SEA
GRANT
PROJECT
OFFICE

ECONOMIC ASPECTS OF SOLID WASTE DISPOSAL AT SEA

By
Professor J. W. Devanney III
Mr. V. Livanos
Mr. J. Patell

Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Report No. MITSG 71-2
November 20, 1970

ECONOMIC ASPECTS OF SOLID WASTE DISPOSAL AT SEA

By

Professor J. W. Devanney III
Mr. V. Livanos
Mr. J. Patell

Report No. MITSG 71-2
Index No. 71-602-New

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASS. 02139

SEA GRANT PROJECT OFFICE

ADMINISTRATIVE STATEMENT

The study resulting in this report on "The Economic Aspects of Solid Waste Disposal at Sea," was carried out at M.I.T. with the financial support from the National Council on Marine Resources and Engineering Development, Executive Office of the President.

This study provides a valuable background to all those concerned with the vexing problems of disposal of the residues of society's activities.

The printing and distribution of this special limited edition of the report was organized by the M.I.T. Sea Grant Project Office under the project established to expedite dissemination of important studies and/or research findings developed at M.I.T. under other than Sea Grant support.

This valuable information dissemination is made possible with funds from a grant by the Henry L. and Grace Doherty Charitable Foundation, Inc. to the M.I.T. Sea Grant Program.

A. H. Keil

Dr. Alfred A. H. Keil

ROOM 3-282 (617) 864-6900 EXT. 7041

"This study was financed by a contract with the National Council on Marine Resources and Engineering Development, Executive Office of the President. However, the findings, recommendations, and opinions in the report are those of the contractor and not necessarily those of the Council, nor do they imply any future Council study, recommendation, or position. It is hoped that this study will contribute to the full discussion of problem areas and issues in marine science affairs."

Acknowledgements

This report was supported by the National Council on Marine Resources and Engineering Development as part of a project studying the economics of ocean activities. The M.I.T. task group gratefully acknowledges the continuous stream of support and direction received from Dr. Robert Kay of the Marine Sciences Council, the project's director.

This report was prepared by a Massachusetts Institute of Technology Interdepartment Task Group under the overall supervision of Dr. A. H. Keil, Head of the Department of Naval Architecture and Marine Engineering. Technical guidance was provided by Professor D. Wilson of the Department of Mechanical Engineering and Professor D. Marks of the Department of Civil Engineering. Principal authors were Professor J. W. Devanney, Mr. Vassilios Livanos and Mr. James Patell of the Department of Naval Architecture.

A large number of governmental officials and industrial authorities have taken an active interest in this report for which we are grateful. We would especially like to thank Mr. C. G. Gunnerson of the Bureau of Solid Waste Management, U.S. Public Health Service, Dr. Milton Johnson of the Department of Commerce, Mr. C. B. Kelley of the Bureau of Water Hygiene, Messrs. N.A. Back and F. Heller of the Corps of Engineers, Admiral Snider of the Coast Guard, Mr. C. E. DeCamp of the Federal Water Pollution Control Agency, Mr. John Annicelli of the New York State Pure Waters Authority, Dr. Melvin First of the Harvard School of Public Health, Drs. Melbourne Carriker and Ivan Valiela of the Marine Biological Laboratory at Woods Hole, and Dr. Richard Stone of the Bureau of Sport Fisheries and Wildlife. We would also like to thank the Bureau of Mines who furnished copious materials on recycling.

We do not wish to imply that any of the above gentlemen are necessarily in agreement with our conclusions for which we alone are responsible.

ECONOMIC ASPECTS OF OCEAN ACTIVITIES

ECONOMIC ASPECTS OF SOLID WASTE DISPOSAL AT SEA

SUMMARY AND CONCLUSIONS

Solid waste has been defined by such groups as the Ad Hoc Group on Solid Waste Management in very general terms to include all"material which is normally solid, and which arises from animal or human life and activities and is discarded as useless or unwanted." The Solid Waste Disposal Act of 1965 uses an equally generally definition. However, this report concentrates almost exclusively on the problems facing the large coastal cities and, in particular, on the problem of disposing of the solids normally found in the refuse collected regularly by these cities.

Given this restricted definition of solid waste, the purpose of this study is to determine under what conditions disposal of these solids at sea becomes economic, where the term economic is interpreted in a sense wide enough to include all the costs and benefits associated with this activity, and not merely those which are reflected in the market.

With respect to solid waste disposal at sea, the main non-market economic variable is the ecological effect which the introduction of solid waste will produce in the marine environment. Our investigations have convinced us that, given the present state of knowledge in this area, it is impossible to either predict reliably the effects of a given dose of solid waste on the marine environment or estimate the values which the public places on these effects.

Given this inability, this report concentrates on a comparison of the market costs of various disposal alternatives and derives through present value analysis unit market disposal costs for sanitary land fill via rail haul, incineration on land, dumping of compacted bales at sea and incineration at sea in a number of situations, pointing out the potential ecological problems inherent in each system, and the relevant available information.

Thus, while this report cannot provide a deterministic answer to the original question of under what conditions solid waste disposal at sea becomes economic, it does serve to narrow the discussion considerably, define the critical unknowns and point out the areas where further study is necessary.

In order to provide a realistic picture of the potential for solid waste disposal at sea, we have considered the problems faced by a large coastal city. In the past, these cities have typically relied on coastal landfill. However, they are rapidly running out of politically feasible shoreline sites. We have taken New York City as the prototypical situation. Our best estimates of the 1970 unit costs of disposal for the New York situation are given in Table I.1. These estimates assume close-in landfill sites are not available. They purport to cover all the market costs incurred from the time garbage leaves the collection truck to its ultimate disposal. They do not include differentials in collection truck haul distances implied by the different alternative. These differentials can be quite significant. Total collection costs,cost to the point at which the refuse leaves the collection truck, average $28 a ton in New York City in 1968. And, in general, incineration and barge haul imply longer collection truck distances than rail haul because more rail haul collection stations can be supplied than incinerators or sea transfer stations. It goes without saying that when one characterizes a complex alternative such as rail haul, sanitary land fill for New York City by a single number one has made a host of assumptions. Suffice it to say, that all these unit figures are based on operations of approximately the same scale and that scale is large enough so that no further economies of scale are likely, and that we believe them to be characteristic of the best of the set of alternatives which they represent. These assumptions are outlined in the body of the report.

The most important limitation of Figure 1.1 is that it takes no account of the ecological effects implied by the different alternatives other than through the fact that the incineration on land figure includes pollution control devices sufficient to meet present Federal standards. Hence, Figure 1.1 is not in itself an argument for or against any of the alternatives, but rather a listing of the premiums that a society will have to be willing to pay to avoid an undesirable ecological effect. For example, the Table indicates that the society will have to be willing to pay 56 cents per ton ($7.34 - $6.78) to avoid dumping at sea. Whether or not the society is or should be willing to pay this price, we are not in a position to say. However, Table I.1 clearly indicates that there will be considerable pressure to dump at sea. Given this pressure and our lack of knowledge of the ecological effects of dumping at sea, research in this area is urgently indicated.

Figure 1.1

UNIT COST OF VARIOUS DISPOSAL METHODS
(Based on NYC Labor, Land, and Construction Costs)

	Cost in $/tons for interest rate i i=5%	 i=8%
A. LAND-BASED		
1. Rail Haul-Sanitary Land Fill*	$ 7.34	$ 7.62
2. Incineration**	10.50	11.00
B. SEA-BASED		
1. Dumping of Compacted Bales		
a. Coastal City***	6.78	7.09
b. City 50 miles inland +	10.61	11.02
c. City 100 miles inland +	10.97	11.37
d. City 150 miles inland +	11.42	11.82
2. Incineration at Sea		
a. Inland Incinerator - Sea Dump	11.46	11.96
b. Water-borne Incinerator	10.89	12.00

* Based on 50 mile railhaul (for derivations, see Appendix 1)

** Includes pollution control equipment sufficient to meet present federal standards.

*** Based on Westchester to Hudson Canyon; baling but no packaging. (80 mile ocean tow)

\+ Baling at inland city, railhaul to coast, and 80 mile ocean tow

Figure 1.1 does not include the potentially very attactive alternative of recycling and reuse of the refuse. At present, this approach is severely handicapped by the costs of processing and the weakness of the markets for the output. Our review of the present state of the art with respect to recycling situations indicates that this situation will prevail for some time, with the possible exception of some utilization of incinerator residue. However, since recycling promises lower ecological costs than all the alternatives listed in Figure 1.1, it may become economic (in a wide sense used herein) considerably sooner than indicated by market pressures.

Examination of Figure 1.1 combined with the realization that (a) a small decrease in collection costs due to Alternative A. 1's more numerous transfer stations would wipe out Alternative B.1's advantage, and (b) that the table does not include the ecological costs imposed on the marine environment by dumping at sea, reveals that New York should be giving careful consideration to the alternative of exporting its solid waste inland. And indeed within the last five years many of the large coastal cities including San Francisco, Philadelphia, and New York have initiated programs investigating rail hauling of solid waste inland. We shall see that rail haul becomes more economic than truck haul at a haul distance of about 50 miles, and that where rail haul is economic it pays to compact the waste in a high density bailer. Within the last two years most of these programs have been discontinued or delayed by rising community resistance to importation of the big city garbage at the planned disposal sites. San Francisco was prevented from disposing of the garbage by sanitary landfill in Nevada. New Hampshire recently passed a law preventing the importation of any out of state garbage, Philadelphia was prevented from dumping compacted and baled garbage in abandoned Pennsylvania mine shafts.

It is not completely clear that such restrictions on big city garbage are completely consistent with the values of the communities to which the garbage might be imported. The costs shown in Figure 1.1 are based on a sanitary landfill meeting rather rigid standards, including daily covering of the stacked bales followed by a two-foot mantle. They are not to be confused with the more common open dumps or modified sanitary landfills. If a community has an area which has already been despoiled such as a sand pit, a strip mine or quarry, sanitary landfill of the area can return the land to useful purpose. Furthermore, considering Figure 1.1 and ruling out for the moment the alternative of going to sea, it is clear that the community receiving the rubbish could potentially extract a fairly handsome fee from the community exporting the garbage. The difference between rail haul sanitary landfill and incineration is about $4.00 per ton. This is the maximum amount which a hard bargaining upland community in a monopoly postion could extract from the large city in return for the privilege of receiving its garbage. Of course, in a free market, bargaining among the upland sites will reduce this fee to something closer to the amount of compensation that the community would be willing to accept to take the garbage. It is not clear why upland communities would want to take themselves out of this competition for they could always refuse the compensation offered. Part of this compensation could take place in the form of careful landscaping and restoration of the completed landfill. Westchester County envisions turning the Croton Point Landfill into a particularly scenic portion of the Hudson River bank complete with hills, pools, and even a zoo.

Be that as it may, it is understandable how broad based restrictions against the importation of garbage are passed. In any political body threatened with importation of big city garbage, a law against such importation is bound to be put forward and anyone who votes against such a law is likely to be characterized as a lover of garbage, a despoiler of the countryside, and probably a pawn of big city interst Few rural legislators would want to put themselves in such a position. More rationally, a person could feel quite rightly that any law is better than no law and that writing a law which carefully protected local public interests and at the same time allowed for mutually beneficial bargaining between the upland community and the big city is politically infeasible. In any event, strict laws are passed and, as a result, most coastal cities are legally prevented from depositing of garbage inland. Figure 1.1 reveals that dumping at sea has considerably lower market costs than the remaining alternatives, hence the pressure to dump at sea.

