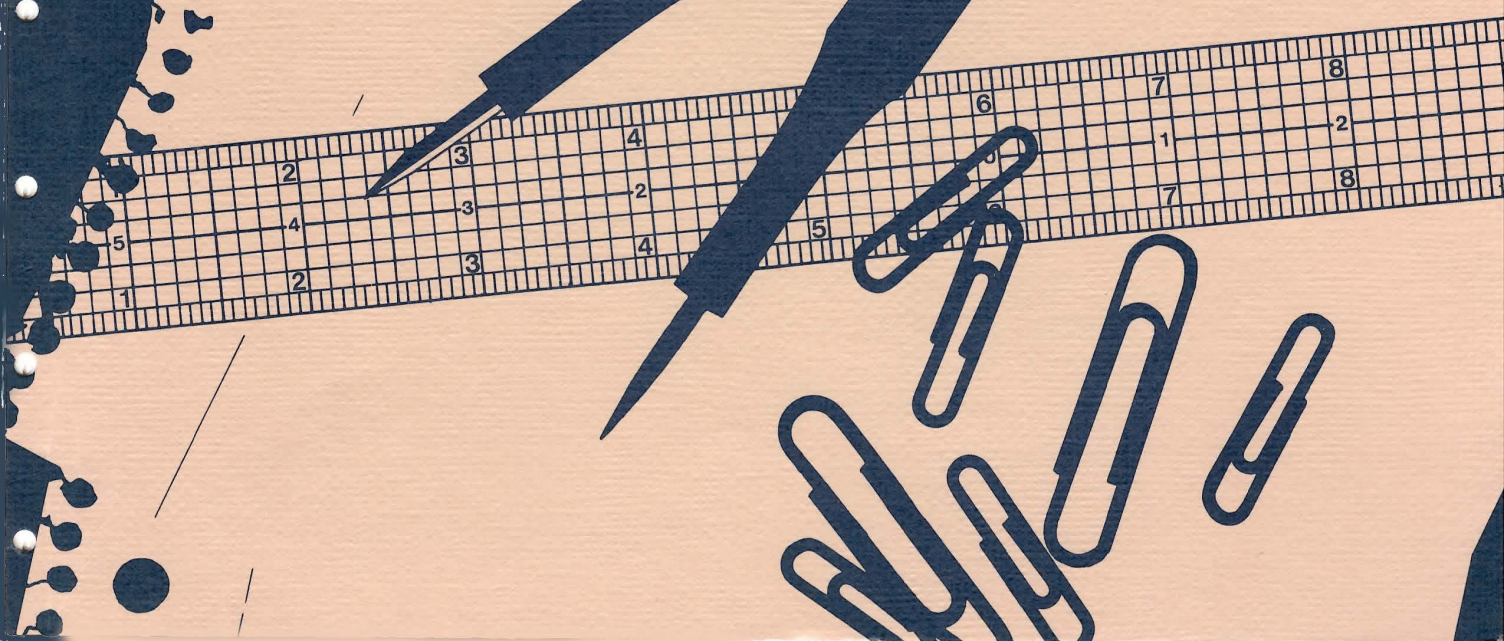
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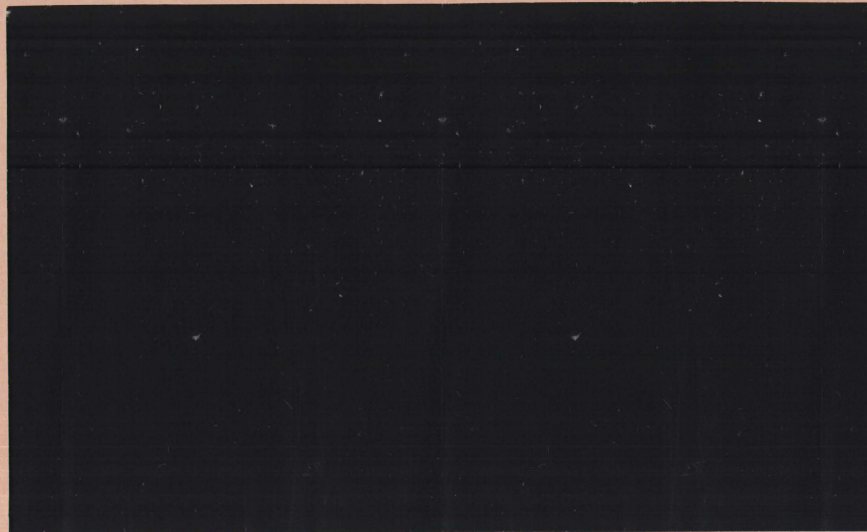


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THE ENVIRONMENTAL IMPACT OF REFUSE  
COLLECTION VEHICLES

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Preparation of this report was supported in  
part by a grant from the Ogden Corporation

15 September 1985

Working Paper # 18

Ref. # 85-11

Approved for Distribution

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## INTRODUCTION

Organized collection of refuse generated by households, commerce and other sectors of society is a fairly recent innovation, which was originally prompted by public distaste for the smells and appearance of rotting garbage accumulated in streets. When it was found that garbage was the source of pathogens and vectors causing major health problems, the regular collection of refuse became a critical part of urban planning. Refuse collection vehicles have evolved from the horse-drawn variety, that was prevalent around the turn of the century, to the many specialized gasoline and diesel powered trucks available today. Most recent studies of the refuse collection industry have emphasized economic aspects, because refuse collection can amount to as much as 60-80% of the entire cost of a collection-disposal system. Environmental aspects of refuse collection have not received widespread attention in the recent literature. One possible explanation for this omission is that most economically beneficial changes that are currently being made or are being considered by the refuse collection industry have environmentally beneficial consequences. For example, as cities move to optimize economic aspects of collection procedures more money will, at least in principle, become available to upgrade pollution control at landfills and incinerators. Further details of the coupling of economics and environmental concerns are discussed in a later section of this report.

## ORGANIZING REFUSE COLLECTION

The organization of refuse collection occurs at two different levels. At the first level, communities will decide who will do the collection, and how payment for this service will be arranged. The community can choose to combine refuse collection, street sweeping and snow removal into a single operation or handle the arrangements for each of these duties separately (see Stevens, 1981 for a discussion of the relative merits of these single and multi-service arrangements). At the next level, refuse collection agencies will make decisions as to the specifics of the refuse collection operation. Elements such as the composition of the truck fleet, the number and types of containers to be used, routing considerations, and vehicle maintenance are included here. The municipality may retain the right to dictate policy regarding any of these specifics (see Hickman, 1981; Moll, 1983 for detailed discussions of the decision-making process in refuse collection). The decisions will generally be determined by economic criteria, and any given decision may have positive or negative effects from the standpoint of environmental impacts.

