To set then the stage for an analysis of transportation systems with respect to waste removal, one has to recognize that waste by definition has no economic value. This suggests that high-tonnage low-cost transportation carriers be utilized as much as possible. Constant cost reduction must be made the only objective for progressive waste management, if mere disposal and not utilization is the primary waste management goal.

Furthermore, all currently known waste disposal methods ultimately require land for a disposal ground. But in urban areas land is in short supply and in demand for more attractive and productive uses. In turn, waste has to be shipped out of such areas over ever-increasing distances and, consequently, bulk transportation facilities become more and more important as the backbone of waste removal efforts.

What then are the basic elements of transportation systems that must be considered in waste removal applications?

In a nutshell, and this is important, transportation can be highlighted as a material- or people-handling system. In this presentation, of course, we deal only with the movement of materials, although materials are and can be moved over pure "people" transportation systems such as local transit lines.

A transportation system can be described as a method of movement by which things "flow" through a system. In terms of movement, things may be handled: (a) horizontally, by such means as trucks, trains or barges; (b) vertically, by elevators or chutes; and, (c) vertically as well as horizontally, by helicopters, conveyors, and pipelines operated either hydraulically or pneumatically.

The actual movement of things is constrained by the physical facilities of a transport system, i.e., the channels of the network. The physical facilities, in turn, may be grouped into the fixed installations of the network, e.g., railroad tracks, roads, and river channels, and the mobile equipment. Thus the available transportation capabilities determine, to a large degree, what kind of transport system can be used in handling the wastes for a given area.

Not all transportation systems, of course, have mobile equipment as such. Pipelines and conveyors as a rule do not have "vehicles," and there is a direct interface between the materials being moved and the fixed system installations. On the other hand, in transportation systems having mobile equipment, the vehicles might be considered containers which provide the interface between the items transported and the fixed installations. The kind of transportation vehicles that are available carries considerable systemic implications. The "vehicles" available determine, for example, whether wastes ought to be liquified, baled, containerized and/or reduced in size in order to obtain maximum system benefits.

The interface structure of a transportation system is of utmost importance in determining the suitability of a given system for waste removal purposes. Whether, for example, industrial, commercial and special wastes such as hospital wastes can be included. Commonly, refuse transportation requires a system to handle a wide variety of materials of all sizes, capable, to various degrees, of "contaminating" the environment. Public health and sanitation aspects must therefore be of overriding concern.

The transportation network itself may be viewed in a building block fashion. It consists of links and transfer points. A link corresponds to a specific transportation channel and may be well defined as, for example, in the case of a rail line or highway. Links of the same, similar, or different modes of transportation may cross each other as, for example, by a railroad crossing or a bridge, or they may provide an interchange as, for example, in a road junction, airline terminal or railroad switching yard. Considering transportation as a building block system, it becomes obvious that the waste management system planner must evaluate many transport alternatives to develop an approach which is tailor-made for a given area.

Ultimately, of course, links to transfer stations where the materials are moved on or off a given transport network. Such a transfer might involve either a change from one mode of transport to another, for example, from trucks to rails or the original loading and final unloading operations. The transfer of materials frequently represents a major share of the total direct operating cost of transportation systems.

Finally, the path of materials being moved through one or more transportation networks might involve a succession of links and transfer stations. In this way networks and/or vehicles interact over space and time, and the selection of an optimum total transportation system might require a considerable amount of network balancing. Factors, such as the following, typically are involved: total trip time, reliability of service, time and effort spent at transfer points, safety considerations, direct operating costs and indirect expenditures such as insurance, interest and storage and impact on the environment and its inhabitants.

Thus, in analyzing existing and potential transportation systems for refuse removal applications, one must consider: the types and amounts of the materials to be transported; the feasibility of transforming the wastes to facilitate transport, and the point of storage and collection; the vehicles and/or ways in which the materials are conveyed; the networks through which the materials move; the number and type of transfer stations needed; the public health, sanitation and safety requirements; and, of course, the time and cost charges.

In dimensioning the waste material handling or transportation system for a given area, it is necessary to make, first, some basic decisions concerning the local refuse removal policies. Questions such as the following must be answered *a priori*:

(1) How large is the area to be served by the system? Are we concerned with only Washington, D.C., proper, which had a population of 764,000 people in 1960 (according to the U.S. Census)? Or is the system to serve the Washington Standard Metropolitan Statistical Area, which had a population of more than two million at the time indicated and was growing at a rate of 36.7 percent per Census decade?

(2) Should the refuse removal system handle all the wastes generated including residential, commercial, industrial and special wastes, or should it deal only with selected categories of refuse such as the residential/municipal wastes?

The composition of residential wastes alone — those generated by the householder — already provides considerable transportation problems. Excluding abandoned automobiles, for example, Washington trucks annually have to remove about 6,700 bulky metal objects such as refrigerators, washing machines, bed springs and oil drums. It is estimated that appliance dealers and private collectors haul an equal quantity of such objects to the disposal sites. In addition, there are putrescible materials, paper, glass bottles, aerosol cans, paint containers, tires, rags, and, of course, automobiles.

Furthermore, the District of Columbia ranks among the major industrial/commercial centers in the United States. In 1965 it had almost 17,900 commercial/industrial establishments covered by the Federal Insurance Contribution Act. This means at least one and probably several pick-ups from each of such establishments every week. These provide employment for almost 305,000 persons. Major business groups in the District produce a variety of waste materials and in 1965 included the following:

TABLE I

BUSINESS GROUPS IN THE DISTRICT PRODUCING WASTE MATERIALS

Business group	Number of employees	Reporting units
Total	304,941	17,879
General construction (demolition wastes)	26,262	1,015
Manufacturing	23,495	689
Food and kindred products (garbage)	4,559	54
Printing and publishing (paper)	13,861	343
Wholesale trade	21,848	1,334
Retail trade	65,839	3,850
Eating and drinking places (garbage)	18,938	1,002
Services (paper, garbage and medical wastes)	104,483	7,038
Hotels and other lodgings	10,810	253
Misc. business services	15,311	849
Medical and other health services	11,539	1,241

It must be remembered in this context, that types of employment not covered by the Social Security Program are not included in the above data. Thus, government employees, self-employed persons, farm workers, and domestic service workers are not covered in the foregoing tabulation.