If one does decide to dump at sea there are two rather different philosophies that one can follow. One approach is to accept the ecological degradation of a designated area and attempt to confine all refuse to that area. The other is to view the ocean as a link in the natural process of returning the wastes to the life cycle. The first alternative points to well packaged dumping in deep water with careful confinement. The second would be to distribute the wastes, after some segregation, throughout the biologically active areas; that is, shallow water and the euphotic zone. We are presently in no position to evaluate these alternatives, but strongly recommend research aimed at this evaluation in view of their completely different ecological effects.

We have completed one analysis which is relevant to this argument. That is an estimate of additional costs of sea dumping as a function of barge haul distance. The results are shown in Figure 1.2 which indicates that the differentials can be quite significant.

Figure 1.2

Incremental Barge Transportation Costs

Towing Distance	Towing Speed	Cost/Ton
20 miles	5 knots	$ .47/ton
50 miles	5 knots	$1.05/ton
100 miles	7 knots	$1.85/ton

It should be noted that compaction of garbage to densities higher than that of sea water is presently at the edge of the state of the art. Bales have been produced from municipal garbage with densities in the 70-75 pound per cubic foot range. However, in our view, no one has demonstrated the ability to consistently produce heavier-than-water bales over a range of garbages. On the other hand, we feel that this ability can be achieved at little more than present baling costs as soon as the need is demonstrated.

In summary:

(1) It is our view that mutually beneficial bargains between the large coastal cities and the upland communities exist which would make inland sanitary landfill, at worst, little more expensive than dumping at sea from the point of view of the coastal city.

(2) Present political organization (both local and state) generally prevents these agreements from being consummated. Changes in this system seem difficult to effect.

(3) Given this fact and the fact that dumping at sea is considerably less expensive with respect to non-ecological costs than the remaining alternatives, we expect to see increasingly large pressures on our coastal communities to dump at sea.

(4) The effects of large amounts of solid waste on the marine ecology are not known, and will require much research to predict with any degree of confidence.

(5) Incineration on land is considerably more expensive than the preceding two methods. Incineration at sea is equally as expensive, and thus is not likely to be a viable contender.

CHAPTER I

INTRODUCTION

I.1 Scope and Outline of Report

The Introduction delineates the scope of our study, outlines the report, provides a general background on solid waste generation in the United States, and explains the method for present value analysis we have used in this study.

This Introduction, Chapter I, examines the present demand for solid waste disposal methods, and attempts to describe the growth pattern of the demand, in order to provide a realistic over-view of the pressures urging us to use solid waste disposal at sea.

Chapter II examines the present technology of the land-based disposal methods of:

1. Incineration
2. Land Disposal
3. Railhaul
4. Recycling

and computes, through present value determination, a cost perton for each method.

Chapter III, which examines the present technology of the sea-based disposal methods of:

1. Ocean Dumping
2. Incineration at Sea
3. Coastal Landfill

points out the potential ecological problems inherent in each system and the relevant available information, and computes, through present value determination, a cost per ton for each method.

I.2 Background on Solid Waste

The United States presently produces about 180 million tons of solid wastes per year exclusive of those solid wastes which are normally handled by sewerage systems and which are not the subject of this report. If present trends continue by 1980, this figure will be 250 million tons, and by the end of the century it will be 475 million tons.

The present generation rate is equivalent to 6.9 lbs/capita/day. Figure 1.3 below shows the sources of this waste, on a lbs/capita/day basis.

Figure 1.3(28)

Solid Wastes Generated in the United States

	Lbs/Capita/Day
Residential	2.4
Commercial	1.0
Bulky Waste	.3
Sub-total	3.7
Industrial	3.2
Total	6.9

Of this, approximately 5.1 lb/capita/day (28) is disposed of in private (non-industrial) and municipal sites. Urban dwellers produce more waste than their rural counterparts.

This waste stream can be broken up into its material components as shown in Figure 2.

Figure 2

Composition and Analysis of an Average Municipal Refuse from Studies Made by Purdue University

Component	Percent of all Refuse by Weight	
Rubbish:		
Paper	42.0	
Wood	2.4	
Grass	4.0	
Brush	1.5	
Greens	1.5	
Leaves	5.0	
Leather	0.3	
Rubber	0.6	
Plastics	0.7	
Oils, paints	0.8	
Linoleum	0.1	
Rags	0.6	
Street Sweepings	3.0	
Dirt	1.0	
Unclassified	0.5	
	TOTAL -----------	64
Food Wastes:		
Garbage	10.0	
Fats	2.0	
	TOTAL -----------	12
Noncombustibles:		
Metals	8.0	
Glass and Ceramics	6.0	
Ashes	10.0	
Composite Refuse, as received		
	TOTAL -----------	24
All Refuse -----------------------------		100

The bulk of this refuse has been handled by landfill sites within the community generating the waste, and by incineration. In the past,most landfill sites were little more than open dumps, and incinerators haphazardly dispensed ash and noxious gases into the atmosphere. The general public has become aware of the dangers posed to the environment and themselves by uncontrolled disposal. This has resulted in air pollution control requirements for incinerators and the replacement of some open dumps by sanitary landfills.

This upgrading of solid waste disposal practices has resulted in higher disposal costs. Last year over three billion dollars were spent in this country for the collection, transportation and disposal of solid wastes. These costs are steadily increasing. Many cities are running out of nearby landfill sites, and are transporting their refuse, farther and farther away. Many municipal incinerators are overage and inefficient and will soon have to be replaced. Other incinerators will have to have better air pollution control equipment installed, which will increase the cost of incineration by 25%.

These factors are becoming especially acute in the coastal metropolitan belts where approximately 40% of the American population resides. These communities are looking to the sea as a disposal site for their refuse.

For example, present landfill sites in New York are expected to last at most seven years and according to some authorities only four. New York has traditionally relied on coastal landfill but finds it politically infeasible to obtain additional shoreline locations for landfills. Boston faces a similar situation. At the same time, development of shredding, compacting and bailing machines has advanced to the point where general garbage can be compacted to densities higher than sea water. This opens up the possibility of dumping at sea with little or no probability of any of the garbage returning to land.

At present, the ocean is being used as a disposal site for construction and dredging wastes, as well as certain types of industrial waste. Figure 3 outlines the quantities of materials disposed of at sea in 1968.

Figure 3

ESTIMATED AMOUNTS AND COSTS OF WASTES BARGED TO SEA IN 1968[a]

Source: Marine Disposal of Solid Wastes, an Interim Summary
Dillingham Corporation, October 1969

Wastes	Pacific Coast Disposal Tons	Pacific Coast Disposal Cost	Atlantic Coast Disposal Tons	Atlantic Coast Disposal Cost	Gulf Coast Disposal Tons	Gulf Coast Disposal Cost
Dredging spoils	7,320,000	$3,175,000	15,808,000[c]	$ 8,608,000	15,300,000	$3,800,000
Industrial wastes (chemicals, acids, caustics, cleaners, sludges, waste liquors, oily wastes, etc.)						
Bulk	981,000	991,000	3,011,000	5,406,000	690,000	1,592,000
Containerized	300	16,000	2,200	17,000	6,000	171,000
Garbage and trash[b]	26,000	392,000	---	---	---	---
Miscellaneous (airplane parts, spoiled food, confiscated material, etc.)	200	3,000	---	---	---	---
Sewage sludge	---	---	4,477,000[d]	4,433,000	---	---
Construction and demolition debris	---	---	574,000	430,000	---	---
TOTALS	8,327,500	$4,577,000	23,872,200	$18,894,000	15,996,000	$5,563,000

(a) Does not include outdated munitions.

(b) At San Diego 4,700 tons vessel garbage at $280,000 per year were discontinued in November 1968.

(c) Includes 200,000 tons of fly ash.

(d) Tonnage on wet basis. Assuming average 4.5 percent dry solids, this amounts to approximately 200,000 tons dry solids per year being barged to sea.

Thus, advances in technology combined with the increasing costs associated with the possible alternatives have greatly increased the pressure to dispose of solid wastes at sea.

The New York State Pure Waters Authority and the Sandy Hook Marine Laboratory have already undertaken very preliminary tests on compacted bales at sea. Two groups have recently been formed in Boston, one with the unimaginative name of Seadump, which are considering contracting with the city to take refuse to sea. It behooves us therefore to consider quickly, but carefully, the costs and benefits resulting from using the sea to dispose of our solid waste.

This report is based primarily on a comparison of the market costs of land and sea-based disposal systems. We have used the present value analysis to compute these costs. Present value, as we have employed it, is explained in the following section.

I.3 Present Value Analysis

Any analysis of alternative capital investments such as alternate solid waste disposal systems necessarily involves the comparison of different time streams of capital. For example, one system may involve a large outlay of capital initially with smaller outlays through the life of the system (e.g. land incineration) while another system might involve a smaller initial capital expenditure but larger annual outlays (e.g. incineration at sea). How do we determine which is cheaper; that is, which system requires less of the community's limited resources when we realize that the dimension of capital is both dollars and time? (The use of one million dollars for two years is greater than the employment of one million dollars worth of resources for a year.)

In this section, we wish to argue that the proper way of comparing different time streams of expenditures is through present value.

The present valued cost of a time stream of expenditures(C_0, C_1, C_2, C_3 . . . C_n) where C_n is the cash outlay in year n and N is the life of the investment,is defined to be

$$\hat{C} = \sum_{n=0}^{N} \frac{1}{(1+i)^n} C_n$$

where i is the interest rate.

The idea behind present value is that delaying an outlay is worth money. An expenditure of \$100 a year from now is not as large as an expenditure of \$100 now for we can commit something less then \$100 now to pay \$100 a year from now. What is the amount we have to commit now given an interest rate of i? It is $\frac{\$100}{(1+i)}$, which amount will grow to \$100 in one year. Similarly, a payment of \$100 two years from now is a still smaller expense for we need only commit $\$100/(1+i)^2$ now in order to have \$100 at the end of two years. In general, the present amount we have to commit in order to make an outlay of C_n dollars n years from now is $\frac{C_n}{(1+i)^n}$. This quantity summed over time is, we shall argue, the proper measure of the total amount of resource that the community must commit now in order to pay off a time stream involving an outlay of C_n dollars in year n. Put another way, it is the proper measure of the cost of the system given that the capital could be usefully employed elsewhere at an interest rate of i.

Now there are several ways that the community could raise this money in the solid waste context. One is that it could tax itself $\hat{C}$ in year 0, and give $\hat{C}$ to the operator of the system, private or public, who would invest the money at i% paying out his costs as they occur. Let us determine his bank balance at the end of the life of the system. It is given by

$$((((((\hat{C} - C_0)(1+i)) - C_1)(1+i)) - C_2)(1+i)) \ldots$$

$$- C_{N-1})(1+i)) - C_N$$

or

$$\hat{C}(1+i)^N - C_0(1+i)^N - C_1(1+i)^{N-1} \ldots - C_{N-1}(1+i) - C_N$$

Dividing through by $(1+i)^N$,

$$\hat{C} - \sum_{n=0}^{N} \frac{1}{(1+i)^n} C_n$$

which equals 0. Thus, given the present valued costs at the beginning of the life of the system, the operator could just meet all his outlays with nothing left over. The present value of the costs then is the amount the community would have to give up now (at time 0) in order to meet the payments.