### Selection of Collection Agencies-

Residential refuse collection is usually arranged separately from collection in the other sectors, such as industry and commerce. These latter sectors generally retain separate control over refuse collection, and usually choose to hire a private collection agency (Haggerty et al., 1973).



There are several different ways that residential collection arrangements can be made. The most common, in order of their use in the United States (Millar, 1982), are:

Municipal: Refuse is collected by employees of the municipality.

Contract: A private collection firm is hired and paid by the municipality, and the refuse collection service is mandatory for the residents.

Franchise: A private collection firm is given the exclusive right to collect refuse in a specified area of the municipality. The firm collects payment directly from the households, and the refuse collection service may or may not be mandatory.

Private: A private firm arranges collection and receives payment from individual households. The municipality may require the firm to be licensed.

Self-Service: Individual households deliver refuse directly to the disposal site.

Municipalities may choose to organize residential refuse collection by some combination of these five options. For example, Kansas City Missouri uses municipal, contract, and private collection in a proportion of 45:48:7, by percentage of residences served (Savas et al., 1980). Such mixed-service arrangements are less common than the single-service methods, being offered by approximately 31% of all communities in the United States (Millar, 1982). This percentage seems to be rising because of the economic advantages that have been demonstrated for the mixed-service systems. Healthy competition between the different service agencies involved usually will maximize the productivity of the entire operation (Committee for Economic Development, 1982; Millar, 1982; Steisel, 1983).

Approximately 50% of all residential refuse collection in the United States and Canada is done by municipal employees (American Public Works Association - APWA, 1981). Larger cities are the most likely to use this type of service (Haggerty et al., 1973; Kemper and Quigley, 1976; Millar, 1982). For example, for cities with population >500,000, roughly 78% have an arrangement where some portion of the refuse collection is done by municipal employees. Self-service refuse disposal arrangements are comparatively rare, except in the New England states, where only 34% of all cities have an ordinance requiring some type of residential wastes collection service (Millar, 1982). An example of a successful franchise arrangement is found in San Francisco, where two private firms (Sunset Scavenger and Golden Gate Disposal) have handled the collection needs of the entire city since 1921 (Solid Wastes Management, 1981a).

Recent trends in the preferences of communities, regarding the type of refuse collection organization, have been toward contracting arrangements (APWA, 1981; Millar, 1982). This reflects the relatively high efficiency and consequent low costs of such arrangements in general, as shown by several economic analyses of the refuse collection industry (Kemper and Quigley, 1976; Savas, 1978; Peterson, 1981).

#### The Refuse Collection Truck Fleet-

Once a particular refuse collection arrangement has been chosen, the collection agency management has the task of sorting out many different options to find a particular

combination that will yield optimum collection efficiency. All of these options are dependent in some way on the refuse collection vehicles that are available. The exact composition of the fleet will be determined by a number of economic and practical considerations, which are discussed below.

Data shown in Table 1 compares the average composition of a private refuse collection agency for the years 1979 and 1983 in terms of total number of vehicles owned and percentage and cost of each type of vehicle in the fleet (Harrington, 1980; Wolpin, 1984). Transfer vehicles are discussed later in the context of transfer stations. A brief description of the other vehicles listed in Table 1 follows (for more details, see Tchobanoglous et al., 1977):

Rearloader: Refuse is loaded into a receiving hopper at the rear of the vehicle. This truck is generally used for curbside or backyard collection in residential areas and requires no special refuse container design.

Frontloader: Refuse is automatically loaded into the hopper from the front of the vehicle with hydraulic lifts. This truck is generally used for high volume refuse collection, usually in the commercial and industrial sectors. The refuse container design must conform to the specifications of the truck hydraulic lifts.

Roll Off, Tilt Frame, Hoist: The hopper and refuse collection container for these trucks are the same unit, which is enclosed on all four sides and can be detached from the truck cab and frame. The trucks differ in the size of the container allowed and the mechanism for removing and replacing the container. They are typically used for construction-demolition refuse collection, but may be appropriate for other purposes when high volumes of waste are generated and the disposal site is reasonably close to the collection site.

Sideloader: This truck is conceptually identical to the rearloader except that refuse is loaded into a hopper located behind the cab on the side of the truck.

Stake, Flat Bed, and Dump Trucks: These trucks are used for

collection of bulky and heavy items that cannot be accommodated by other vehicles.

Satellite Vehicle: This is a small vehicle that is used in residential areas in conjunction with a rearloader or sideloader. Refuse from a small neighborhood can be loaded into the large container of the satellite vehicle. The refuse is mechanically transferred to the larger truck for transport to the disposal site.

Because frontloaders, sideloaders and rearloaders generally dominate the fleets of refuse collection agencies (e.g., Table 1), the discussion in this report will focus mainly on uses of these types of trucks. All of these vehicles have a mechanism for compacting the loaded refuse to increase refuse weight capacity (discussed below).

A comparison of the two surveys shown in Table 1 reveals several striking trends in the refuse collection industry, in addition to the obvious rising costs of collection vehicles. First, the average number of trucks per hauler increased from nine to forty-five in only four years. This dramatic change reflects the emergence of many regional and national collection agencies in the 1980's, whereas single-city service was common previously (see, e.g., Kemper and Quigley, 1976). The second striking trend is the increasing percentage of sideloaders in the average truck fleet. Rearloaders and sideloaders dominate in both surveys because these trucks are preferred for residential collection, which is the major service of the average agency (Table 2).

The increased popularity of the sideloader in the refuse collection industry reflects the numerous advantages offered by these trucks for many residential operations. The sideloading design is particularly convenient for curbside

Table 1. Comparison of 1979 and 1983 average truck fleet composition for the private refuse collection industry.

Year:	<u>1979</u>	<u>1983</u>
Total Vehicles:	9	45
%Rearloaders:	38.1 (\$31,083)*	22.2 (\$45,000)
%Sideloaders:	6.5 (\$26,562)	37.8 (\$68,000)
%Frontloaders:	18.5 (\$63,333)	11.1 (\$86,000)
%Roll Off, Tilt Frame, Hoist:	19.7 (\$51,331)	11.1 (\$62,500)
%Stake, Flat Bed, Dump Truck:	9.8 (\$17,187)	6.7 (\$17,000)
%Satellite Vehicle:	5.9 (\$11,666)	11.1 (\$9,000)
%Transfer Vehicle:	1.8 (\$63,750)	6.7 (\$70,000)

\*Average cost of vehicles purchased in the past year is given in parenthesis.