Finally, the amounts of wastes to be handled through a transportation system depend also upon the waste disposal practices utilized or required at the point of waste origin. Grinding transfers the wastes into the sewer system and home incineration reduces the volume and the frequency with which wastes have to be picked up.

(3) The third set of questions addresses itself to the spatial distribution of waste generating units. A high concentration of such units as, for example, in high-rise buildings or large city apartment blocks, might suggest the establishment of vacuum, chute, or similar collection and transport systems. One-family housing settlement patterns, on the other hand, probably require that the collection and at least part of the total transport be handled by truck. Data from the 1960 Census of Population and Housing indicate wide spread density patterns for Washington, D.C. proper on a Census Tract basis. Correspondingly, they suggest some significant spatial differences in residential waste generation. Data for selected census tract settlements range as follows:

Number of rooms per housing unit: 1.2 to 7.5 rooms

Number of persons per housing unit: 1.1 to 4.1

Median family income: $2,912 to $19,815

Consequently, the intracity waste handling and transportation requirements might vary considerably if a system is to be devised which serves all areas on a tailor-made and highly desirable basis. High density areas, for example, might suggest the application of an integrated container system starting at the point of waste origin while low density areas might continue to do with the common garbage can or disposable paper or plastic sack. Industry has developed various types of waste collection and transport equipment to meet the requirements of different urban settlement patterns.

(4) The fourth set of questions, of course, must deal with the area's existing and the potentially available total transportation systems. The Washington transportation system reflects the fact that the District of Columbia is the seat of the Federal government.

The Washington, D.C., area is traversed by three railroads and the Potomac River. In addition, there are many highways leading in and out of the area. A 25-mile subway system costing some $431 million is planned for the metropolitan area. It is conceivable that it could be used during the night-time hours as part of a waste transportation system. The existing incinerators and landfills might also provide readymade locations for transfer stations.

The existing mass transportation system of railroads and rivers serving the Capital connects the area effectively with the outlying regions in which the ultimate disposal of wastes might take place. This could conceivably be accomplished on a long-range basis by all-round desirable and advantageous methods. The present Washington transportation system, with its highways, railroads and the Potomac River, thus allows the waste removal planner a wide range of alternatives for system development in terms of both the mode of transportation and the ultimate destination. This view is based on the belief that: (a) wastes can ultimately be disposed of in an unobjectionable manner; (b) wastes can often be used to increase the value of marginal land; and, (c) since there is widespread public opposition and fear to the mere thought of living near a waste disposal facility — as if it were an ammunition dump — they should be located as far away from high-density population centers as is economically feasible.

(5) The fifth and final set of major questions concerns the system participants. It must determine who is to operate which part of the system, who is responsible in what way for total system performance, how the burden of

cost is to be distributed, who might provide the waste inputs, for example, private collectors, municipal forces, and/or self-disposers such as a private citizen coming with his station wagon and a can of grass clippings on a Sunday afternoon. Last but not least, it must be determined how the wastes must be delivered to conform to specific system requirements, for example: should the wastes be packaged, baled, or pre-containerized. Should they be put in paper sacks or metal and/or plastic cans, etc.? This involves the regulation of human behavior so the system can function with a reasonable degree of efficiency.

It is obvious that answers to the above questions and subquestions do have considerable systematic implications regardless of what transport and material handling system one uses.

It is also obvious that the selection and development of any system will materially affect the livability of any given area. Every community represents, however imperfectly, a system for living and simultaneously an engineering system. Only the interaction of both systems make the parameters of community life and growth.

Furthermore, it is obvious from the presentation thus far that refuse-removal-material handling and/or transport systems are very complex and have numerous ramifications. The transport system begins with the on-site storage of wastes at the point of origin. The refuse originator is part of the transportation system if he has to bring his garbage can to the curbside at a predetermined time.

In view of the many system elements and the potentially large number of system performance factors, it is impossible for me to cover the subject in great detail. Time limitations suggest that this presentation's primary purpose is to discuss the subject in terms of current knowledge and suggest promising areas for imaginative research. Only system development work, including techno-economic and socio-economic as well as management analyses, will produce results which will make this area's waste removal a showcase for the nation and for the world as well.

In looking, then, at specific transportation systems with respect to waste removal operations, it must be recognized that basically three system development approaches are involved: (a) The transfer of existing technologies "as is" into the waste removal field. Such technologies might come from other fields of commercial/industrial endeavor or the vast U.S. Government research and development efforts including, in particular, Public Health, NASA, and Department of Defense projects; (b) The development of these technologies in terms of specifically tailor-made waste removal applications; and, (c) The long-term development of perhaps completely new technologies which would turn the current nuisance of wastes into a useful national resource. It does no harm to apply visionary thinking and objectives to a mundane problem such as refuse removal. We must have the courage to direct the promise of research wholeheartedly toward the solution of our everyday problems, and we also must have the stamina to back up our courage through generous action. It is a sorry situation and a poor reflection on our sense of values that we stand on the threshold of putting a man on the moon but still handle the wastes we produce using methods developed during the horse-and-buggy era. The state-of-the-art has not yet advanced to the point where it can be regarded as a sophisticated waste disposal management science. But with the impact of the Solid Wastes Program things have begun to move and significant progress is being made to employ the opportunities modern science and technology do offer. The success of research in other areas, given only firm and urgent objectives, most certainly justifies any conviction or hope we might dare to have.

Specific existing material handling and transportation system can, of course, cover a potentially wide area and only some selected highlights can be given here.