Of course, communities usually find it politically difficult to tax themselves in this manner. Generally, a more feasible alternative is to borrow the money. In this case, it may not be obvious that present value still measures the amount of capital that must be devoted now to pay for the system. Consider, for example, the other extreme from completely debt free financing. Let us suppose we borrow $\hat{C}$ dollars at an interest rate of i and assume we pay off the entire loan at the end of the life of the system with money we obtain from the taxpayer at that time. As in case (1) at the end of the life of the system, the operator's bank balance will be zero. Yet the community will owe its creditors $\hat{C}(1+i)^N$ dollars. How much capital must the taxpayers set aside now in order to meet this debt. The answer, of course, is $\hat{C}$ which will grow to $\hat{C}(1+i)^N$ at the end of the life of the system.

In both extreme cases (1) and (2), the same investment from the taxpayers was required. In one case, the agency was given the money early and invested it at i%; in the other case, the taxpayer was allowed to keep the money and invest it himself at i%. From the point of view of the economy, the results are exactly the same reflecting the fact that in both cases, exactly the same time stream of expenditures was involved, the same amount of capital was used up.

In actual fact, communities follow neither of these extremes. Usually they borrow enough for their initial capital expenses paying the money back during the life of the project with revenues collected during the project's life on a more or less equal basis annually. This is merely a mixture of the above two alternatives; and in terms of the amount of capital the community would have to put aside now, the results will be exactly the same.

Suppose for example, the community decides to borrow $\hat{C}$ and collect equal payments annually in order to pay off this loan at the end of the life of the system.

If A is this equal annual charge then

$$A(1+i)^N + A(1+i)^{N-1} + \ldots A^0 = \hat{C}\,(1+i)^N$$

or

$$\frac{A}{(1+i)^0} + \frac{A}{(1+i)^1} + \frac{A}{(1+i)^2} + \frac{A}{(1+i)^N} = \hat{C}$$

$$A \sum_{n=0}^{N} \frac{1}{(1+i)^n} = \hat{C}$$

The question then is how much must the taxpayers put aside now to be able to make these payments. In order to make an outlay of A now, they must put aside A now. In order to make an outlay of A a year from now, they must put aside $\frac{A}{(1+i)}$ now. In order to make an outlay of A two years from now, they must put aside $\frac{A}{(1+i)^2}$. And so, or a total of $\sum_{n=0}^{N} \frac{A}{(1+i)^n}$ which by the above equation = $\hat{C}$. In terms of present value, this case is equivalent to case (1) and (2) as expected. Of course, communities generally choose to pay off their debts during the life of the project rather than by a large sum at the end. It should be clear by now that this will not change the amount of resources that must be devoted at present to the project for earlier repayment of the loan will decrease the amount paid in exactly the same amount that it decreases the time for taxpayer capital to accummulate. From the point of view of the economy, it is inconsequential whether the community pays off the creditor as soon as it can or lets the money accummulate at i% in its bank account paying the creditor i% for the privilege.

However, the different repayment schemes are relevant to the choice of a cost/ton measure. If one were to tax the community at the initiation of the project for the entire present value of the costs of the project, the proper measure would be C/(total tons moved during the life of the project).

If on the other hand, an annual payment scheme is used as in (3), then A/(tons moved annually) will be a more meaningful figure. This number will be greater than that for the prepayment scheme reflecting the fact that the taxpayer is allowed to keep his money longer.

In this report we have chosen to show the cost/ton under the assumption of equal annual payments. This is an arbitrary judgment. The important point is that we be consistent across projects in defining cost/ton. As long as we do this, any of these measures will correctly rank the alternatives. However, we need to know the definition of cost/ton in order to evaluate the differences in required resources implied by the different costs/ton. From this point of view $\hat{C}$/total tons is the simplest. However, as noted above, this figure may be misleadingly small to the taxpayer who expects to get charged this cost annually.

The interest rate used should be the opportunity cost of capital; that is, the productivity of the dollars involved if they were employed elsewhere. In a free market economy, this opportunity cost is approximated by the prime rate minus the rate of inflation. Rather than attempt to predict what the opportunity cost of capital will be in the future, we have performed all our present value analysis for both 5 and 8 percent under the assumption that this will will cover the range of likely future possibilities.

CHAPTER II

LAND-BASED DISPOSAL METHODS

This Chapter examines the present technology of the following land-based disposal methods: incineration, land disposal, railhaul, and recycling. The present and proposed operating procedures are detailed, and, by utilizing a present value determination method, a price per ton disposal cost is computed. The results of this Chapter are then summarized.

II.1 Incineration

Incineration is a refuse reduction, rather than a refuse disposal, process. The solid waste residue must still be ultimately disposed of after the incineration process. As of 1968, 9% (1) of American refuse was incinerated prior to ultimate disposal.

Incinerator capacity has steadily increased since 1950, as has the percentage of solid wastes that are incinerated before disposal. However, despite predictions of further growth of incinerator capacity, incineration as a method of solid waste reduction has many problems. Many of the incinerators in large cities will either have to be replaced or closed down because they are overage (1). The capital costs for a large municipal incinerator have been steadily increasing because of higher land values, construction costs,and the added expense of efficient air pollution control equipment.

The analysis of incineration is presented under the subheadings Volume Reduction, Air Pollution from Incinerators, Incineration with Heat Recovery, and High Temperature Incineration.

Volume Reduction

The average ton of refuse has a volume of 13.3 cubic yards (150 lb/cu. yd.) (28) at the generating source. This volume is usually reduced 80 to 90 percent by incineration (4). In this process, usually 98 to 99 percent, by weight, of the combustible materials can be converted to water vapor and carbon dioxide (28). The total weight reduction is commonly between 75 and 80 percent (28). Incineration before landfill will greatly prolong the life of the landfill site and provide a more stable and compact fill material.

In some instances ferrous metal salvaged from the incinerator residue is sold to the copper smelting industry (2). Glass and non-ferrous metals may also be recycled if a market exists. At the Stanford Research Institute, a method of grinding incinerator residue and using it as a "cement" of sorts is being investigated. The Bureau of Mines is actively investigating a system of mechanical, and magnetic separation of incinerator residue. This is discussed in more detail in the section on recycling.

Air Pollution from Incinerators

The objective of incineration is to convert refuse moisture and organics to components of the atmosphere by controlled and enclosed combustion. The chimney gases, which are the primary products of incineration, consist of carbon dioxide, water vapor, nitrogen, a solid residue of ceramics, glass, metals and various other ashes, sulphur oxides, and other inorganic gases.(26) The carbon dioxide and water vapor are easily absorbed into the atmosphere, but the large particles, the dust and the noxious or corrosive gases constitute pollutants. The general public is increasingly demanding that air pollution be controlled.

A wide variety of air pollution control equipment has been developed. These include settling chambers, mechanical cyclones, wet scrubbers, electrostatic precipitators and baghouse filters.

The following Figure 4 summarizes the qualities and relative cost of the various equipment available.

* Some scientists have expressed concern over the rising level of carbon dioxide in the atmosphere pointing to possible effects on the earth's energy balance. We have not analysed this problem in any depth, but it appears that research in the area is certainly warranted. Once again our analysis concentrates on market costs and their implications for the near term.

Figure 4

TYPES OF CONTROL EQUIPMENT (1,26,28)

Equipment Type	Comparative Space(%)	Efficiency (%)	Basic Limitations	Relative Capital Cost Factor
Electrostatic Precipitator	100	90-99	Does not remove soluble gases. No installation working in U.S. municipal incinerators. Efficiency low on large particles	3-4
Scrubber* (flooded plate)	33	90-99	Possible mist emitting from stack. Clarification and neutralization of wash water required water usage	2
Mechanical cyclone (60" tangential)	33	75-90	Low efficiency on small particles. Erosion from abrasive fly ash.	1
Baghouse filter	110	99	Size and Complexity of system, need to reverse flow to clean filter, choice of filter bag material.	4
Settling Chamber	67	40-60	Low efficiency	not applicable

* Scrubber includes water treatment plant.

Figures 5 and 6 from Ref. (1) shows how these relative cost factors differ over a wide range according to the specifications of each individual incinerator.

Day and Zimm (26) has estimated the annual cost of operating this equipment for an 800 ton/day plant in Washington, D. C. at $327,500 for electrostatic and mechanical air pollution control. For similar equipment of the wet scrubber type, the annual operating cost would be approximately $260,000 (26).

The initial capital cost would be:

Electrostatic and Mechanical (26)	Wet Scrubber (26)
$2,939,800	$2,247,400

Since the scrubber is cheaper in both initial and annual costs, it will generally be the preferred alternative. Assuming a real interest rate of 5% (no inflation) and an equipment lifetime of ten years, the unit cost of pollution control to meet the present federal standards is $2.94 a ton on an 800-ton per day plant. This number is particularly relevant to the viability of an incineration at sea scheme for it is the margin with which the at-sea incineration alternative has to operate before it is more expensive than incineration on land, assuming the federal standards are to be met in the urban area. If the differential costs of going to sea are more than $3.00 per ton, it will be cheaper for the community to pay the price of the control equipment.*

It should be noted that while the U.S. Department of Health, Education and Welfare found the scrubber sufficiently effective from the viewpoint of the present federal levels, if more stringent controls are postulated, then the more effective mechanical and electrical system may have to be purchased. Indeed, for the District of Columbia location that H.E.W. was studying, despite the fact that

* As we shall see, the advantages that at-sea incineration has with respect to disposal are small, about 30¢ per ton of input.