Table 2. Average percentage of the total refuse collection service provided to the residential, commercial, and industrial sectors by private haulers in 1979 and 1982\*.

Sector	1979	1982
%Residential	45.5	58.0
%Commercial	35.0	29.0
%Industrial	19.5	13.0

\*Data from Harrington (1980, 1983).

collection. Also, sideloaders are readily adapted to a fully automated system, where the driver does not leave the cab of the truck during pickup. Automated refuse collection is thought by many to be the residential refuse collection operation of the future (Public Works, 1984a).

In addition to the inherent advantages of sideloaders over rearloaders mentioned previously, there are other advantages of the sideloaders manufactured in this country that are not directly related to the point of entry of refuse into the truck. In an effort to compete with the more traditional rearloaders, manufacturers of sideloaders have paid particular attention to factors such as maneuverability, gas mileage, ease of maintenance, and operator comfort, mobility and safety to increase the attractiveness of their product (e.g., Solid Wastes Management, 1982; World Wastes, 1983a,b). One important advantage of sideloaders is that the manual and automated trucks can be safely operated with two and one man crews, respectively. Since labor costs average nearly 60% of total collection costs (Millar, 1982), the reduced crew sizes necessary for manual and automated sideloaders can result in substantial savings, despite the fact that specialized containers must be purchased in the case of the automated trucks (Steisel, 1983; Maxfield et al., 1984). One limitation of the automated vehicles is that they may not be useful in areas having heavy on-street parking problems because the trucks cannot be maneuvered into position directly adjacent to the containers in such cases (Sanitation Industry Yearbook, 1983).

## ECONOMIC CONSIDERATIONS AND ENVIRONMENTAL CONSEQUENCES

Collection agencies are always faced with decisions regarding (1) details of the truck fleet, (2) frequency of collection, (3) crew size, (4) location of container pickup, (5) routing of vehicles, (6) refuse collection containers to be used by customers, (7) vehicle maintenance and cleaning schedule, and (8) transfer stations. These decisions are all interrelated and will have direct and/or indirect effects on environmental factors including odors, vectors, littering, noise, and emissions.

Environmental factors related to refuse collection are regulated to some extent by federal, state and municipal legislation. The hopper of all refuse collection vehicles are required to be entirely enclosed during transport to the disposal site as a result of legislation from the Resource Conservation and Recovery Act of 1976. This requirement limits the amount of odors, vectors and litter that can emanate directly from the vehicle. Emissions of hydrocarbons, nitrogen oxides, and carbon monoxide are regulated according to standards established by the U.S. Environmental Protection Agency (EPA). Noise pollution is regulated by the Noise Pollution Abatement Act of 1970.

### Details of the Truck Fleet-

Once the composition of the truck fleet has been decided, the refuse collection agency has several options available regarding the details of truck design. The most important of these, from both economic and environmental standpoints,



include: (1) engine type; either gasoline or diesel powered, and (2) refuse weight capacity.

The average percentage of recent vehicle purchases having diesel type engines, taken from the 1979 and 1983 surveys discussed previously (Table 3), clearly indicates the recent trend of the refuse collection industry toward diesel power. This is mainly due to the greater fuel efficiency of diesel compared to gasoline powered engines (NYCDOS, pers. comm., 1985). For example, the recent St. Louis conversion to a nearly complete automated side loader collection system was accompanied by simultaneous conversion to diesel power (Sanitation Industry Yearbook, 1983). The gasoline powered vehicles formerly used for refuse collection in St. Louis delivered only about two miles per gallon, whereas the new diesel engines give up to five miles per gallon. This type of broad-scale conversion to diesel power may have some adverse environmental side-effects, because diesel engines emit about 50 times more particulate matter than gasoline engines (U.S. EPA, 1979). The particulate matter, by itself, causes health hazards by promoting various respiratory diseases. Diesel engine particulate matter is also known to contain carcinogenic components such as dioxins (Bumb et al., 1980; U.S. EPA, 1985). For these reasons, and because of increased popularity of diesel engines, the EPA has set new rules to regulate particulate emissions from heavy-duty diesel powered vehicles like refuse collection trucks, which will go into effect in 1988 (U.S. EPA, 1985).

Table 3. Percentage of refuse collection vehicle purchases by the private collection industry having diesel powered engines in 1979 and 1983\*.

Year:	<u>1979</u>	<u>1983</u>
%Diesel Rearloader:	73	99
%Diesel Sideloader:	33	99
%Diesel Frontloader:	97	100
%Diesel Roll Off, Tilt Frame, Hoist:	95	50
%Diesel Stake, Flat Bed, Dump Truck:	54	60
%Diesel Satellite Vehicle:	-	18
%Diesel Transfer Vehicle:	100	100

\*Data from Harrington (1980) and Wolpin (1984).

Unlike the type of engine used in refuse collection vehicles, recent trends in the refuse weight capacity preferred for collection vehicles should have favorable consequences for the environment. Refuse weight capacity is determined by a combination of the volume capacity plus the compaction pressure that can be applied to the refuse. Table 4 gives the range of refuse volume and weight capacity for refuse collection trucks that are on the market in the United States today.

Each time a refuse collection vehicle becomes filled to capacity, it must empty the load at the disposal site. The transit to the disposal site takes up valuable labor time, uses fuel, and promotes vehicle deterioration. Thus, by increasing the weight capacity of a vehicle, fewer trips to the disposal site will be required and savings in labor, fuel and truck maintenance costs will result. For this reason, the refuse collection industry has been moving in the direction of vehicles that offer high volume capacity and compaction pressure (Harrington, 1980, 1983; Wolpin, 1984). This trend should have favorable environmental consequences because any change that results in lower total truck travel time will decrease total truck emissions, other factors equal.

#### Collection Frequency-

Collection agencies will generally want to minimize the frequency of refuse collection in order to reduce fuel, labor, and vehicle maintenance costs. If, however, the frequency of refuse collection is too low, alternative options for dealing

Table 4. Refuse volume and weight capacities for frontloaders, rearloaders and sideloaders available in the United States.