There are pipelines, for example, and piping systems could, considering the community as an engineering system, originate right in the housewife's kitchen. Existing technology in the field is highly developed. Even solids in the state of slurries are moved with success. However, initial capital costs are high and efforts toward the acquisition of right-of-ways may be frustrating. On the other hand, operating costs are quite low, amounting to roughly pennies per ton/mile for all kinds of materials moved.

Piping systems can be operated pneumatically or hydraulically. The Federal government, through the Public Health Service Solid Waste Program, currently is sponsoring research which considers a water/sewage borne system and a 30 to 40 percent solid slurry for center city applications and a pneumatic system for the outskirts of settlements. The systems, of course, must operate under pressure since refuse loading changes water and sewage into a very complex fluid. In principle, materials can be piped over unlimited distances and it has to be determined where economics require cutoff points.

Pipelines are used or considered for all kinds of materials which are transported in large volumes. Coal, for example, is moved 110 miles by pipe into the Cleveland area. Today, there are about 20 phosphate rock pipelines in the U.S. handling over 30 million tons of rock per year. These lines are 14 to 16 inches in diameter and range in length up to 5 miles. Solids lines have also been built to move gilsonite, limestone and borax. According to present technology, however, it is required that the solids do not undergo any undesirable change, including flow characteristics, as a result of the mixing of the solids and liquids or of the transportation process itself.

Pneumatic systems have been tested in Sweden. A system has been recently established in a large housing project which will ultimately include 2,600 dwellings. This system moves refuse, by suction, at a speed of about 90 feet per second in pipes of about 2 feet in diameter. The vacuum in the system is created by electrically-driven turbines. It moves the refuse from selected system channels at predetermined times and one vacuum unit thus can serve a great number of channels depending, of course, upon the rate of channel loading. Pipe systems extending a distance of up to about 2,500 yards are currently visualized. This concept is currently being considered for installation in a large housing project in Westminster, England. The capital cost per flat (apartment unit) is calculated to run about $310, while the annual operating costs are estimated to range from $12 to $15 per unit.

The advantages of pipe systems for local collection activity are numerous despite the heavy original investment requirements. Pipe systems require little labor, they can move the wastes to storage areas which are conveniently accessible through a 24-hour day including weekends, and there is no spillage, smell or noise. Although pipe systems may not be economical today if compared with other more conventional collection systems, the picture may change in the near future as refuse quantities and collection cost continue to increase. In waste disposal transportation systems we deal with service life spans of 5 to 8 years for refuse trucks and 20 to 30 years for incinerators.

I might also point out, in passing, that other factors besides cost alone should be considered in determining the type of waste disposal system that would serve the best interests of the community. For example, the pneumatic pipes referred to above could conceivably be installed in utiladors which would contain water mains, electric power lines, telephone lines, sewers and drains as well as postal tubes. They could be designed for easy access by covering them with prefabricated slabs which could serve as sidewalks. This would eliminate the need to inconvenience the motorist by noisy road opening operations when it becomes necessary to repair utility lines and also eliminate the garbage container and the noisy refuse collection operations. This concept, it seems to me, should be tried out at an early date in a high density urban area under the Model Cities Act.

Another means of moving wastes from high density and highly congested areas may be cargo helicopters. Helicopters capable of conveying payloads of several tons are available. Their operating costs range around $3 to $5 per aircraft per mile depending, of course, upon the total amount of miles flown. Cost per ton per mile may amount to only $1.50 to $2.00 and perhaps even less, if helicopter advances developed for use in Viet Nam reach the civilian market. Helicopter transport already is employed successfully and profitably for industrial applications in the building of power transmission lines.

However, the purchase price of helicopters is rather high. Many helicopters are still made to order. Helicopters which are most commonly used by the Marine Corps in Viet Nam and by the Viet Air Corps cost about $225,000 per unit in civilian markets. By contrast, crane-type helicopters which are not yet commercially available and which are capable of carrying 50 people or a 10-ton payload may cost up to $2 million per unit. Twin-turbine helicopters capable of flying 25 people and already in commercial use cost about $600,000 to $800,000.

Thus, helicopters may be utilized in only specific operating conditions where, for example, traffic density and congestion does not permit the operation of collection vehicles at an acceptable pick-up and transport performance level.

The long-distance transportation of bulk materials is primarily the domain of railroads and barges. Comparing in turn the spatial service restraints of barges and railroads one finds that railroads are more ubiquitous. Thus railroads offer more options in terms of both the communities and people to be served directly and the selection of diverse disposal sites. Railroads are also capable of moving large tonnages, generally up to 150 tons per vehicle, and thousands of tons per train, at high speeds. However, the District is situated along the Anacostia and Potomac rivers. Depending upon land reclamation opportunities along the river or the advancement of ocean disposal techniques, barges might provide waste removal service, perhaps for a selected part of the materials such as demolition wastes.

To give an order of magnitude for the ton-mile cost of barging, it may be stated that depending upon the number of barges being towed, speed, upstream or downstream transport of wastes, the ton-mile cost may range from $0.005 to $0.025.

Barges cost about $90 per ton of carrying capacity. The most commonly used barge is about 195 feet long and 35 feet wide and has about a 3-foot draft. However, there are also jumbo barges which are considered most efficient for large-scale operations because they have a carrying capacity from 1,000 to 1,500 tons. In evaluating barge cost as well as highway and air transport cost, one must recognize of course, that a significant share of the actual transportation cost is borne by the national investment in each form of transportation.

Railroads, of course, have a varied experience in the mass transport of materials and the corresponding loading and unloading of cars. Goods are handled through roll-on/roll-off, lift-on/lift-off containers through unitizing or the stacking of containers, through gravity loading or unloading, and through hydraulic or pneumatic pressure. Railroads are characterized by a high fixed investment in trackage while the rolling stock needed for the handling of refuse might be relatively inexpensive. A covered hopper car capable of carrying a payload of about 80 tons costs about $25,000. Rail transportation costs depend, of course, to a large degree, upon the tonnage hauled. Recent proposals made for the hauling of refuse over a distance of 80 to 100 miles quote a rail rate of $2.75 per ton at the rate of 1,000 tons per day and $2.15 at 3,000 tons per day. The latter is based on the use of three transfer stations, but excludes the transfer and disposal costs.