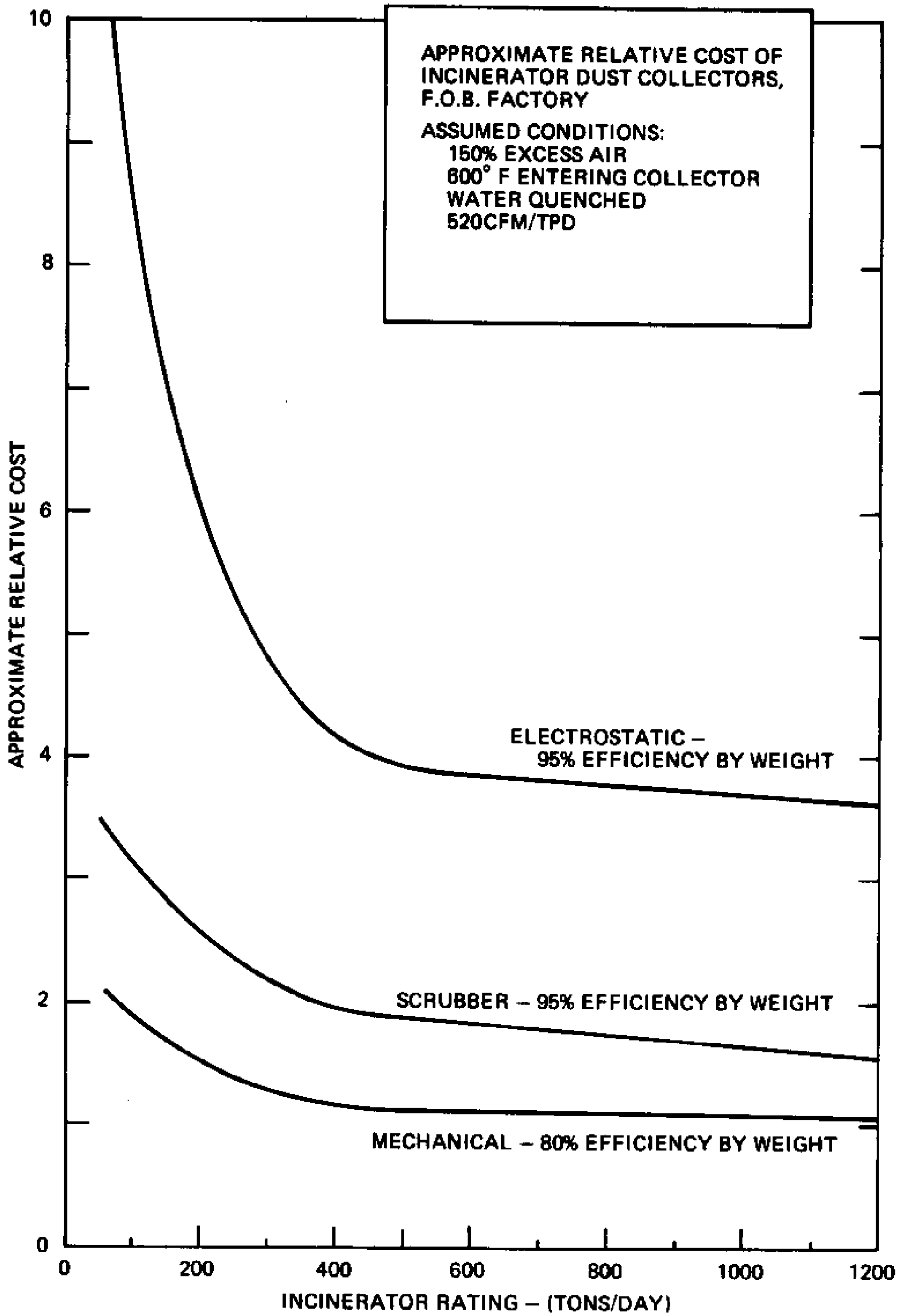
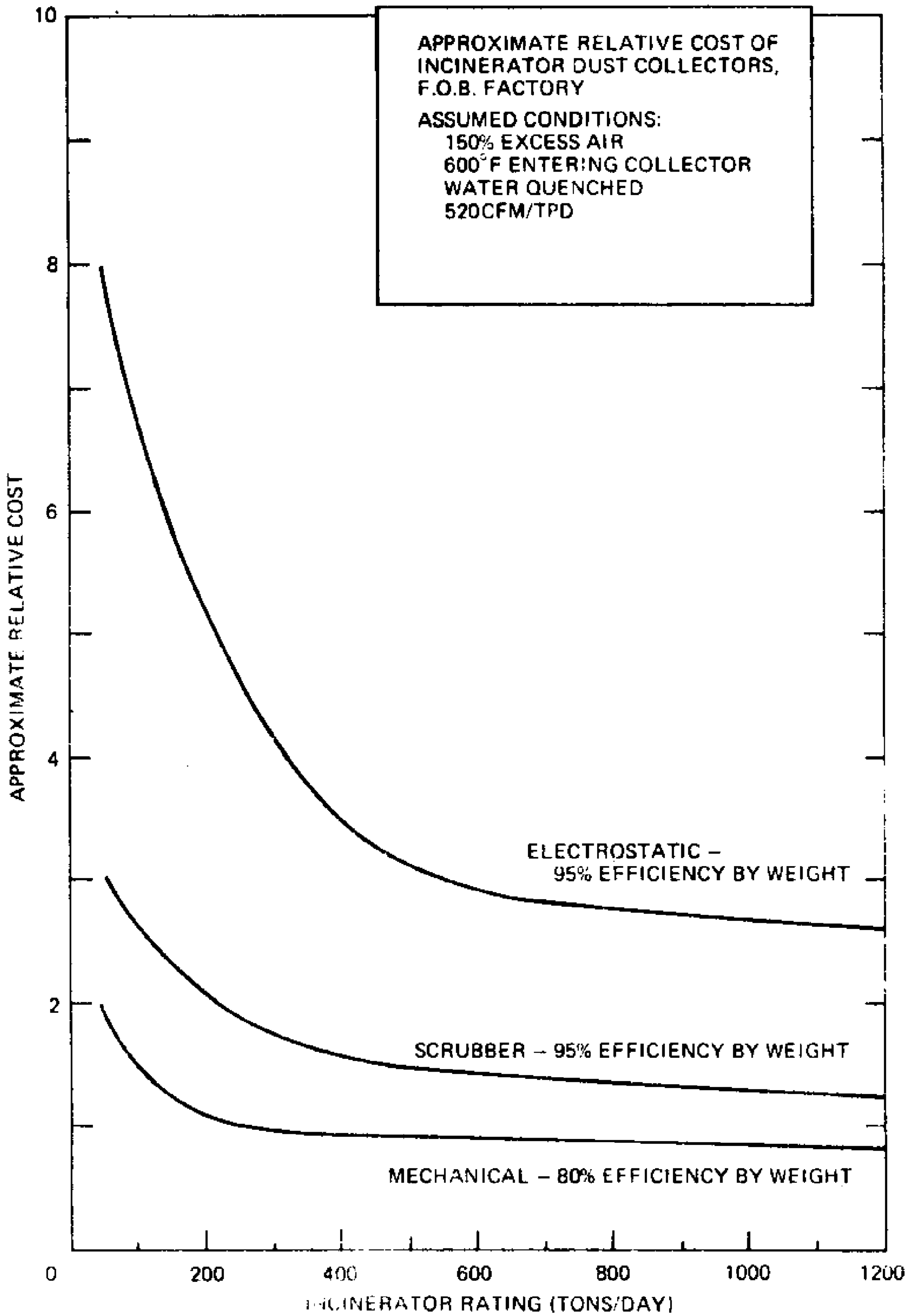


FIGURE 5 RELATIVE COSTS OF INCINERATOR POLLUTION CONTROL SYSTEMS AS A FUNCTION OF SCALE



APPROXIMATE RELATIVE COST OF INCINERATOR DUST COLLECTORS, F.O.B. FACTORY
ASSUMED CONDITIONS:
150% EXCESS AIR
600°F ENTERING COLLECTOR
WATER QUENCHED
520CFM/TPD
ELECTROSTATIC – 95% EFFICIENCY BY WEIGHT
SCRUBBER – 95% EFFICIENCY BY WEIGHT
MECHANICAL – 80% EFFICIENCY BY WEIGHT
APPROXIMATE RELATIVE COST
INCINERATOR RATING (TONS/DAY)
0
2
4
6
8
10
200
400
600
800
1000
1200

FIGURE 6

the scrubbers met the pollution requirements, the electromechanical system was recommended on the grounds of no mist plume and no thermal pollution of the water source. A scrubber for an 800-ton/day plant will require about 750 gallons/minute and will heat this water 18.5°F. Thus, this latter consideration will be important only for communities with very limited water sources. If this choice is made, pollution control will cost $3.50 per ton on the same basis as above.

Finally, even assuming perfectly effective pollution control devices by present day definitions, incinerators will still discharge quantities of carbon dioxide into the atmosphere. Some ecologists are concerned over the long term effects of increased carbon dioxide in the atmosphere on the world weather pattern. We have not investigated this problem in this report.

Incineration with Heat Recovery

Refuse is not an ideal fuel. The composition of refuse varies over a wide range, as does the heating potential it could produce. In some European incinerators with heat recovery, coal is added to the refuse to produce a more consistent and higher quality fuel. The steam would have to be sold to a nearby user, who would require steam on a 24-hour basis. The most obvious users of this steam would be electricity generating plants. Other uses could be community steam heating or air conditioning.

Some cooperation between the users of the steam and the designers of the incinerator would be necessary. In many cases, the extra expense of boilers and a steam distribution system will outweigh the return from the sale of steam.

The following table compares a 4,000 ton per week refractory incinerator with and without heat recovery. The costs include only variables that are affected by the decision to have or not to have heat recovery.

	Refractory	Refractory with Boiler
Initial Cost (26)	3,583,000	5,737,000
Annual Cost (26)	656,000	1,007,000

Assuming a 20-year life and a 5% interest rate, this leads to a unit cost of $4.55 per ton for the plant without heat recovery. In order for the plant with heat recovery to match this figure, this steam must be worth $1.04 per thousand pounds. The best kind of steam that can be expected from an incinerator boiler is 200 p.s.i.g. saturated. All modern electrical generation stations are based on superheated steam so that, unless and older turbine was available nearby, generation of electricity from this steam would require a separate electrical plant which would be less efficient than its competitors both because of the thermodynamics and the economics of scale encountered in power generation.

In sum, we do not feel that heat recovery can substantially reduce the cost of incineration and therefore will use a plant based on no heat recovery in comparing incineration with its competitors. This conclusion is substantiated by past history with actual heat recovery systems, the uses of whose products were in-house needs and supplying neighboring buildings with heating steam. Several incinerators which were equipped with boilers have taken them out of service and at present no U.S. incinerator sells either steam or electrical power on a commercial basis.

Some of the European installations use waterjacketed furnaces rather than refractory material. The H.E.W. study finds that the decreased costs of replacing incinerator lining and the additional potential for steam generation do not balance the increased capital and operating costs of these water wall installations.

High Temperature Incineration

Recently an extremely high temperature process, the Melt-Zit incinerator, has been studied. This system uses temperatures of 2600 to 3200 °F to reduce all non-combustibles to an inert molten slag. A Bureau of Solid Waste Management study of a pilot plant operation indicates that the system is not yet sufficiently well developed for full scale implementation. Problems with high coke and limestone consumption and deterioration of the lining were encountered in the test runs. Initial economic analyses indicated that if the system could be made to operate up to specifications, the incineration costs would be about $1.00 a ton more than conventional high temperature incineration due mainly to increased fuel costs (25). This difference would have to be made up in savings in input segregation costs, savings in disposal costs due to the inertness and high density of the residue.

It is our opinion that economic pressures and technological process will continue to push the most economical temperature of incineration upward. However, systems such as the Melt-Zit are at present not competitive with conventional 1800° installations. Therefore, we have used the cost of the latter in characterizing land-based incineration.

Costs of Incineration

Capital costs of land incineration vary over an extremely wide range. Figure 7 shows the results of a historical survey of 170 cities taken by the Bureau of Solid Wastes Management. The capital costs per ton vary by a factor of 30. This is probably due as much to difference in accounting methods as in actual costs, but it does display the kind of variance we must deal with. These are 1966 figures and in general the systems surveyed do not meet the present pollution control equipment requirements. Since we are basing our comparison on a large coastal city where land and construction costs can be expected to place it in the upper 25 percentile of Figure 7, we feel that a capital cost of about $10,000 per ton-day rated capacity based on a 24 hour operation and pollution control equipment meeting federal standards in a reasonable figure. This figure is also cited in references (26) and (5).

Operating costs have a similar range as Figure 8, also from reference (28), indicates. More detailed analysis is available from reference (5) which indicated that, for the Des Moines area, total incineration costs have been estimated at $6.50 per ton (5) in 1966 dollars including 30 cents per ton of input for disposal of the residue.