Vehicle	Volume Capacity (cubic yards)	Weight Capacity (tons)
Frontloader	20-40	5-14
Rearloader	9-32	2.5-16
Sideloader	5-38	1-15

with wastes such as littering and burning may become more attractive to community members (Young, 1972). Also, the odors, vectors and litter resulting from open stationary containers in the neighborhood may increase to intollerable levels. In this case, the indirect effect of low refuse collection frequency will be increased odor, vectors, littering and emissions from open burning of refuse in the neighborhood.

Roughly 60% of all cities in the United States provide once-a-week refuse collection (Millar, 1982). Twice-a-week and more frequent collection has declined in popularity because of very high costs, which may be as much as 50% higher than once-a-week operations (Kemper and Quigley, 1976). Larger cities and warmer climates tend to favor higher collection frequencies (Millar, 1982). The latter is apparently related to increased problems with vectors at higher temperatures (Sanitation Industry Yearbook, 1983). Higher collection frequencies in large cities is necessitated by more rapid accumulation of refuse in areas with higher population densities (Kemper and Quigley, 1976).

#### Crew Size-

The collection crew size may have an indirect effect on environmental factors in a community because cities generally have a fixed budget for labor to deal with street sweeping and snow removal in addition to refuse collection. If the total budget is reduced, as occurred during fiscal crises in many cities in the late 1970's and early 1980's, one or more of

these areas will necessarily suffer adverse effects.

One example of the effects of refuse collection crew size on environmental aspects of communities comes from a recent experience in New York City. Beginning in 1974 the Department of Sanitation (DOS) was faced with large cuts in manpower due to budget restrictions. In order to ensure that refuse collection would continue in the City, the street sweeping labor force had to be substantially reduced. This caused environmental aspects of city streets to deteriorate markedly (Steisel, 1983). The refuse collection operation was revamped to help alleviate this problem. The major change was that sideloaders, requiring only two crew members, were added to the fleet of collection vehicles. Also, rearloaders, which had previously been operated by three man crews, were cut to two man crews. These changes had very little effect on the quality of the collection operation, but enabled diversion of a large portion of the work force back to street sweeping, which caused a near immediate improvement in the cleanliness of streets.

Economic analyses of Connecticut refuse collection operations by Kemper and Quigley (1976) showed that a decrease in the crew size of rearloading vehicles from three to two members caused only about a 6% reduction in the amount of refuse that could be collected in a day by one vehicle. This means that the productivity of the collection operation per crew member increases substantially upon reducing the crew size. Thus, it appears that, in the general case, reduction

of rearloader crew sizes to two members should have favorable effects on the economic aspects of refuse collection due to reduced labor costs.

The average crew size used for refuse collection in the United States is roughly 2.6 persons per vehicle (Millar, 1982). This average is probably dropping with time due to economic considerations discussed above. Continued rise in the use of automated collection systems is expected to bring average crew size nearer to the minimum of 1 person per vehicle in the future. Three and four man crews are still fairly common in the United States, despite the economic disadvantages. One reason for this is that many communities continue to operate back-of-the-yard collection (discussed subsequently), in which case large crew sizes are necessary (e.g., Tchobanoglous et al., 1977).

#### Location of Container Pickup-

The three general types of refuse container pickup in residential areas are curbside, alley, and back-of-the-yard. Alley pickup is primarily limited to multi-family housing units. For single family dwellings, a choice must be made between curbside and back-of-the-yard service. Back-of-the-yard service is done for customer convenience. This type of service can help to promote participation of customers in recycling operations that may accompany refuse pickup. The burden of materials separation, imposed on customers, is partially offset by the convenience of the pickup service.

The Connecticut refuse collection study discussed

previously (Kemper and Quigley, 1976) showed that costs of operating back-of-the-yard refuse pickup were as much as 50% higher than curbside pickup, even before considering the increased crew size that is usually necessary for back-of-the-yard collection. This was primarily attributed to the longer time required to collect a given amount of refuse in the case of back-of-the-yard pickup. Time translates into money in the sense that greater fuel consumption, vehicle deterioration and higher labor costs result from long collection times, as was mentioned before. Also, longer truck operation time translates into greater truck exhaust emissions in the neighborhood. Therefore, although the higher collection costs for back-of-the-yard pickup can in some cases be offset by higher collection rate charges to customers, the adverse environmental effects of increased truck emissions will not be cured by this action.

Planning of refuse container locations in commercial areas is of particular importance for both economic and environmental considerations. In Fresno California, for example, the builders of new buildings and remodelers of existing structures are required to include clear identification of refuse storage areas (Sallee, 1983). Building plans are reviewed by the Solid Waste Management Division of the city to insure that refuse areas can be easily accessed by collection vehicles. In the absence of this type of planning, refuse from commercial operations may be set out in areas that are inaccessible to trucks, which will increase



both the costs of collection and environmental hazards from truck emissions.

### Container Types-

The type of container that must be used in a refuse collection operation is dictated almost entirely by the refuse collection vehicles in use. Commercial collections by frontloading vehicles requires containers that conform to the dimensions of hydraulic lifts on the trucks. The range in refuse capacity for these containers is roughly 1-8 cubic yards (Tchobanoglous et al., 1977). One fairly recent innovation in the design of the containers is the use of plastic tops that can be easily opened and closed by customers (Solid Wastes Management, 1981a). These types of container tops should help reduce odors, vectors and littering resulting from containers that are left open.

For residential areas, 30-50 gallon cans and bags have been used almost exclusively in the past. Recent trends have, however, been toward the use of much larger containers (300-600 gallon), particularly for multi-family dwellings. These containers can be handled efficiently by automated collection vehicles, whereas, in the past low volume containers were necessitated by limitations of manual collection.

The economic advantage of using high volume refuse containers is that the time required for collection of refuse from a single large container can be substantially lower than that required to collect refuse from many small containers. One environmental advantage of high volume containers is the

reduction of vehicle emissions due to shorter collection times. Another advantage of these containers is that, because refuse is concentrated in a single area, rather than being spread throughout a neighborhood in small containers, the overall impact of odors, vectors, and litter emanating from containers is reduced (Sanitation Industry Yearbook, 1983).

#### Vehicle Routing-

Designation of routes for collection vehicles to ensure that vehicle time is used in the most efficient possible manner is a crucial factor for the economics of any collection agency's operations. A simple change in routing can change an economically disastrous operation into one which is viable (e.g., Lott, 1984).

Collection vehicle routing can influence total vehicle emissions in a city in two different ways. First, unnecessary emissions from collection vehicles will be caused by trucks being on the road for more than the minimum time required to collect and transport refuse. Second, if routing is arranged in such a way that traffic congestion is produced, then an increase in emissions from all vehicles involved will result. Under legislation resulting from implementation of the Clean Air Act of 1977, routing of all vehicles in many cities must be coordinated to yield the lowest total emissions possible. Thus, the routing of refuse collection vehicles must be coordinated with general traffic flow in these cities to reduce overall environmental impacts.