Transfer stations appear to be the key to the "long-distance" transport of refuse since the loading operations start the long-distance section of a transport system. Transfer stations can be designed as stationery or mobil units and they might utilize a variety of material handling techniques such as conveyors, presses and rams, pumps, air power systems, vibrators, containers including the corresponding loading and unloading devices, the air-cushion handling of unitized loads, automated storage and retrieval of containers including dockside prepositioning devices and the necessary instrumentation such as weighing and identification devices to aid management in running the system at peak efficiency. Depending upon the equipment used and the amount of refuse to be handled transfer stations may require investments from $80,000 up to $1 million excluding land cost. Operating cost, of course, vary with the volume. A recent railroad proposal estimated the transfer station cost at $0.42 per ton at a handling volume of 500 tons daily and at $0.22 per ton at a 1,500-ton daily volume.

Finally, almost everyone is familiar with the U.S. truck and trailer systems. The existing state of technology offers vehicles capable of carrying 120,000-lb payloads. But few states permit these 60-ton payload rigs on their roads, and highways designed to carry heavier loads will be required if greater loads are to be carried by this mode of transportation.

Gross operating cost per vehicle mile for gasoline and diesel engine powered trailer combinations range from about $0.35 at a loaded gross weight of about 22,000 pounds to about $0.65 at 120,000 pounds and $0.90 at 180,000 pounds. The average payload for a 22,000-pound trailer combination is about 7 tons; for 120,000 pounds loaded gross weight, about 40 tons; and for 180,000 pounds, about 60 tons. The cost per ton-mile for freight-hauling trailer combinations, traveling at a minimum average speed of 50 mph, range from about $0.05 to about $0.015 if the trailers are fully loaded. Trailer combinations, of course, are a means for long distance hauling and total transport system cost must include the transfer station cost as well as the local collection cost. The transportation cost, excluding depreciation of equipment, of a typical 18- to 22-cubic-yard packer truck carrying from 3 to 4 tons of compacted refuse, is estimated at $0.35 to $0.40 per mile.

The available basic means of transportation offer a large number of application alternatives for refuse material handling and transport systems. Local waste piping systems, for example, might be integrated with railroad tank cars. Helicopters may be used in conjunction with railroad or highway vehicles. Each system, of course, can be operated independent of the other. The coordinated management of transportation systems might lead to salvage opportunities which will not exist if wastes continue to be handled by a multiplicity of small-scale operations.

In the end, of course, every solution will be a local solution. Today's existing and potential available technology offers many alternatives for imaginative applications. Not all solutions will cost out the same, and economics must play an important role in system acceptability. But cost and objectives are relative and vary from locale to locale. What may be prohibitive for one area might provide the very remedy for another area.

In conclusion, I would like to commend the equipment manufacturers for the ingenuity they have displayed in developing new and improved products to serve this important field of activity. The Solid Wastes Act of 1965 has helped to generate the kind of constructive thinking that will, I am sure, lead to some significant breakthroughs in the development of new concepts, as well as, the application of technology used in other fields to the age-old problem of handling and disposing of solid wastes.

LAND RECLAMATION

Frank R. Bowerman *

THANK YOU, MR. CHAIRMAN. Ladies and gentlemen: I would like to direct my comments this morning toward the theme that has grasped me with increasing conviction during these past 20 years of fairly close familiarity with solid wastes problems. That theme is that solid wastes can be considered an asset, rather than a liability if we will only release our thinking from older stereotyped patterns. A profound change occurs in our consideration of solid wastes when we turn from an assessment of the problems attendant upon routine collection and disposal, and start thinking about the potential solutions that can be found in the imaginative and constructive use of solid wastes. Some of these potential solutions lie in sanitary landfilling. That is the focus of my discussion this morning. But that is not to say that we cannot find plus values for solid wastes in other areas of disposal: For example, the recovery of waste heat from incineration; the obtaining of useful humus for soil building through composting; and the salvage and recovery for further use of metals, glass, rags, and other discards from our affluent society. Note how different our approach becomes when we start to consider the possibilities that lie in such planning. I would very much hope that the theme of this conference becomes much more than a consideration of the problems and solutions for solid wastes management in the District of Columbia; rather, that the conference direct its attention toward the optimization of solid wastes management here and in the region surrounding the District, so that this area becomes the national showcase for solid wastes management and points the way for the rest of our nation. Is this an impossible dream? I don't think so. We dreamed a dream in Los Angeles County in 1949 and by 1956, some seven years later, we had converted that dream into a reality. You see, dreams only provide the challenge; it is hard work and perseverance that provide the reality. But dreams can become real, and I'd like to show you by way of some slides the simple but effective techniques that I helped develop in using sanitary landfilling for the construction of parks, golf courses, and botanic gardens in Southern California.

One of our prime criteria was that the sanitary landfills would be operated just as though they were a private business. Governmental agencies can

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* Assistant to the Vice-President — Development. Aerojet-General Corporation. Mr. Bowerman's entire presentation was made while using slides for illustration.

do this if they set their minds to it. In our case, each of the sites became self-sufficient through the charging of prices for disposal. The hours were established just as with any business establishment. In the interest of the people around the various landfills we closed on Sundays, so that there would not be any activity on those weekend days when most refuse collection activities have ceased. The hours of opening were such as to protect the people during the evening and early morning hours against the noise that comes from a sanitary landfill. Each site has its own weigh-scale facilities, so that the charges are assessed directly on a tonnage basis. A distinction was made between "difficult-to-handle" materials, such as tree trunks, refrigerators and the like; the price for that is double the normal price. Currently in Los Angeles County the cost for refuse disposal is $1.25 per ton — that's the charge, not the cost; most of the large landfills in Los Angeles County are operating at costs of around 60 to 70 cents per ton, including overhead and all charges. So these are actually making money; government makes a profit. But the Sanitation Districts commit that profit back to a useful public purpose and the moneys which are surplus to the needs of the operation are being put into a reserve fund for buying more land as the existing landfills are used up. At the larger landfills there are two, and in one case at a very large landfill, three, weigh-scales, since if the customer is to be well served he must be provided with the means for prompt weighing. We cannot have costly collection vehicles and drivers standing in long lines of traffic waiting to be served.