Des Moines of course is a very low cost area compared to the large metropolitan complexes which are our prime concern in this report. Recent cost histories of New York and Chicago installations indicated operating costs along of $4.73 and $3.67 respectively per ton. On the basis of Figure 8, we estimate operating costs for a modern incinerator with adequate air pollution control equipment will be about $8.00. Given an operating cost of $8.00 per ton and a capital cost of $10,000 per ton per day and assuming a plant life of 20 years and an inflation-free interest rate of five percent, this leads to a unit disposal cost of $10.50. At 8%, the unit cost becomes $11.00 per ton input.

It is of interest to us that the disposal costs of the residue are a surprisingly small percentage of this total, about 35 cents per ton of input. This is due primarily to the factor of five or more reduction in volume accomplished by a modern incinerator. The significance of this is that at-sea incineration's ability to dump its residue directly does not result in a large savings in total disposal costs.

In sum, we estimate that 1970 unit disposal costs of incineration capable of meeting federal standards will run from $6.50 per ton to perhaps $12.00 per ton, the latter figure being more characteristic of the large coastal metropolises than the former. Since we are primarily basing our comparison on the New York situation, we will use this number in ranking the alternatives. Metcalf and Eddy in a detailed study of the Westchester County situation estimates unit cost of incineration at $12.99 per ton. The difference between their figure and ours is due primarily to the fact that they escalated the wage rate without accounting for inflation by increasing the interest rate with which the project should be discounted.

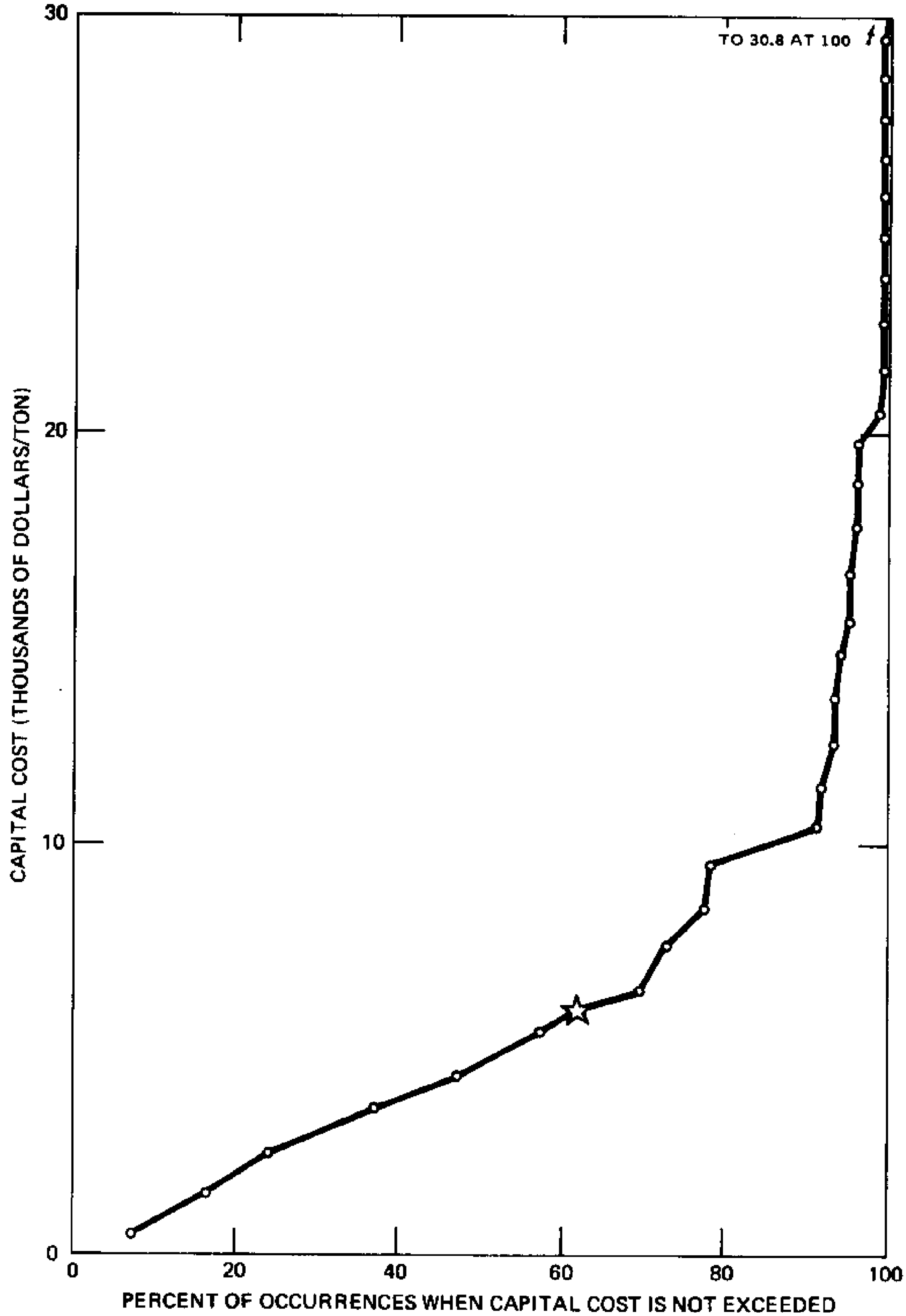


FIGURE 7 DISTRIBUTION OF CAPITAL COSTS OF INCINERATION

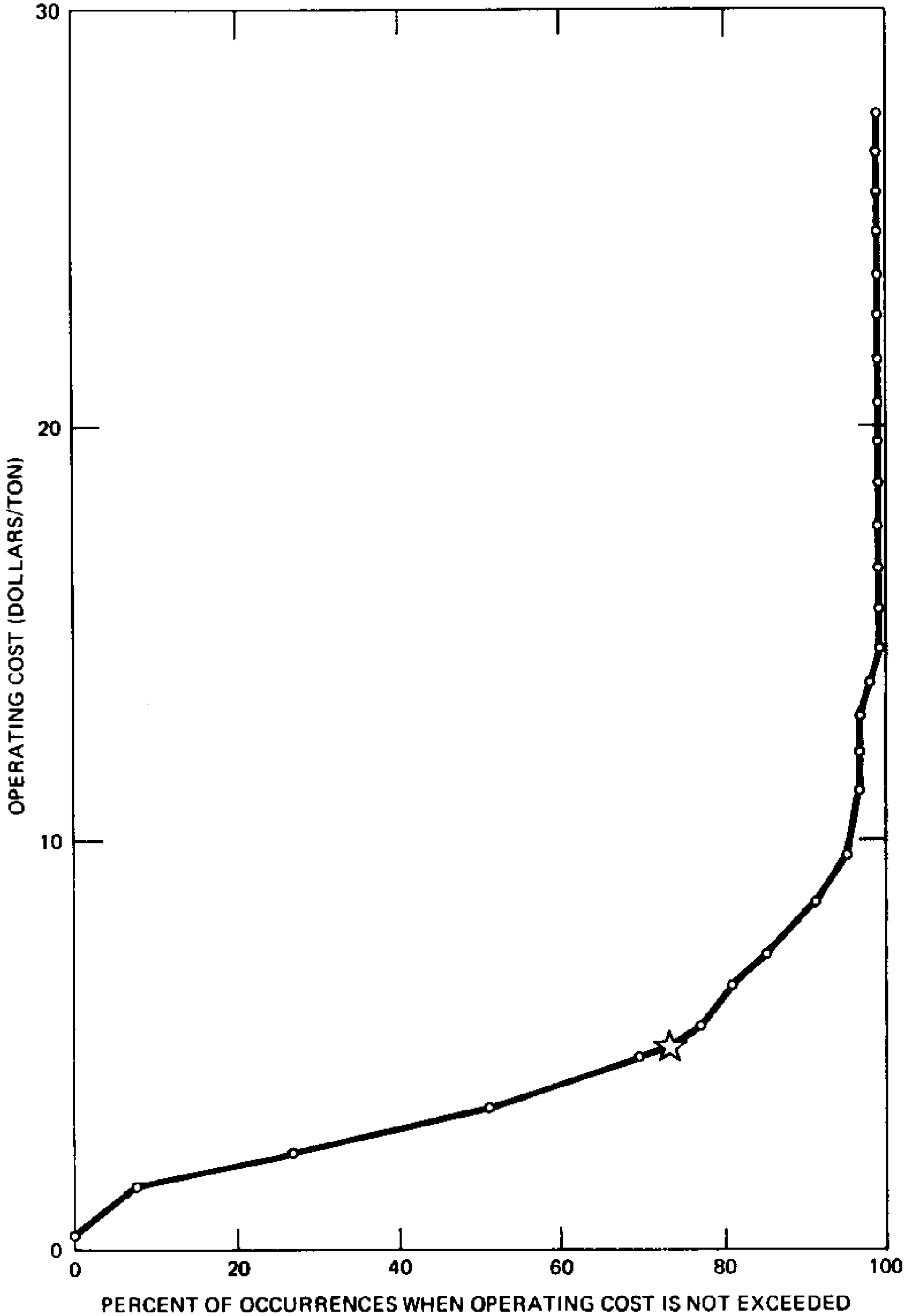


FIGURE 8 DISTRIBUTION OF OPERATING COSTS OF INCINERATION

II.2 Land Disposal

Land disposal is by far the most widely used method of solid waste disposal in the United States today. Available records indicate that there are 90,000 recognized land-disposal sites. Of this number, about 19,000 were planned, and some 12,000 are subject to a degree of local control that would identify them as "sanitary" or "modified-sanitary" landfill sites (3). The vast majority of land-disposal sites constitute a public nuisance and a national disgrace.

Land-disposal sites, when properly managed, can form an attractive disposal system. These sites take unsorted refuse of varying composition and provide a final deposit for the refuse. This section will provide a discussion of the hazards of uncontrolled land-disposal and the costs and benefits of sanitary landfill.

As noted in the introduction to this section, open dumps are the most prevalent type of disposal site used in the country. This type of operation is usually accompanied by continuous or periodic burning. Open dumps require little capital or operating costs where land is available. On the other hand, they are health and fire hazards, unsightly and malodorous, require substantial amounts of land which is hard to utilize after the dump is closed, adversely effect neighboring property values and are a cause of air pollution.

The disadvantages and hazards outweigh the advantages of the open dump in even a moderately urbanized area. For the coastal municipalities we have in mind we do not regard open dumping as worth costing. Most of these communities have stopped uncontrolled dumping some time ago.

The sanitary landfill is described by the American Society of Civil Engineers as: "A method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume and to cover it with a layer of earth at the conclusion of each day's operation, or at such more frequent intervals as may be necessary."

Landfill disposal often offers the most economic method of disposal, as well as being a system that can accept almost all refuse and dispose it in a safe and beneficial manner. Landfill can often be integrated into planned land reclamation, whereby lands which formally had little or no economic value can be made to yield recreational and economic benefits and lands which have been despoiled, quarries, sand pits, etc.,can be restored to use.

A sanitary landfill operation requires a good deal of planning. The landfill must be well integrated into the total refuse collection and disposal system. Operating procedures should be carefully outlined, and the economic and technological facts about the operation should be studied. Preliminary planning should include an active public information program to explain to the public what makes a sanitary landfill work well and what benefits can be expected. In most cases, public acceptance or rejection of a disposal system is the most important factor in the choice and planning of that system.