The exact routing system that can be used depends upon the particular circumstances of the community in question. For example, in cities providing collection by private agencies alone, several companies may operate in the same neighborhood. In this case the routing of vehicles cannot be organized in an optimum manner. This is probably one reason that private collection of refuse is the most expensive collection alternative available to cities in the United States (Kemper and Quigley, 1976; Savas, 1978).

If refuse collection vehicle routing is centrally coordinated, then many factors can be taken into account to yield the most efficient system possible. The general principles which should be followed in all cases include the following (after Tchobanoglous et al., 1977):

- (1) Wherever possible, routes should be laid out so that they begin and end near arterial streets, using topographical and physical barriers as route boundaries for any particular vehicle.
- (2) In hilly areas, routes should start at the top of the grade and proceed downhill as the vehicle becomes loaded.
- (3) Routes should be laid out so that the last container to be collected on the route is located at a point that is nearest to the disposal or transfer site.
- (4) Refuse collection at traffic-congested locations should be done as early in the day as possible.
- (5) Sources at which extremely large quantities of wastes are generated should be serviced during the first part of the day.
- (6) Scattered pickup points where small quantities of wastes are generated should, if possible, be serviced during one trip or on the same day.

Designation of specific sections of a community that will be serviced by individual vehicles avoids overlapping, which is

inefficient and can cause traffic congestion. The size of the different sections will depend primarily upon the population density, frequency of collection, and whether the service is curbside, alley or back-of-the-yard. All units in a section will be serviced once or twice in a week, depending upon the level of service provided.

Keys to routing of collection vehicles include proper designation of the size of sections to be serviced and selection of the appropriate strategy for maximizing efficiency in servicing the sections. For a small city, these tasks can be accomplished through trial and error simulations with refuse collection vehicles. Larger cities require computer simulation to accomplish the enormous task of routing coordination. Computers are now an integral part of most refuse collection agencies because they can help coordinate routing in this way and can perform many other tasks using software that is specifically designed for refuse collection management (see, e.g., Dexter, 1984). Generally, the computer simulations will balance routes by tonnage of material collected and total time required to accomplish collection and disposal.

#### Vehicle Maintenance and Cleaning Schedule-

The average depreciation time for a refuse collection vehicle in the United States is about six years (Harrington, 1983; Wolpin, 1984). With proper maintenance this depreciation time can be extended to ten or more years (Solid Wastes Management, 1981a; Smiley, 1983). Because of the high

costs of purchasing a new vehicle (Table 1), proper vehicle maintenance is necessary for any economically viable refuse collection operation. Also, vehicle downtime that is caused by mechanical breakdowns can be very costly to the agency. It may be necessary to work collection crews overtime to offset the temporary loss of a vehicle from the fleet (Smiley, 1981). Vehicle maintenance has environmental significance in the sense that exhaust emissions and gas consumption will be minimal in the case of a properly maintained vehicle. Also, vehicle downtime that would otherwise be avoided by proper maintenance may translate into missed collections, which can lead to increased litter, odors, and vectors in the areas effected.

Many of the larger refuse collection agencies hire vehicle mechanics as part of the staff (Solid Wastes Management, 1981a,b). A minimum number of the most frequently needed vehicle parts are kept on hand for routine maintenance. Larger jobs are contracted out. In addition, trucks are kept on a regular maintenance schedule and any problems that develop during any day of operations are corrected immediately (Solid Wastes Management, 1981a,c).

It is important that, when a mechanical problem develops in a vehicle, it is detected immediately. Regular cleaning of vehicles is necessary so that residue that may inhibit visual detection of mechanical problems does not accumulate on vehicle parts (Solid Wastes Management, 1981d). For this reason, daily cleaning of refuse collection vehicles is

recommended on economic grounds. Regular cleaning will also reduce litter, odors and vectors that may emanate from the vehicle itself.

### Transfer Stations-

A transfer station is a site that is located at some intermediate distance between collection vehicle route areas and the disposal site, where refuse is transferred to large tractor-trailers. The transfer trailers, which have capacity for 10-15 compacted collection truck loads, haul the refuse to disposal sites. The transfer step may be accomplished by direct dumping of refuse from collection vehicles into transfer trailers. Refuse may also be dumped into a container, where refuse is compacted before being placed into transfer trailers. Several other options are available, depending upon the purposes planned for the transfer facility operation and volume of refuse handled in a single day (see Hindman, 1983; Smiley, 1984; and below).

Transfer stations become cost effective when the distance to the disposal site is great enough that costs associated with operation of the facility are less than the costs of collection vehicle transit to the disposal site. In many cases the decision to build a transfer station is prompted by closure of a nearby landfill site and the lack of another alternative site in close proximity to collection routes (e.g. Cook, 1983; Roth, 1983; McKagen, 1983; World Wastes, 1984). The average collection vehicle haul distance (distance traveled from the end of a route to the final destination) for

the United States is 10.2 miles (Millar, 1982). It is likely that this average would be much higher if it were not for the existence of transfer stations. For example, a comparatively large fraction of cities with population >500,000 operate transfer facilities (56% of those surveyed by Millar, 1982), and these large cities also have the lowest average haul distance (9.7 miles compared to 10.2-12.8 miles for other cities).

Figure 1 shows a diagram which illustrates the behavior of costs mentioned above as a function of haul distance to the disposal site (after Haggerty et al., 1973; see Hendrickson, 1984 for more details). Costs for transfer operations and collection vehicle transit both rise as a function of distance to the disposal site. This is primarily due to fuel consumption, vehicle maintenance and labor costs in both cases. Because the transfer operation involves much fewer vehicles, the corresponding slope of costs vs. distance is shallow relative to the case of direct collection vehicle transit. Thus, at some transit distance, the combined costs of building and operating a transfer facility become less than the costs for direct collection vehicle transit to the disposal site.