The L. A. County Sanitation Districts have specially designed transfer-trailer rigs for use at their transfer station. A diesel tractor pulls a semi-trailer which in turn pulls a full trailer. The two trailers are identical, the second one being converted from a semi- to full trailer by the use of a dolly. These units can carry up to 24 tons per trip, and the present state of economics in Los Angeles, and I would guess that it's not far different in the Washington area, is that by the use of this transfer equipment, remote landfill sites up to 50 miles distant from the transfer station, can be used economically as compared with costs for incineration. By that I mean a 50-mile trip out and a 50-mile trip back is about the breakpoint in Southern California for comparing the costs for transfer and landfill with the current costs for incineration. You see this extends the possibility for sanitary landfilling to a very large area.

The basic operation at Los Angeles County Sanitation Districts' Landfills calls for the dumping of the solid wastes at the base of the hill; the hill is created artificially at the commencement of the operation. By pushing the material upward, the bulldozer tracks grind, pulverize and compact the material much more effectively than if the material is placed on the top and the bulldozer simply runs over the larger, deeper mass. Good landfilling practice requires each day's operation to be sealed tightly with an earth cover of at least one-foot thickness. For areas that are to be left for a year or more between filling, two feet of earth cover are placed and for a final cover, where the operation is to be terminated with a golf course or a park or arboretum, three feet of earth are placed. as final cover.

The piece of equipment that is standard on the Districts' sanitary landfills is the Caterpillar D-8 bulldozer or its equivalent. The operator is furnished an air-conditioned helmet. This has a small cooling and heating unit attached to a flexible piece of hose that leads into a helmet which serves as a safeguard as well as to prevent the breathing of dusty air. It has been a very important factor in the operation and has protected the men against a number of otherwise bad injuries.

At the larger sites, a number of bulldozers, which weigh about 25 tons apiece, are used, and the operators become very skilled in their performance. It is necessary to go through a training period to show the men how to operate the equipment in this type of environment. It is different than the normal type of earthmoving. Many different types of vehicles are serviced at sanitation district landfills. Los Angeles County sites may be a little more difficult to operate than most of the municipal operations because they are open to the general public. When Jane and John Doe come in with a trailer load of material, they may occupy the dumping space for quite a bit of time while they push the wastes off with a shovel; special provisions must be made at a public site, which is open to everyone, as compared to municipal sites where the truckloads arrive in 3- to 5-ton lots.

The Mission Canyon Landfill site is in one of the finest residential areas in that part of Los Angeles. Homes have been constructed on undisturbed land and the fill is being carried on in the immediately adjacent area. It is interesting that the landfill was in operation before any nearby homes came into existence. When this site was planned, ridges of land were deliberately left in the hands of the private subdividers, because they were far too expensive for the Districts' purposes and earth was not needed for cover. When these pieces of land were subdivided, the question arose as to whether they would be readily saleable. The answer is that the subdividers sold most of those parcels of land at prices upwards of $35,000 per lot, averaging about three lots per acre, and the homes that have been constructed on these lots are in the $75,000- to $125,000-class. These homes immediately overlook a sanitary landfill. It sounds incredible but homeowners are well aware of the fact that the planned use for this site — and the plan is actually in the form of a legal document which cannot be revoked — is the finished landfill will become a golf course, and the residents will have a beautiful view lot overlooking the golf course. The golf course will be terraced and interesting terrain will be provided so that the golfer won't have an easy go of it; that will be done after the plans are finished for the ultimate golf course configuration.

There are probably about 35 different cities using this sanitation district's sites at present. In order to make use of some canyon sites, access roads have to be built and they should be well maintained. Pipelines with high pressure water supply are essential for keeping down the dust and for fire protection. A basic earth mover is a twin-powered scraper — these are rubber-tired so that they can move rapidly and can carry a lot of dirt with just one driver. A water-wagon (6,000-gallon capacity) with a nozzle on the front and sprinklers on the front and rear is used for keeping down the dust, for fire prevention and for keeping papers from blowing around. It is very important that rainfall drainage be provided. Completed portions of the fill should have adequate surface drainage to keep the rainfall from percolating down through the rubbish and maintain it in a drier condition. One of the Sanitation Districts' finished landfills is now called the South Coast Botanic Garden. Before the commencement of the fill the bottom of the mined-out pit was actually 100 feet below street level. The plan called for the reestablishing of an original ridge line, and there is now a total of about 140 feet of fill. Homes were on one side of the street at the time that the landfill started; there were vociferous protests, but those same people are now very good friends of the Sanitation Districts and happy to have a botanic garden across the street instead of an old mined-out pit. One of the "bonuses" built at one of the more remote sites was an overnight camping facility along the side of the road. When you give people proof of a plus benefit, it rather sugarcoats the entire proposal. In this case there was an approximate 10-acre roadside rest camp provided to show the people in the area that the District had good intentions and that the ultimate use of the landfill would be for park purposes. People don't want to wait until the landfilling is all done before they get some use of the property. Many people don't trust government anyhow, thus it's just as well that you show them right at the beginning that you're honest! At another site two "little league" ball diamonds have been constructed on a landfill in the center of a large canyon; only a portion of the canyon had been filled at the time and the ballparks were built in order to get that area under use without waiting for the entire canyon to be filled, since the complete filling of that very large canyon was estimated to take another fifteen years. When the fill is completed the ball diamonds will have been covered up and no longer useable, but two 18-hole golf courses will be provided on the final surface. Since the city of Glendale owned the canyon site, the Districts worked out an arrangement whereby they leased the property at a 25 cents-per-ton charge. During the life of the operation of the sanitary landfill at this site, the City of Glendale will net 3.75 million dollars from their part of the charges for disposal. The city has been willing to commit, in writing, those funds to the construction of the future regional park to be built at the location.