Site selection is an important engineering step to establishing a sanitary landfill. The land area - or more important the volume of space - required is primarily dependent upon the character and quantity of wastes to be disposed. This varies of course with each project, but as a rule of thumb, 7 acre-feet (11,293 yd^3) per 10,000 population per year is frequently used or a little over a cubic yard per person per year.

Zoning restrictions and accessibility are also factors in choosing a landfill site. These are often conflicting constraints, and the distance to a landfill site is usually considerable. The transportation element in any disposal system is an important part of the total cost, so that it is important to investigate transfer stations and alternative systems.

The availability of cover material should also be investigated, because the additional cost of hauling cover material to the site over long distances may be restrictive. Sandy loam is considered to be an excellent cover material since it contains 50 to 60 percent sand and the remainder is clay and silt in equal amounts with good workability and compaction qualities. A soil containing too much clay presents operational problems during wet weather and can crack in dry, exposing the garbage to vermin, surface run off and releasing odors. Too granular a soil will not prevent passage of flies and may create a water pollution or erosion problem by permitting surface run off.

Over the years three general methods of landfilling have been developed: the area method, the trench method, and the ramp method.

Abandoned quarries, strip mines, gravel pits, borrow pits, gullies or rolling land are suited to the area method. In the area landfill a day's refuse is dumped in one spot. A bulldozer then spreads and compacts the wastes. A six inch layer of cover material (ideally taken from the adjoining slope or working face) is placed over the fill to form a "cell". Successive cells are built next to or atop each other until the landfill is completed. A final two to three foot seal of cover material is spread and compacted over the entire area to finish off the fill.

In a trench landfill a progressive trench is cut into the ground and solid wastes are dumped into this trench. The solid wastes are spread thin, compacted and covered with earth excavated from the trench. Level or gently sloping land is best suited for the trench method if the water table is not near the ground surface. The material excavated from the trench can be used for the next day's covering operation, which is an advantage over hauling the cover material to the site. A disadvantage is that more equipment may be necessary for a trench-type landfill than for the area type.

In the ramp or slope method, the refuse is dumped on an existing slope. After spreading and compacting the material on the slope it is covered. The process is repeated until the landfill is exhausted.

During the operation of any type of landfill attention must be paid to proper compaction, the size of the working face, the depth of the cells and the cover.

Certain materials may have to be excluded from sites. These may include explosives, dangerous chemicals, demolition wastes, dead animals, and so on. However, almost all ordinary household refuse in acceptable.

The most common piece of equipment used at disposal sites is a track-type tractor with a bulldozer blade. The various manufacturers of landmoving equipment generally can provide a wide variety of equipment to suite various conditions. Some road maintenance and fire control machinery may also prove to be necessary.

There are a large number of present landfill operations which masquerade under the title of sanitary landfill but which do not meet the stringent standards under which we are costing sanitary landfills. In terms of the definition on page 34, they are not sanitary landfills. They are known to sanitary engineers as modified sanitary landfills. The modified sanitary landfill is left uncovered until the fill is completed or only periodically covered. The sanitary landfill is compacted and covered daily. The modified sanitary landfill is not as carefully controlled as sanitary landfill; therefore, the health, fire and pollution hazards are correspondingly greater. Finally, due to its poorer compaction, the completed modified-sanitary landfill is not as useful an asset as would be the completed sanitary landfill.

While there is undoubtedly a place for modified-sanitary landfills of varying degrees of quality, especially in rural areas, the usurpation of the title sanitary landfill by these operations is unfortunate in that it may generate unwarranted public opposition to a proposed sanitary landfill. That is, the public is objecting to its image of the external effects of a sanitary landfill which effects may not exist to the degree expected in a stringently controlled site.

Given this public image of 'sanitary' landfill, a careful educational program in which the citizens of the locale of the proposed site are informed of just what the costs and benefits to them will be is indicated before they are asked to decide on the desirability of a landfill operation and its mechanisms.

The cost of sanitary landfill is discussed in the following sections identified by the sub-headings:

- Initial Costs
- Operating Costs
- Transportation Costs Associated with Landfill
- Salvage Value of the Fill
- Summary of Costs.

Initial Costs

The initial costs of a sanitary landfill include land, planning and design, construction of access roads, provision of utilities and shelter and equipment costs.

As in the case of all disposal systems, the initial investment cost of landfill varies widely with location.

Land is often condemned and then used by the community. Often, since the land was marginal in the first place, the cost is small. A good estimate to use is $1000/acre purchase cost. Thus, a 250-acre site would cost about $250,000 (5). Increasingly, communities are paying a fee for use of the land, which is then included in the operating costs. The cost of equipment varies from $10,000 for trucks to $35,000 for heavy earth moving equipment. The total equipment cost is about $250,000 for a 250-acre site. The engineering fees again vary with the extent of surveys and planning to be done; a $20,000 to $150,000 range is typical. The on-site construction is another variable factor. For a 250-acre site, approximately $200,000 must be spent on site development costs.

As a general rule initial investment seems to vary between 30% and 50% of the present value of operating costs. New York City reported capital expenditures of $0.56/ton for 1968. For Des Moines, Iowa, fixed costs were about $.30/ton. These two cases form a reasonable range of fixed investment costs/ton.

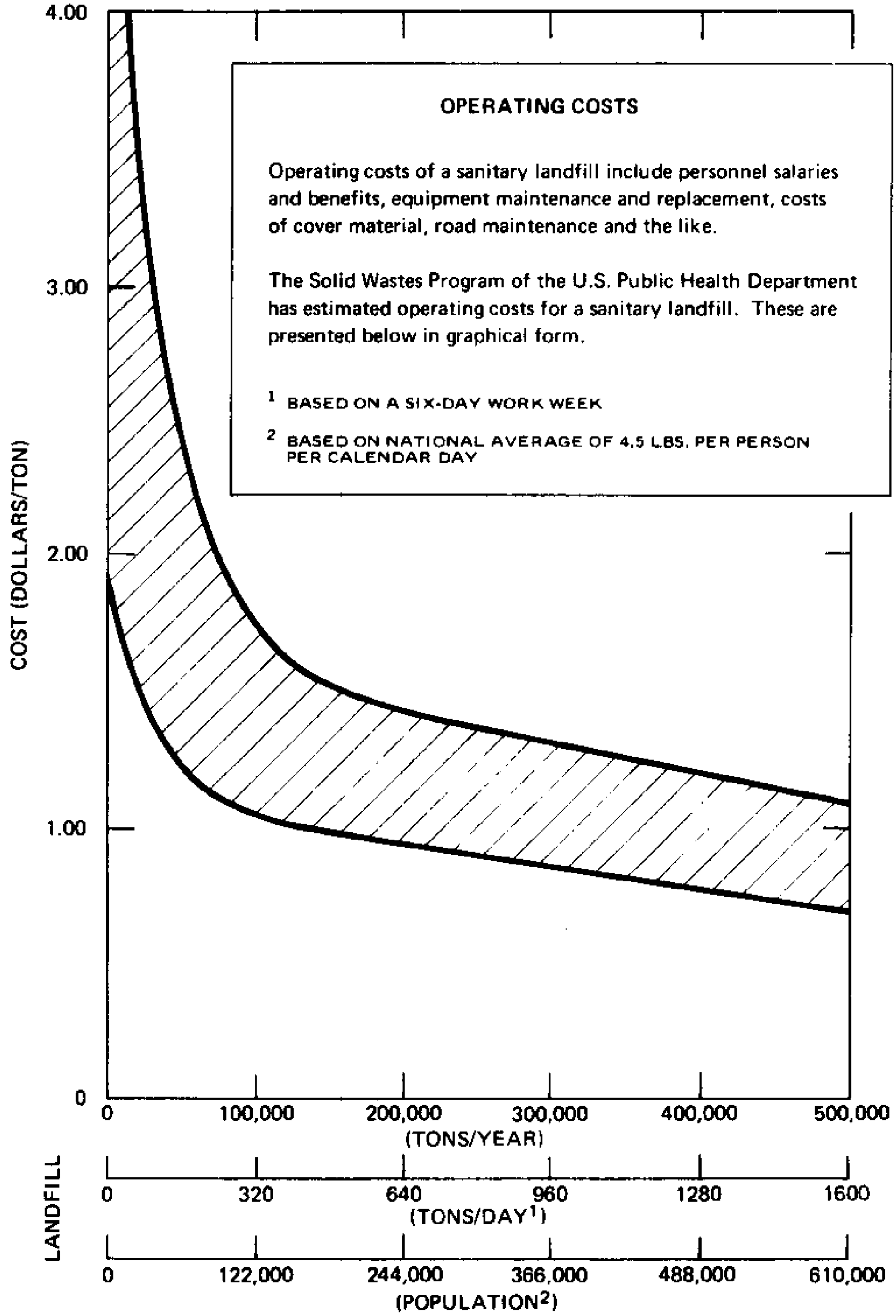


FIGURE 9 OPERATING COSTS OF LANDFILL AS A FUNCTION OF SCALE

Des Moines, Iowa, has estimated operating costs of $0.91/ton based on 652,000 tons/year. New York City, with higher than average costs for most everything, reported operating costs of $1.35 (0.18 for personnel fringe and pension benefits). New York City disposed of 6.5 million tons in sanitary landfills in 1968. Thus, sanitary landfill costs in New York before transportation are about $1.91/ton while Des Moines experienced landfill costs of about $1.21/ton. A national survey conducted by Ralph Stone and Company found the following costs/ton for various categories of sanitary landfills. The results were: $0.83 for cut and cover (trench method), $0.48 for canyon and ravine, $0.65 for pit and quarry, and $1.17 for others. Metcalf and Eddy in a survey of large scale in upstate New York found final disposal costs ran from .66 to .70 a ton depending on the site. This is based on high density compacted garbage at about 70 pounds per cubic foot as opposed to the other figures which are based on site compaction by tractors to about 35 pounds per cubic foot.

Transportation Costs Associated with Landfill

The costs of transferring the waste from the collection trucks and its subsequent transportation to the landfill site are an extremely important portion of the costs of a sanitary landfill.

The costs of transporting the rubbish to the fill will usually be several times the cost of final disposal. Figure 10 compares the costs of various land transportation as a function of haul distance including:

a) no transfer from packer truck
b) haul of low density compacted garbage by trailer truck
c) haul of high density compacted garbage by rail.

The Metcalf and Eddy study indicates that in those situations where railhaul is economic, i.e. distances over 50 miles, high density compaction is superior to low density compaction. Similarly, for those hauls in which transfer from the packer truck to a larger truck is appropriate low density compaction is indicated. Figure 10 assumes that a packer truck averages 30 miles an hour with 3.3 tons of refuse aboard, that the gross operating costs of this truck is 35 cents per mile and that a crew of three are on board with total compensation of 12.00 per hour. Figure 10 is conservative with respect to the no transfer alternative in that it assumes that no additional trucks needs to bought due to the longer truck haul implied by this alternative. However, it is at least conceivable that a bargain could be made with the labor unions by which the entire crew need not accompany the packer truck the entire distance to the disposal site which would cut packer truck haul costs considerably.