Several factors must be considered to evaluate the significance of a transfer facility from the standpoint of environmental impacts. A positive aspect of transfer facilities is that total truck travel time should be reduced as a result of operations, which may reduce total vehicle emissions. If, however, the transfer facility is improperly

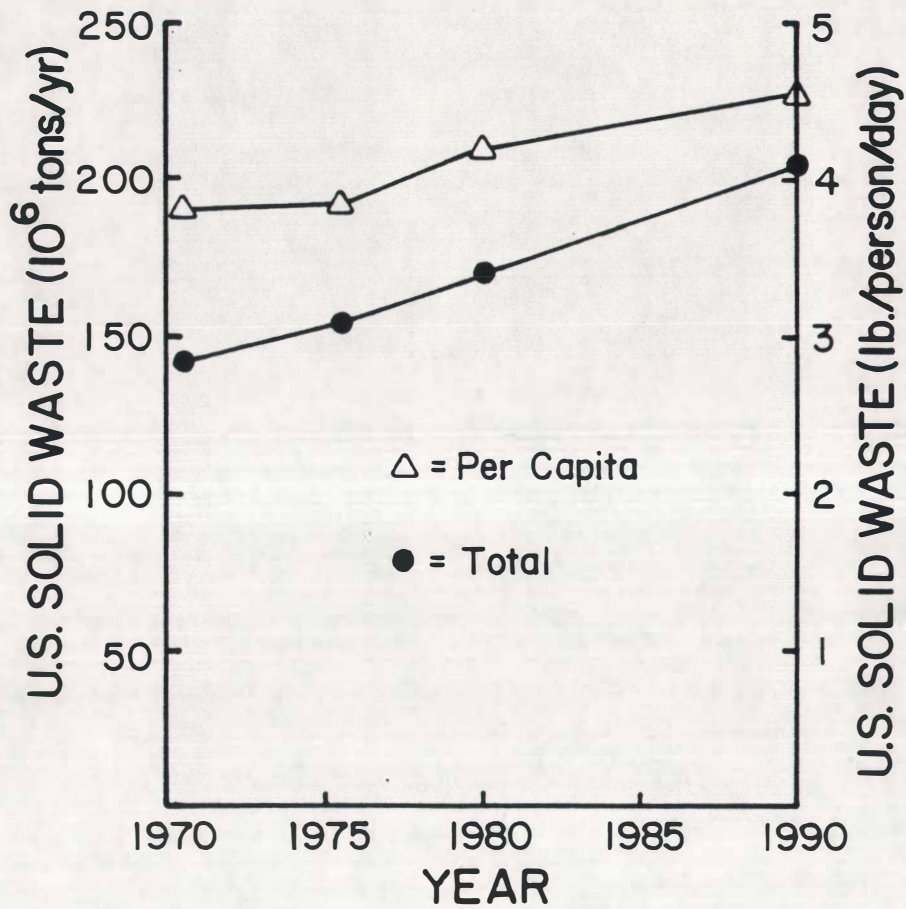


Figure 1. Qualitative comparison of costs for direct haul of refuse to the disposal site and a transfer operation (after Haggerty et al., 1973).



designed to accomodate traffic, vehicle emissions may actually be increased because of delays to other vehicles in addition to the refuse collection trucks. In this case the transfer facility will become a point source for vehicle emissions and any surrounding areas may be adversely affected. Other potential hazards associated with improperly designed transfer facilities include odors, vectors, and litter.

In a detailed study of Texas transfer facilities, Kimball and Weaver (1984) concluded that a properly located and built transfer facility will have minimal environmental impact on the surrounding areas. In fact, people living in the immediate vicinity a transfer station are, in many cases, not aware of the existence of the facility. The authors of the study concluded that an acceptable transfer station should include the following features in addition to those suggested purely for the purposes of aesthetics (see Kimball and Weaver, 1984 for complete details):

- (1) All dumping containers should be inside a main building to reduce blowing trash from outside dumping.
- (2) Water sprays, fans, and/or vacuum collection should be employed to control dust and odors.
- (3) An 8-12 foot tall fence should be built close to the main building to provide effective control of blowing litter. The entire property should be surrounded by an additional fence for additional litter control. The outer fence should have inside vegetation to screen the facility from the general view of the public. Both fences must be policed on a regular basis to remove accumulated litter.
- (4) Traffic control signs and personnel should be used to prevent congestion problems and traffic accidents.
- (5) Trucks should not be allowed to park on the grounds unless covered, garage-style facilities are provided.

Figure 2 shows a transfer station that was designed for

use in Sacramento, California with these features in mind (Bracken et al., 1981). In this case a dirt mound with trees surrounding the entire property constitutes the vegetation screen to hide the transfer facility from view on the outside. Personnel hired for the facility are for grounds and building cleanup, traffic direction, operation of weighing scales, and equipment maintenance. Several other design features of this facility were incorporated to reduce environmental impacts.

Service vehicles and empty refuse collection trucks leave the transfer station in figure 2 by a separate route from the loaded trucks, to reduce traffic congestion problems. Other types of transfer stations may have separate loading areas for refuse collection vehicles and for individuals from the community to further reduce traffic congestion (Smiley, 1984). Scales located at the entrance of the facility for refuse collection trucks determine the weight of the refuse dumped by vehicles as a basis for charging customers and for future decisions regarding transfer station expansion. Refuse is usually dumped into a hopper, where conveyor belts load material into two stationary compactors. The compacted load is then mechanically transferred to transfer trailers. A floor storage space built into the facility is meant for peak loading times, when the stationary compactors cannot accommodate the entire flow of refuse into the facility. This floor storage area reduces traffic congestion problems during peak hours of operation. Use of a floor dumping area also gives transfer facilities an area that can be used for