As part of the public relations efforts, the Districts conducted Rotary and Kiwanis Club luncheons, right on the surface of the fill with the operation being conducted in the background. The men enjoyed it and were completely convinced that the operation was innocuous. These men went back into their community and convinced other people that the operation was just as had been promised.

On one of the hills in Los Angeles County a landslide occurred and three homes were destroyed. The lots on which those homes rested slid down into the bottom of the small canyon. The people further up the canyon were worried that the same thing would happen to their homes. As a result, the City staff and District engineers obtained from these people free access rights to their backyards for sanitary fill purposes.

By landfilling the canyon, the people obtained security against further landslides, as well as usable backyards. The only thing that the property owners contributed other than the use of their property was that they each chipped in about $100 per lot to buy the drainage pipe that was installed for draining rainwater through the canyon. It's an area with a good many horse lovers, and so a good number of the backyards were converted into corrals. There are many many instances where such things can be done, and once you have done one or two, then the invitations start rolling in asking you to assist in other such operations. It's a good partnership between government and citizens.

In order to make sure that the landfills did not contaminate the ground water, the State Water Quality Control Board in cooperation with a local sanitary engineering firm conducted a study on gases and percolating effluents. A full-scale test was made using various materials to "seal off" simulated disposal sites. In going from laboratory to full scale, a pit was dug in the ground, lined with burlap and then lined with polyvinyl chloride plastic sheets. Gas probes were placed down through the polyvinyl into the outer area; also gas probes were placed inside so that a check could be made on the difference in the concentrations of gas. The pit was then filled with refuse in a normal compaction procedure; that test was a failure. When we dug down to find out why the gas concentration was as high outside as inside, we found that one thing that had been overlooked was that as the material settled, it stretched the polyvinyl, scratching the sidewalls and perforating the plastic. So, back to the drawing boards and the next attempt produced much better results with an asphaltic material. I confidently predict that with more development we will come up with ways and means of making sanitary landfills secure in almost any type of a ground water environment.

In conclusion, may I respectfully suggest that the technologies that are available today are ever so much better than in 1949 when we set out to develop a countywide program in Los Angeles County. Then we had to cut and fit as we went along; today, a wealth of know-how exists, ready and waiting to be applied. Can we not dream another dream? Is it possible that from the fires and ashes of Kenilworth will rise, like the phoenix bird, a system for solid wastes management that will be the pride and not the disgrace of our beautiful capital city?

REFUSE REDUCTION PROCESSES

Elmer R. Kaiser *

THE SOLID WASTES of our society comprise two basic types, which can be distinguished at the outset. The first, which we call *refuse* is the household, trade, and industrial waste which contains organic combustible matter and usually a lesser but important fraction of noncombustibles, such as glass, ceramics, metals and mineral matter (ash). This paper relates to the reduction in volume and weight of such material. A second . . . important type that will be excluded from discussion, but which is nevertheless an associated municipal problem, we call *rubble,* such as broken pavement, concrete, stone, bricks and excavation materials. Such material is sufficiently devoid of organic or putrescible matter as not to require processing beyond transportation and compaction at suitable sites. A third type, excluded for the present purpose, is the *metal scrap* that normally moves to scrap processors for recycling in the metal trades.

The refuse of a metropolitan area of the size and population of the District of Columbia is so voluminous that reduction in volume is basic to any practical method of disposal. Reduction in weight is secondary. Reduction in both volume and weight is ideal. This paper treats the subject without special reference to any specific urban area.

A community's refuse varies daily, weekly, and seasonally within important limits, and should be investigated for specific areas. However, much can be learned from a near-average mixture, as the principles of waste reduction apply broadly and can be adapted to given situations.

The composition of a municipal refuse, which represents average conditions, at least for an East Coast area, is presented in Table I. The data were obtained by hand sorting of 4 lots of 1,500 to 2,000 lb each, taken at different times of the year from an incinerator plant bunker. They have been found to compare closely with data from other U.S. sources.

The daily solid wastes collected from residences, parks, trade and industrial establishments may be considered to weigh 150 lb per cubic yard (5.5 lb per cu ft) in receptacles or piles, prior to loading into vehicles. This is a good base point to begin a discussion of reduction processes, because it is from this point on that the refuse leaves the public or customers to be served.

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* Senior Research Scientist, Department of Chemical Engineering, New York University, Bronx, New York.

TABLE I

EXAMPLE REFUSE COMPOSITION IN WEIGHT PERCENT

Cardboard	7
Newspaper	14
Miscellaneous paper	25
Plastic film	2
Leather, molded plastics, rubber	2
Garbage	12
Grass and dirt	10
Textiles	3
Wood	7
Glass, ceramics, stones	10
Metallics	8
Total	100

Assuming 4.5 lb waste per capita day, a generally accepted figure, the volume at the source of such waste from a community of one million persons is 30,000 cubic yd per day.

Compaction-type vehicles will temporarily reduce the volume depending on the pressures produced, because the air voids in the refuse charged to the vehicles are about 95 percent of the space occupied. Compaction in the vehicles is ordinarily not over a factor of 2 or 3 because of the forces required. The vehicles then deliver the refuse to reduction sites or plants, where partial restoration to the initial volume results from unloading.

REDUCTION PROCESSES

Refuse reduction is practiced by several processes: (1) Open burning at dump sites; (2) Burning in conical metal chambers; (3) Landfilling, sanitary or otherwise; (4) Composting, with sale of compost; (5) Incineration without heat recovery; (6) Incineration with heat recovery.

On a pilot scale, at least one municipal plant in Demark is pyrolyzing the refuse by destructive distillation to reduce it and to produce useful products.