The truck to truck transfer costs are based on the 200 ton per day low density truck to truck compaction station studied by Metcalf and Eddy in which waste is dumped from the packer truck, compressed to about 20 pounds per cubic foot and loaded onto a twenty-five ton trailer truck. Metcalf and Eddy estimates the cost of the trailer truck at 75 cents a ton on the basis of a seven-year life at 5% interest. Operating costs of this type to truck are estimated at 50 cents per mile, an average speed of 30 miles an hour has been assumed and total compensation to the driver per hour of time on the moving truck at $5.00. The railhaul graph is based on high density compaction (70 pounds per cubic foot) at $4.80 per ton (32) and the transportation costs are based on a series of figures quoted by the Penn Central to Metcalf and Eddy for the Westchester County situation which we have fitted by a fixed cost type function:

$$t(d) = 2.00 + .01\, d$$

where t is the transportation costs per ton and d is the one way haul distance.

Figure 10 is only a very gross approximation to the transportation costs associated with sanitary landfill. In particular, it ignores important differentials in packer truck hauls to transfer stations. Any particular application would require a much more detailed model. However, it is believed to be generally correct and, if so, the implication is clear. The crossover point between no transfer and truck to truck transfer is quite low, about ten miles haul distance. In effect, almost any generation area which can support a 200-ton/day transfer plant and which does not have very close landfill sites, should effect this transfer. The crossover point between large truck and rail occurs at about 50 miles haul distance. However, the rail haul figures are based on a 1500 ton per day plant which many areas cannot support. Metcalf and Eddy found that for the more remote sections of Westchester, the least expensive solution was to effect the truck to truck transfer and then transfer from the large truck to rail.

Note that once the rail transfer has been effected, the line haul costs are almost negligible compared with the total disposal sites. That is, an extra 50 miles of railhaul distance will increase the total disposal costs by less than ten percent This statement has important implications for the potential market for at-sea dumping.

The Salvage Value of the Fill

Sanitary landfill can turn solid wastes into a community asset. When combined with a rational planning approach, marginal lands can be reclaimed and be made into valuable pieces of geography. Ralph Stone and Company, Inc. in a national survey found the following future uses of landfill sites. Recovery of land for recreational use was sited most frequently (45%). Golf courses, baseball diamonds and tennis courts as well as general parks are included in this category. This usage is most frequent because non-compacted refuse often cannot support heavy loads. If the landfill is allowed to settle for a number of years, the load it can support is increased. Using compacted refuse will also increase the supportable load.

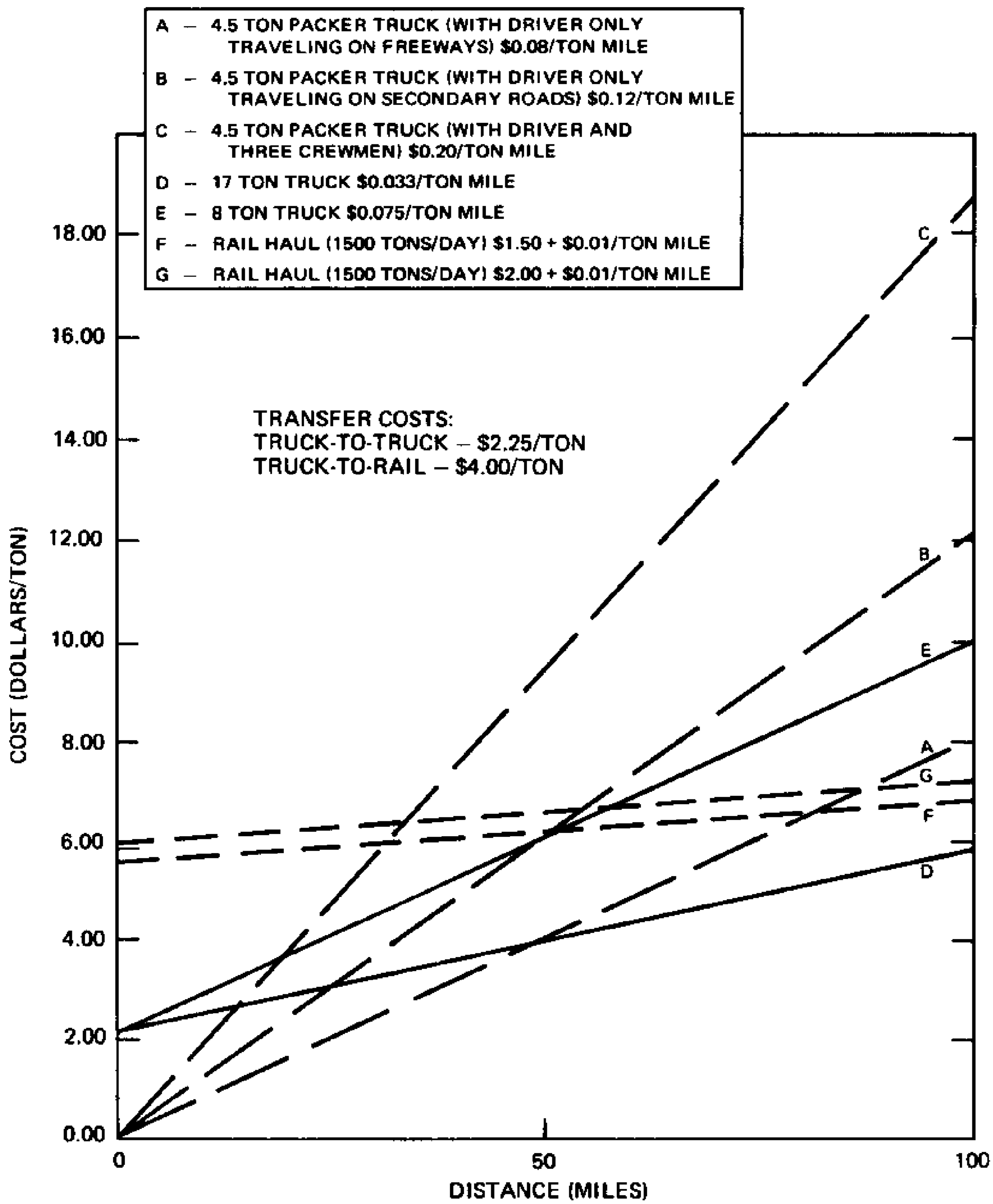


FIGURE 10 COMPARATIVE TRANSFER AND TRANSPORTATION COSTS

Industrial (9%), agricultural (7%) and commercial use (5%) trailed behind as uses of completed landfills. Two percent were to be open space after completion, and undetermined or no future use was reported in 26% of the sites surveyed. Apartment housing and light industrial parks have been built on landfill sites. Our cost figures included only the costs of the covering mantle and do not include the costs of beautifying or developing that land nor the resale value of the completed fill or, equivalently, the net present value of the benefit-cost stream which the community can obtain from the site after its completion.

This value can be substantial. If, for example, we assume the fill doubles the value of the land, a conservative assumption if we are using borrow pits, abandoned quarries and the like, then at 5% and a 13-year fill life the present value of resale is equal to the original land cost. If the fill has a shorter life span, this present value will be greater than the original land cost.

Since land costs are typically about 1/4 the initial investment cost which in turn may be about 50% of overall final disposal costs and final disposal costs are generally one third or less of the total disposal costs associated with landfill, including the resale value of the land, in this case double the value in 13 years, would result in about a 5% reduction in unit costs. Of course, the higher the original land costs, the more important the resale value becomes and the larger the error from ignoring it. We have not included any salvage value in our comparisons. This makes our results somewhat biased against sanitary landfill, but not significantly so, if a low cost site is contemplated. In any comparison of actual alternatives in a particular situation, the value of the finished site should, of course, be estimated and included in the analysis.

Summary of Costs

The unit disposal cost of sanitary landfill for a large coastal community will vary from about \$5.00/ton for sites within 10 miles of the generation area to about \$8.00/ton for sites requiring railhaul. Since New York City, our sample case, is due to run out of sites within its own boundaries in 4 to 7 years, we will use the latter figure in comparing sanitary landfill with its alternatives.

II.3 Railhaul Disposal of Solid Waste

This section develops in detail the costs of railhaul of solid waste in support of the overall figures given in the last section and as a prerequisite to determine the market costs associated with railhaul plus dumping at sea.

The concept of railhaul disposal of solid wastes is gaining support in both the government and private sectors, and is one of the few concepts on which thorough, comprehensive studies are becoming available. Most of the data and projections presented in this section were provided by the American Public Works Association (46) and the New York State Pure Waters Authority (48).

These studies list the main advantages which can be gained through railhaul solid waste disposal.

1) A strong possibility for a low-cost total disposal system. Railhaul permits strategic location of transfer stations, and the economies of scale available in a regional (as opposed to local) system.

2) A reduction of air and water pollution and other environmental health hazards.

3) A solid waste disposal system with high degrees of both reliability and flexibility.

4) A system which will have widespread application throughout the U.S.

The Railhaul concept allows a great deal of flexibility in designing the overall system structure. The following systems have been proposed: System R1 - Railhaul Sanitary Landfill, System R2 - Railhaul Incineration, and System R3 - Railhaul Ocean Dumping; these are discussed in the following sections.

System R1 - Railhaul Sanitary Landfill

This system consists of the following three steps:

a) Trash is delivered by primary collection vehicles to centrally located transfer stations and is compacted into bales.

b) Bales are transported by rail to sanitary landfill sites.

c) Bales are placed in sanitary landfill.

This system alternative is the one selected by the American Public Works Association as the most feasible of the alternatives available and most worthy of further study. It is also the one recommended to the New York State Pure Waters Authority by Metcalf & Eddy Engineers as the indicated solution for Westchester County, New York. Steps a and b are shown schematically in Figure 11.

The first step begins with packer or compaction type trucks entering an enclosed dumping area and discharging their contents into a storage bin. An overhead crane transfers the refuse from the storage bin to a conveyor belt which feeds the shredding units. (Shredding proved to be neccessary to assure high-density compaction.) From the shredding unit the material is transferred by conveyor to the baling unit, where it is compressed into high-density (approximately 65 lbs/ft^3) bales. These baling units include integral automatic strapping equipment. These bales are then placed in the rail car by a traveling crane.

The second step begins when refuse bales are transported in specially designed side-loading enclosed rail cars. Rail car manufacturers have indicated that the design will present no particular problems, and railroad representatives indicate that a contract to provide the required service could be negotiated.