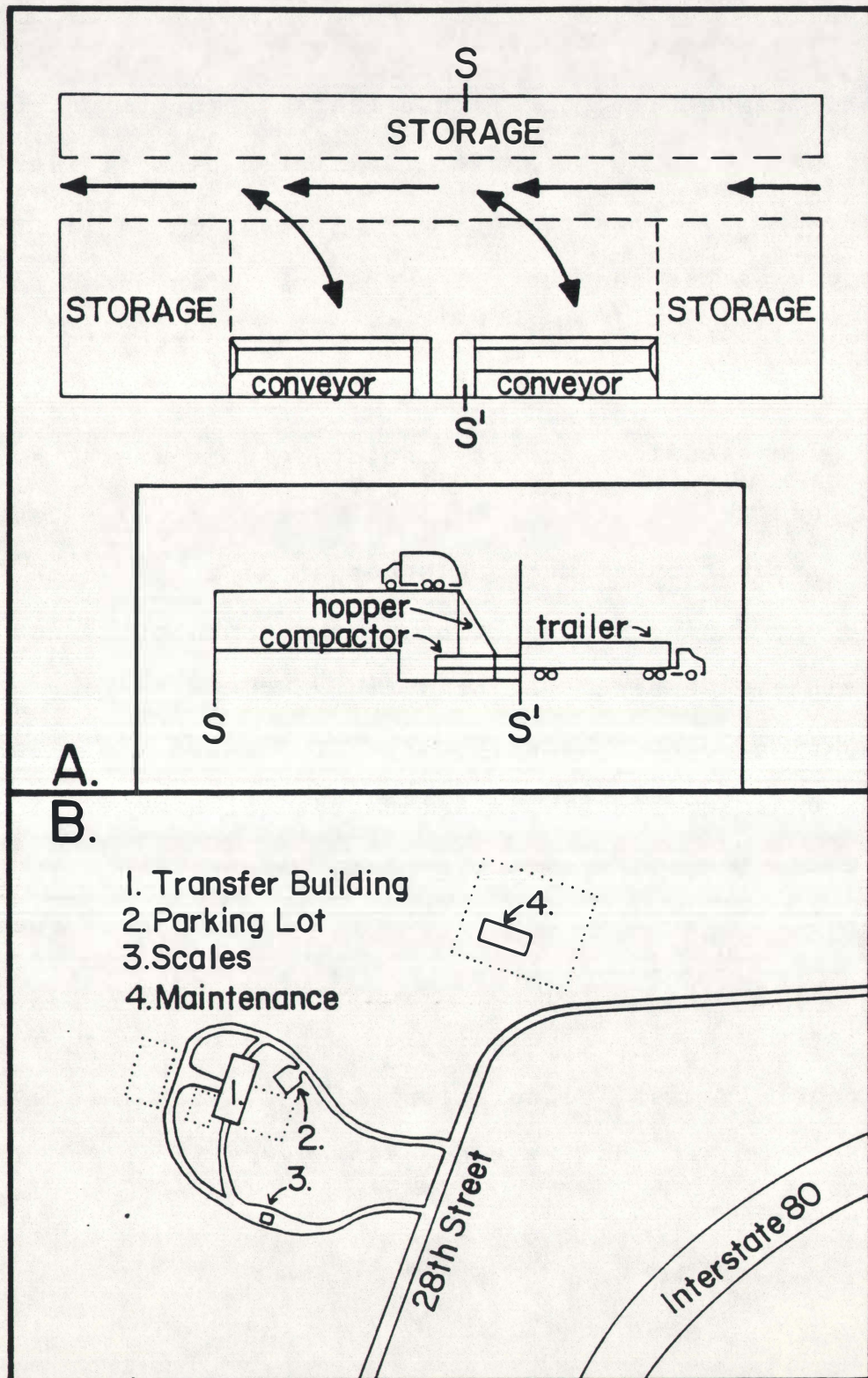


Figure 2. Design of a transfer facility for Sacramento, California (after Bracken et al., 1981); A.) The transfer building (arrows show the flow of traffic); B.) The transfer facility site (dotted lines show locations of buildings for possible

separating out materials to be recycled (Smiley, 1984). Separate containers may also be designated for recyclables in small communities where a substantial proportion of refuse is transported to the transfer facilities by individuals (e.g., Roth, 1983). Simultaneous use of transfer facilities as waste disposal sites and recycling centers is intended to reduce the total flow of materials to landfills, thereby increasing landfill life.

The transfer facility depicted in figure 2 has been designed to include the capability for future expansion so that separation of materials deposited at the site for energy recovery during incineration of the combustible components is possible. Combined use of a transfer and incineration operation may increase the significance of the site as a source of emissions. Emissions resulting from the incineration process must be balanced against the reduced travel of trucks to the disposal site, and consequent reduced truck emissions, to determine the total environmental impact in any given case. Calculations presented below suggest that, in general, mass incineration will have far more significant effects on air quality than even a very large number of refuse collection vehicles.

#### NEW YORK CITY: A CASE STUDY

The New York City refuse collection operation has gone through many recent changes due to economic problems mentioned before. Data quoted in this section regarding the details of the refuse collection operation, as it is now organized, were

taken from Steisel (1983), NYCDOS (1984, 1985), Public Works (1984b), and several personal communications with the NYCDOS (Deputy Commissioner Ronald Contino, in particular). The refuse collection operation is handled so that all residential refuse collection is done by municipal employees and all commercial and industrial collection is performed by private haulers. The private haulers transport waste to disposal sites in New Jersey. The Department of Sanitation, headed by Commissioner Norman Steisel, is in charge of residential refuse collection, street sweeping and snow removal. Residential refuse constitutes roughly 81% of all refuse generated in the City.

#### Details of Refuse Collection-

Table 5 gives the composition of the truck fleet used for refuse collection by the NYCDOS. Prior to 1980, there were no sideloaders in the fleet, whereas today these vehicles comprise roughly 25% of all trucks. The sideloaders were initially used only in low refuse generation areas of Staten Island and Manhattan, but are now dispersed throughout other areas of the City. The volume capacity of trucks ranges from 20 cubic yards for the older rearloaders to 25 cubic yards in other trucks. Each truck collects about 10 tons of refuse per day and makes a single trip to the disposal site. Trucks travel an average of 15 total miles per day. High truck volume and weight capacity (compare with Table 4) as well as careful routing considerations (discussed below) lead to a

Table 5. The refuse collection fleet operated by NYCDOS

Vehicle	Number in Fleet
Rearloader	1,743
Sideloader	498
Frontloader	76
Roll Off	13
<u>Total</u>	<u>2,331</u>

very efficient overall collection operation.

All of the NYCDOS refuse collection vehicles have diesel powered engines, which deliver an average of about 2.5 miles per gallon fuel efficiency. These trucks constitute the second highest source of diesel emissions in the City, next to buses. There are about 5,600 diesel powered buses which travel the streets and highways of the City daily (Natural Resources Defense Council, 1985).

Routing of trucks in New York City is done by computer simulation, such that all routes are balanced according to tonnage and total operation time. Each household is serviced an average of 2.5 times per week, which is high in comparison to most other cities in the United States. High collection frequency is necessary because of the high population density in New York City. Collection frequency has actually declined from 3.6 collections per week in 1975. This reduction in collection frequency was necessitated by budget cuts that took effect beginning in 1974, as discussed previously.

The NYCDOS employs in excess of 150 mechanics to maintain collection vehicles on a routine basis. Vehicle maintenance costs average about \$12,000 per truck every year. All trucks are cleaned daily to remove nuisances and aid in vehicle maintenance. As a result of careful truck maintenance, an average of only about 10% of the truck fleet is out of service at any one time. This corresponds almost exactly with the number of trucks kept on standby to compensate for downtime, and only 2-3% of all scheduled collections are missed each year. This percentage is down from the 15% missed collection

frequency recorded in 1975, when truck maintenance took on a lower priority.