To the extent that salvaging of solids is practiced in conjunction with each of these processes, or the conversion of the solid residue of burning to useful products, the reduction of refuse is enhanced. In each case, solid matter is left for disposal by burial.

Open Burning at Dump Sites

The reduction of refuse volume and weight by open burning is practiced today where public and private funds have not been provided for more acceptable methods. The objections are numerous. The practice results in serious air pollution from smoke, fly ash, noxious gases and vapors, and odors.[1] The combustion of organics in the residue is not complete, leaving putrescible matter for decay, as food for vermin, rodents and birds. The fires are influenced by wind and rain; they smoulder for long periods, if not continually, depending on how well they are managed and on restrictions as to the type of material burned.

Because of the lack of complete burnout of the solids, incomplete decrepitation of glass bottles, little or no melting of aluminum articles, etc. the resulting residue would probably be 35 percent of the weight of the example refuse. The reduction in volume is hence not so complete as might otherwise be possible.

Variations of open burning are in use, such as in dish-shaped excavations, and even in refractory-lined pits, the latter with a system of overfire air nozzles. Modern air pollution criteria cannot be met by such methods as fundamental laws of combustion, heat transfer, and fluid mechanics are violated.

Open burning of refuse has been outlawed by six states and should be replaced by sanitary procedures.

Burning in Conical Metal Chambers

A number of conical metal burners have been installed in the United States to burn sawmill wastes, industrial and municpal rubbish. These burners are low in first cost and are an improvement over open burning because they confine the burning zone and prevent paper from blowing around the site.[2]

A high excess of air is introduced into the chambers to prevent temperatures that would be destructive to the metal shell and liner, and to the screen at the top where the combustion gases are emitted to the atmosphere. Forced air is supplied under the burning pile in the chamber, when the units are so equipped.

Because of the limited temperatures, and the direct path of the gases and entrained particles to the outside, the result is more smoke and fly ash than can be tolerated in populated areas. The reduction in refuse weight and volume can be greater than by open burning, depending on the care exercised in managing the fire. However, where the noncombustibles are allowed to accumulate and choke the porosity of the burning pile, and where quenching with water is used to expedite removal of the residue, some combustibles will be present.

Recently, one or more conical burners have been equipped with gas washers to trap fly ash from the gases. This is a step in the right direction, the evaluation of which will be of interest.

Sanitary Landfilling

The deposition of refuse in or on an engineered site, followed by compaction with tractors, and later by soil cover, results in a density of 750 to 900 lb per cubic yard. The densities vary, as would be expected, with the amount of bulky refuse with a high void content. Assuming 900 lb per cubic yard, the daily refuse from one million inhabitants would occupy a volume of 5,000 cubic yards or 3.1 acre feet. The refuse volume in landfill is thus one-sixth of the volume it had when it left the generating source, while the weight remains essentially the same. The total for the year would be a volume of 1,130 acre-feet or a 45-acre plot filled 25 feet deep.

Of course, it is possible to build a hill with sides sloped to 20 to 25 degrees, as is being done near Frankfurt, Germany, with trees planted on the slopes, and with a restaurant and viewing area at the top. The 15-year accumulation of refuse from one million inhabitants would build such a hill in the shape of a 150-foot truncated cone, with top 404 feet in diameter and base of 1,130 feet in diameter. Cover material would be extra, but would probably be excavated at the site. This example is offered to illustrate the magnitude of waste accumulation, and not as a proved solution to the problem.

Composting

The degradation of the organic fraction of municipal refuse by bacterial action may be classed as a reduction process. The weight loss of organic solids is about 40 percent through its partial conversion to carbon dioxide and water vapor, which diffuse harmlessly into the atmosphere.[3,4]

Wood, rubber, plastics, oily rags, metals, glass, stones, and minerals are not altered and are removed, more or less, from the material to be composed or from the final product.

The process depends for economics upon a market for the compost as a soil conditioner or humus. Composted refuse is not fertilizer because of its low nitrogen content, but it is useful in farming and horticulture. The experience to date here and abroad is that the market will accept limited tonnages, but not nearly as much as can be produced from the refuse of a large metropolitan area.

As a reduction process, composting is in a special category. Magnetic devices, picking belts and products sieves remove noncompostable reject materials which are disposable in landfill sites. Depending on the process, more or less of the sand, ash, glass and plastics appear in the final product in shredded or ground material. The volume occupied by the uncomposted residue depends on the weight, degree of shredding, and compaction. The volume will be at least as much as from a good refuse combustion process, both considered on the same basis of no salvage.

Incineration

Incineration is a refuse reduction process, the objective of which is to convert refuse moisture and organics to normal components of the atmosphere by enclosed and controlled combustion. The primary products are chimney gases consisting of carbon dioxide (CO_2), water vapor (H_2O), and nitrogen (N), and a solid residue of glass, ceramics, metals and mineral ash. Excess air supplied for complete combustion, consisting of nitrogen, oxygen and water vapor, passes through the incinerator and exits with the gaseous products of combustion. The carbon dioxide and water vapor from the combustion of the cellulose and other organic matter thus return to the ecological cycle from which they came.

It should be remembered that plants are the source of wood, paper, food, textiles and organic matter, and that plants require atmospheric carbon dioxide and rain water for growth. Whether by combustion or natural decay, essentially the same amount of CO_2 and H_2O are recycled to nature.

The chemical and thermal processes by which reduction is achieved through combustion is readily explained by a few simple tabulations. The refuse composition of Table I becomes the refuse analysis of Table II below:

TABLE II

TYPICAL REFUSE ANALYSIS

	Weight, percent	Lb per ton of refuse
Moisture	28.0	560
Carbon	25.0	500
Hydrogen	3.3	66
Oxygen	21.1	422
Nitrogen	0.5	10
Sulfur	0.1	2
Glass, ceramics, etc.	9.3	186
Metals	7.2	144
Ash, other inerts	5.5	110
	100.0	2,000

The calorific valve (HHV): 4500 British thermal units (BTU) per pound.