The New York City collection and disposal system is unique relative to other operations in the United States from the standpoint of transfer stations. A total of nine transfer stations are located strategically throughout the City and all of these are barge, rather than truck, transfer facilities. Barge transfer stations are necessary because the majority of all of the New York City refuse is disposed of at the Fresh Kills landfill, located on Staten Island. Truck transport would add enormously to the City's traffic congestion problems. Refuse from collection vehicles is dumped into the barges, which have capacity for approximately 650 tons each. Cranes remove the refuse from barges for tractor-trailer transport to Fresh Kills. The City recently purchased 45 new barges, bringing the total number in operation up to 100.

Use of a large number of transfer facilities in New York City translates into an average haul distance for collection vehicles of 7 miles, which is very low in comparison to the national average of 10.2 miles quoted previously. There are, however, disadvantages of the heavy reliance on barges for refuse transport. The 1979 strike of tug boat operators cost the City in excess of 4 million dollars because of the extra transport distance required to take all generated refuse to the Fountain Avenue landfill in Brooklyn, the only other major landfill in New York City. The latest plans of the City are intended to reduce this heavy reliance on a single mode of



refuse transport, by implementing more truck transfer stations in combination with planned resource recovery facilities.

#### Environmental Impacts of the Collection Operation-

Some of the indirect environmental consequences of the refuse collection operation in New York City have already been mentioned briefly. Street sweeping and refuse collection are coupled because these operations are controlled by a single budget. It is necessary for the collection operation to be as economically efficient as possible so that street cleanliness is not adversely effected. The budget cuts of 1974 resulted in a decline in the percentage of streets rated "acceptable" or better by Scorecard (a monitoring system implemented by the Mayor's Office of Operations) from 75.2% in 1975 to 53.0% in 1980. Once the refuse collection operation was revamped as described previously this percentage rose to about 61% in 1983. Because of the frequency with which refuse collection vehicles are washed, there have been no widespread complaints regarding vectors, odors and litter emanating directly from trucks. From an environmental standpoint, the New York City refuse collection operation appears to be operating at a near-optimum level in most cases.

In most cases it is difficult to quantify the exact environmental impact of a refuse collection system. This is not the case for vehicle emissions, which are regulated by federal legislation, as mentioned before. Maximum total emissions rates for regulated pollutants can be calculated from the federal standards knowing the total number of trucks

on the road and travel time per day. There has been growing concern over the planned use of mass incineration combined with resource recovery in New York City due to potential air quality reductions, and it is relevant to ask how these facilities compare to the refuse collection operation in terms of pollutant emissions.

Table 6 compares selected pollutant emissions projected for the mass incineration facility which is planned for construction at the Brooklyn Navy Yard with those from the entire refuse collection fleet in New York City. Emissions from the Brooklyn Navy Yard facility are estimates taken from NYCDOS (1985). Total truck emissions were calculated in most cases using current EPA standards in grams/horse-power/hour with: (1) an estimate of 200 horse-power for the average collection vehicle, (2) fifteen miles of travel per day for New York City trucks, and (3) 2,331 trucks (Table 5) moving at an average speed of about 4.5 miles per hour (NYCDOS, pers. comm., 1985). Particulate emissions were calculated from the EPA standards that will go into effect in 1988 (U.S. EPA, 1985), and are probably minimum values for 1985 emission rates. Total tetrachlorodibenzo-p-dioxin (TCDD) and 2,3,7,8-TCDD emissions were calculated from the particulate emissions using the dioxin concentrations in diesel particulates given by Bumb et al. (1980). These compounds are included here because of the availability of data and because the compounds are some of the most toxic and carcinogenic substances known to man. All total emission rates are probably correct to

Table 6. Projected pollutant emissions from the Brooklyn Navy Yard (BNY) resource recovery facility compared to emissions calculated for the entire New York City Department of Sanitation (DOS) refuse collection fleet.

Source	Tons per Year*					
	CO	NOx	HC	TP	Total TCDD	2,3,7,8-TCDD
BNY	366	2973	65.7	161	$3.7 \times 10^{-5}$	$2.4 \times 10^{-6}$
DOS Trucks	6916	4774	580	268	$6.2 \times 10^{-9}$	$8.0 \times 10^{-10}$

\*CO = carbon monoxide, NOx = total nitrogen oxides, HC = total hydrocarbons, TP = total particulates, TCDD = tetrachlorodibenzo-p-dioxin.

within about an order of magnitude because of the assumptions involved in calculations. This level of accuracy is sufficient for the comparisons made here.

Table 6 shows that although total emissions of most pollutants from refuse collection trucks are greater than a single resource recovery operation in New York City, differences between the two sources are not large. Also, projected dioxin emissions from the resource recovery operation are several orders of magnitude higher than those calculated for refuse collection vehicles. Because of major problems that may be caused by dioxin emissions (see, e.g., Commoner et al., 1984), these data indicate that concern over air quality in New York City is properly directed mainly at the disposal end of the waste collection and disposal system. Also, since New York City should be among the top cities in the country in terms of refuse collection vehicle emissions, because of high population density, this assertion should apply to most regions of the United States. From these observations, it would appear that the best policy at the present time is to optimize economic aspects of refuse collection to ensure that finances are available to upgrade pollution control in incinerators and landfills, where the more serious environmental problems occur. Optimization of economic aspects of refuse collection will usually not occur at the expense of environmental aspects because of federal regulations and the coupling between economics and environmental concerns discussed throughout this report.

## CONCLUSIONS

Most of the recent trends in refuse collection procedures used in municipalities of the United States are dictated primarily by economic incentives. Communities are moving toward more cost effective refuse collection organization systems. Automated sideloader collection with large volume trucks and stationary containers are either being used or considered for future use in many areas of the country because such collection systems may minimize labor, fuel, and maintenance costs. Transfer stations are becoming more abundant as waste disposal sites become more remote from the areas where refuse is generated.

In most cases, economic and environmental concerns are coupled such that the economic factors combined with federal regulations ensure that refuse collection results in minimal environmental impacts. Most of the environmental problems caused by refuse generated in communities occur as a result of operations at disposal sites. An added benefit of optimizing economic aspects of refuse collection procedures should be that finances, which might otherwise be tied up in refuse collection, will be available for pollution control at disposal sites.

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