In a well designed and operated U.S. incinerator, the refuse is burned on moving grates in refractory-lined furnaces with ample air supplies both through and over the burning bed of refuse. Furnace temperatures are controlled in the 1,400 to 1,800 F range, with temperatures in the bed of up to 2,500 F.

The ingredients that join in the combustion process include refuse, stoichiometric air, 200 percent excess air, and air moisture, in the amounts shown in Table III. Part of the excess air enters the system after the primary combustion chamber.

TABLE III

INPUT FOR COMBUSTION AT 200 PERCENT EXCESS AIR

	Lb per ton refuse
Refuse, mixed	2,000
Dry air	18,930
Air moisture	250
Total lb	21,180

The refuse moisture is evaporated during the initial stage, after which ignition proceeds through the charge. Combustion and distillation occur in the burning layer, with over 96 percent completion of combustion in the gas space above and beyond. Even the metals present are partly oxidized, with corresponding gain in weight.[5] The resulting products, including primary products, air contaminants and unburned carbon, are listed in Table IV below:

TABLE IV

PRODUCTS OF INCINERATION

Stack Gases		Lb/ton	Volume, cf	Dry vol, %
Carbon dioxide	=	1,738	14,856	6.05
Sulfur dioxide	=	1	6	(22 ppm)
Carbon monoxide	=	10	135	0.06
Oxygen	=	2,980	35,209	14.32
Nitrogen oxides	=	3	23	(93 ppm)
Nitrogen	=	14,557	195,690	79.57
Total dry gas		19,289	245,919	100.00
Water vapor		1,400	29,424	
Total		20,689	275,343	
Solids, dry basis				
Grate residue		471		
Collected fly ash		17		
Emitted fly ash		3		
Grand total, lb per ton of refuse		21,180		

Hence, the 2,000 lb of refuse is reduced to 488 lb, of which 21 lb or 4.3 percent is carbonaceous char and other combustibles. Putrescible matter should be under one percent of the residue.

Volume Reduction by Incineration

The ton of refuse had a volume of 13.3 cubic yard (150 lb/cubic yd) at the generating source. As the result of compaction in the collection trucks, and later when loaded into the 25- to 30-foot deep bunkers of the municipal incinerator, the refuse volume decreased to 5.7 cubic yards (350 lb/cu yd). The loose incinerator residue of 488 lb (dry basis) leaving the furnaces occupies about 1.0 cubic yard, of which 75 percent is the volume of the tin cans, wire and metallic items. The residue is saturated with water from quenching, which merely adds weight but not volume.

When the residue is deposited in landfill, compacted by tractor in the usual manner and left for a year, the tin cans disintegrate to rust. The final bulk density is 2,700 lb per cubic yard of dry matter.[6] Allowing for the gain in weight of the metal converted to oxide, the residue from the original ton of refuse occupies 523/2,700 = 0.194 cubic yard. The material contains voids because of the granular nature of glass shards, fused clinker, loose ash with a minor amount of combustibles.

The volume reduction by incineration is indeed impressive. Starting with 2,000 lb of refuse, the comparable volumes are indicated below:

	As collected at source	Raw refuse landfilled	Incinerated and residue landfilled
Cu yd	13.3	2.22	0.194
Vol ratio	68.5	11.5	1.0

Where incineration leaves more unburned matter in the residue than the 4.3 percent allowed for in this example, the residue volume is greater and the volume ratios less favorable. The ratio is also influenced directly by the proportion of inerts in the refuse.

Metals salvaging from the incinerator residue is practiced at some incinerators, with shipments of the shredded tin cans to the copper industry. In France and Germany, the steel is baled and sold to the blast furnaces, where it is converted to molten pig iron. The residual tin content has discouraged the U.S. steel industry from purchasing such scrap.

The nonmetallic fraction of the residue can be sintered into concrete aggregate, as is done in Berlin-Ruhleben, but such material must ordinarily compete with stone and sand. A sized fraction of the residue grit would also be useful for sanding streets during icy weather.

Attention is called to the demonstrated possibility of oxidizing and melting the incinerator residue. The glass component is liquid at 1,800 F and most of the ash is molten at 2,350 F. The mutual solution of the oxide assists the melting process. The molten magma can be flowed into simple molds to harden into large pieces with a density of 2.40. When the slag stream is run into water, a coarse black glassy sand is produced, which would have use as a road or concrete aggregate. The bulk density of this glassy sand is 1.47 lb per cubic foot (2,500 lb per cu yd). The bulk density of a 50-50 weight mixture of larger and smaller aggregates is about 102 lb per cubic foot (2,760 lb per cu yd) uncompacted.

We thus have the technical possibilities for reducing to nil the volume of land required for incinerator residue. Economic factors will control the ultimate solution in any area.

Air Pollution Control of Large Incinerators

Incinerators of over one ton per hour input employ forced underfire air to develop economical rates of operation and effective operating temperatures. As the material burns the minerals are released as ash. Particles of dust and bits of paper are carried upward and out of the primary combustion chamber in amounts ranging from 10 to 40 lb per ton of refuse. About half of the weight of these entrained solids is carbon, which largely burns to carbon dioxide in secondary combustion zones and refractory-lined flues; the remainder stays in suspension or is trapped.

The "filtering" of the solid particles from the final combustion gases is usually preceded or accompanied by a gas cooling stage employing water sprays, the addition of air, or both. The gases may take an irregular path through sets of wetted baffles which trap dust. The gases may also be swirled intensively in cyclonic dust collectors which remove solids from the gases by centrifugal force. Gas scrubbing by intimate contact and turbulent mixing with water is another method for efficient dust removal. In the United States tests have been run in recent years with electrostatic precipitators and bag filters, both highly effective in industrial applications. Electrostatic precipitators of 98 to 99.5[7] percent efficiency are used in many large new incinerators in Europe. In other words, the means are available for reducing incinerator dust emissions to meet the new dust-emission standards.

Referring again to our example refuse and incineration process, we indicated a dust emission of 3 pounds per ton of refuse. Such determina-