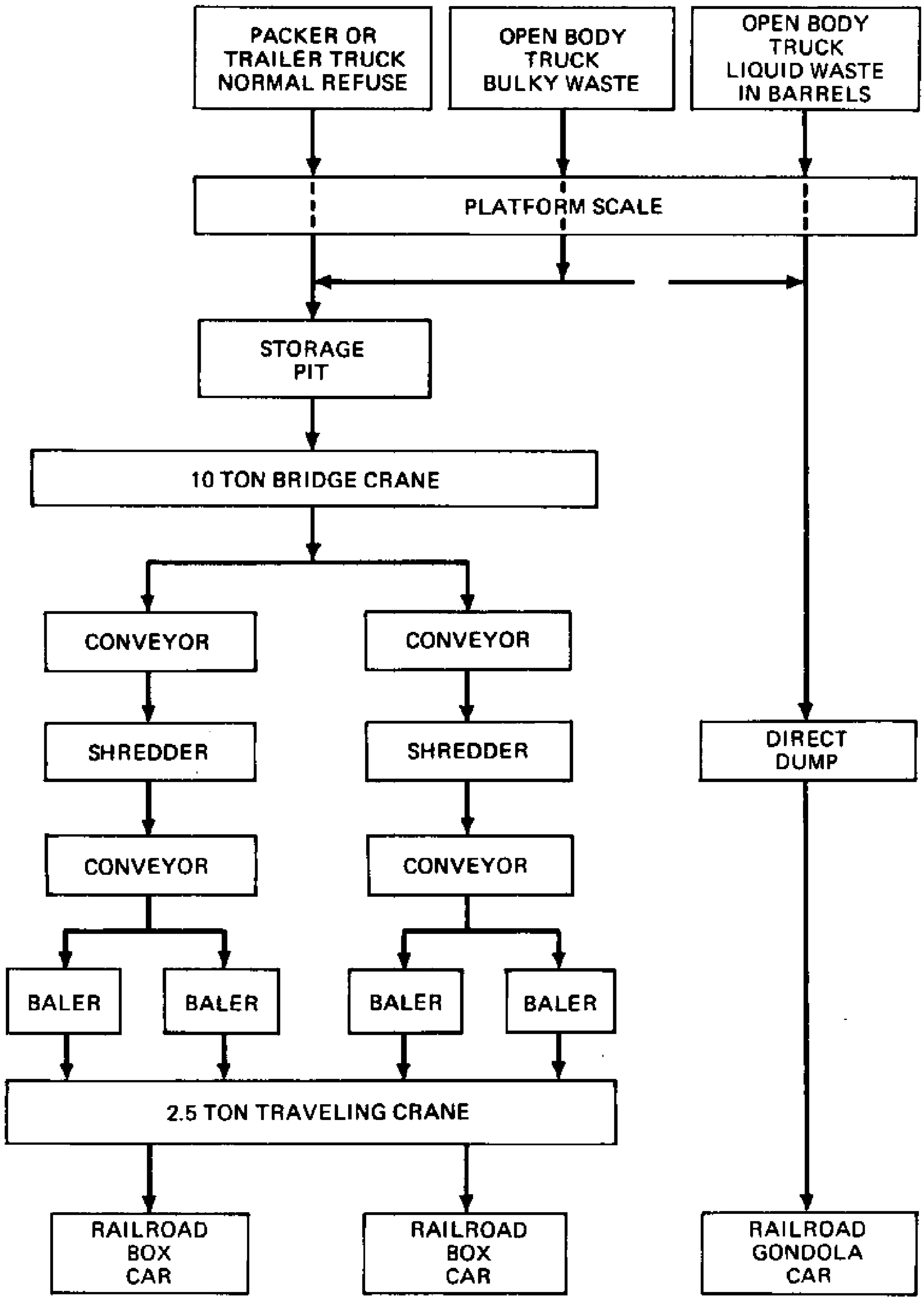


FIGURE 11 RAILHAUL SANITARY LANDFILL CONCEPT

The third step consists of unloading of the bales at the disposal site. They are then carried to the open face of the landfill operation, and disposed of as prescribed in the description of landfill operation given in Section II.2.

The economic analysis of this system R1 was carried out and is reported in detail in Appendix 1. It leads to the conclusion that the cost for disposal by means of this system is $7.34/ton ($7.62/ton) if an interest rate of 5% (8%) is assumed.

System R2 - Railhaul Incineration

This system consists of the following four steps:

a) Trash is delivered by primary collection vehicles to centrally located transfer stations and is compacted into bales.

b) Bales are transported by rail to regional incinerator.

c) Bales are unstrapped and incinerated.

d) Incinerator residue is disposed of by sanitary landfill or sea dumping.

This system differs from system R1 only in the final disposal operation, incineration rather than landfill.

As shown in Section III.1, the cost of incineration in a plant capable of handling 1,000 tons/day of refuse is $10.50/ton, assuming a 5% interest rate. Comparing this with the high-density compaction, sanitary landfill procedure which costs $0.66/ton eliminated this system alternative from further consideration.

System R3 - Railhaul Ocean Dumping

This system consists of the following three steps:

a) Trash is delivered by primary collection vehicles to centrally located transfer stations and is compacted into bales.

b) Bales are transported by rail to dock-side facilities and loaded onto barges.

c) Barges are transported to disposal sites and bales are deposited on sea bed.

This system is described and analyzed under Ocean Dumping Methods, Section IV.1.

II.4 Recycling and Composting

We have already mentioned the inherent attractiveness of recycling in the face of the ecological effects of conventional disposal methods and in view of the non-renewable nature of much of the material in refuse. The more obvious candidates for reclamation are paper and paper products, ferrous metals, aluminum and other non-ferrous metals, glass, and rubber. In addition, organic refuse which composes 20 to 25% of the total in typical municipal waste streams (3), can be composted and, at least potentially, sold as a plant nutrient. We will consider each of these in turn.

Paper and Paper Products

Approximately 50 million tons (3,6) of paper and paper products were used by Americans in 1967. Roughly 80% (6,20) of this was a one-time use after which the products have been discarded. Paper products constitute between 40% and 50% of all solid wastes (3). Of the 40 million tons of paper waste, 25% or 10 million tons were recycled. For the last few years, paper manufacturers have been meeting 20% of their raw material needs from recycled paper (the rest of the raw material needs were met primarily by wood pulp). (6,20) This rate has been slowly declining recently. (6,20) At one time 50% of the paper industries input needs were furnished by salvaged paper. If the price were competitive and the paper were in useful form, the paper industry could meet up to 80% of their raw material needs from recycled paper products, putting considerably less pressure on our forest resources (6).

Of the 10 million tons of paper reused, a substantial portion was industrial wastes from printing activities, manufacturing scrap, and large commercial, industrial, and govermment establishments. A much smaller percentage is from domestic, small commercial schools and office sources. Collection from these sources cannot provide a reliable input for a large paper mill.

There are technological problems in the reuse of magazines and most intermediate grades because of the filler materials. These problems are not overwhelming and indeed could be overcome if an incentive were provided. There are almost no technological barriers to the reuse of paperboard and newsprint.

Separation at the generating source and efficient collection would result in more paper being recycled. Development of machinery to separate paper from mixed refuse would similarly increase the use of salvaged paper. The paper industry will grow 100% in the next 16 years. If 50% of its new demand could be met by recycled paper, it would release 91.5 million acres of forest land for other uses (6). For the U.S., this could result in considerable savings in foreign exchange. Paper products are among the easiest to recycle and a major effort should be made to take advantage of this.

Ferrous Metals

In the past, attempts to recycle ferrous metals have focused on the recovery of tin cans. Before and during World War II, many municipal incineration installations were able to profitably sell their tin cans. In the early 1950's Los Angeles was able to finance the collection of the residue of backyard incinerators by selling the rights to the metals (principally tin cans) in this residue. The principal market for tin cans is the copper smelting industry, in which application the existence of tin in the metal is not a disadvantage. Recently, there has been a trend away from tin can recovery. The American Public Works Association in a survey of six municipal systems (five of which have practiced some recovery of ferrous metals) noted that only one was still doing so (55). An analysis of the lone hold out, Atlanta, revealed the marginal nature of the recovery operation as far as the city was concerned. Atlanta's most recent contract resulted in a price of $11.50 per ton. The marginal costs associated with the additional processing required by the sale was valued at $11.21. This cost does not include the savings in final disposal cost which we will see elsewhere can be expected to be of the order of $7.00 per ton if railhaul is required. On the other hand, due to the presence of the tin, the APWA report found evidence that the market for tin cans would be quickly saturated by any substantial increase in the amount recovered. The present market for general ferrous scrap is not a great deal stronger. The APWA report notes that a recent quote for scrap in Milwaukee was $6.00 per ton. A great deal of scrap is presently exported for want of domestic markets. Of course, this situation can be expected to change as the supply of raw material becomes increasingly more limited in the face of exponentially increasing demands. However, this cannot be expected to happen overnight. The short run trend has been that the costs of separating and processing the scrap have risen faster than the value of the scrap itself.

Aluminum

Four aluminum cans have a scrap value of one cent. Production of aluminum from raw bauxite is an expensive process requiring large amounts of power. The recycling of aluminum scrap may be economically feasible in the near future given development of inexpensive means of segregating aluminum from other non-ferrous metals. Some efforts are presently being made to recycle aluminum, but these are on a very small scale. There are almost no technological barriers to reuse of aluminum.

Other Non-Ferrous Metals

Lead, copper, zinc, and tin have high salvage values. However, these metals are often found in alloys or other forms which make reuse difficult. The quantities involved are also small. In general the recycling of these metals will require advances in technology. The Bureau of Mines is presently conducting research on the separation of valuable non-ferrous metals from incinerator residues and fly ash (56, 57). However, this work is still at the laboratory stage.

Glass

Fourteen million tons of glass is present in the waste stream (3,4). Glass has a low scrap value, and manufacturers have been reluctant to accept salvaged glass, unless it is sorted by color and grade, and contains no metal. The main barriers to the recycling of glass seem to be economic, not technological in nature.

The basic raw material, sand, is not in short supply in many parts of the country. Once again, the APWA found the present market for whole or crushed glass quite limited in terms of the supply which would result from large scale recovery operations.

Rubber

Rubber enters the waste stream mostly as discarded tires. These would seem to be easily salvageable. However, since there are so many grades of rubber, no large scale recycling is taking place today. Rubber in other forms is difficult to segregate and salvage.

Plastics

Plastics form a small, but increasing, part of the waste stream. At present most plastics are non-degradeable. Increased attention should be given to the development of bio-degradable plastics. Reuse of plastics apart from recovery of their heat value, would be very difficult.

Automobiles

Six million automobiles were scrapped in 1966 (3,6), the first year that the scrapping rate nearly equaled the discarding rate. Salvage of automobiles is profitable in most instances and private industry, with government incentive should be eventually able to solve this aspect of solid wastes disposal. More study in this field is needed, however, as well as continued government incentives.

The Bureau of Mines is presently conducting research into more economic methods of segregating automobiles into their component raw materials and possible uses of the results. Among the latter is the use of car bodies as a reductant in the processing of nonmagnetic taconite, a presently unusable resource(56).

Large scale recycling of car bodies is a fact and we expect the trend to continue. Of course, the municipal refuse collection stream presents a considerably more difficult segregation problem than that associated with car bodies.

It is symptomatic of the present state of the art in refuse segregation that the bulk of the segregation at composting plants is by hand picking. This is clearly infeasible on the scale required by our large cities. Efforts to develop mechanical separators are underway. At MIT, a laboratory system is being studied which uses a combination of electronic and electromagnetic garbage sensors to segregate the garbage stream according to its electrical properties. Standard Research Institute has also been developing a segregation system.

The most promising attack on the segregation problem appears to be that undertaken by the Bureau of Mines (58). This effort is aimed at incinerator residues and at present is limited to and takes advantage of the volume reduction inherent in incineration, which is a substantial limitation given the costs of incineration. However, we believe it points the way toward economic segregation systems. The system is outlined in Figure 12. It is based on a rather ingenious combination of screening, magnetic separation, deformation (which takes advantage of the fact that glass crushes while metals, being malleable, are not reduced in size), more screening and finally a hydraulic classification. The Bureau has undertaken a number of laboratory tests based on this system and is presently constructing a 1000-pound per hour processing plant. This is a promising start.

The problem of segregation could be made considerably easier by packaging and manufacturing design which accounts for the disposal problem. Here we have in mind not only the avoidance of non-biodegradable products, of composite products which cannot be separated into their material components, but also the physical or electrical tagging of objects to facilitate segregation. For example, it might be possible to identify hard-to-segregate materials by radioactive tags which could easily be sensed by segregation equipment.

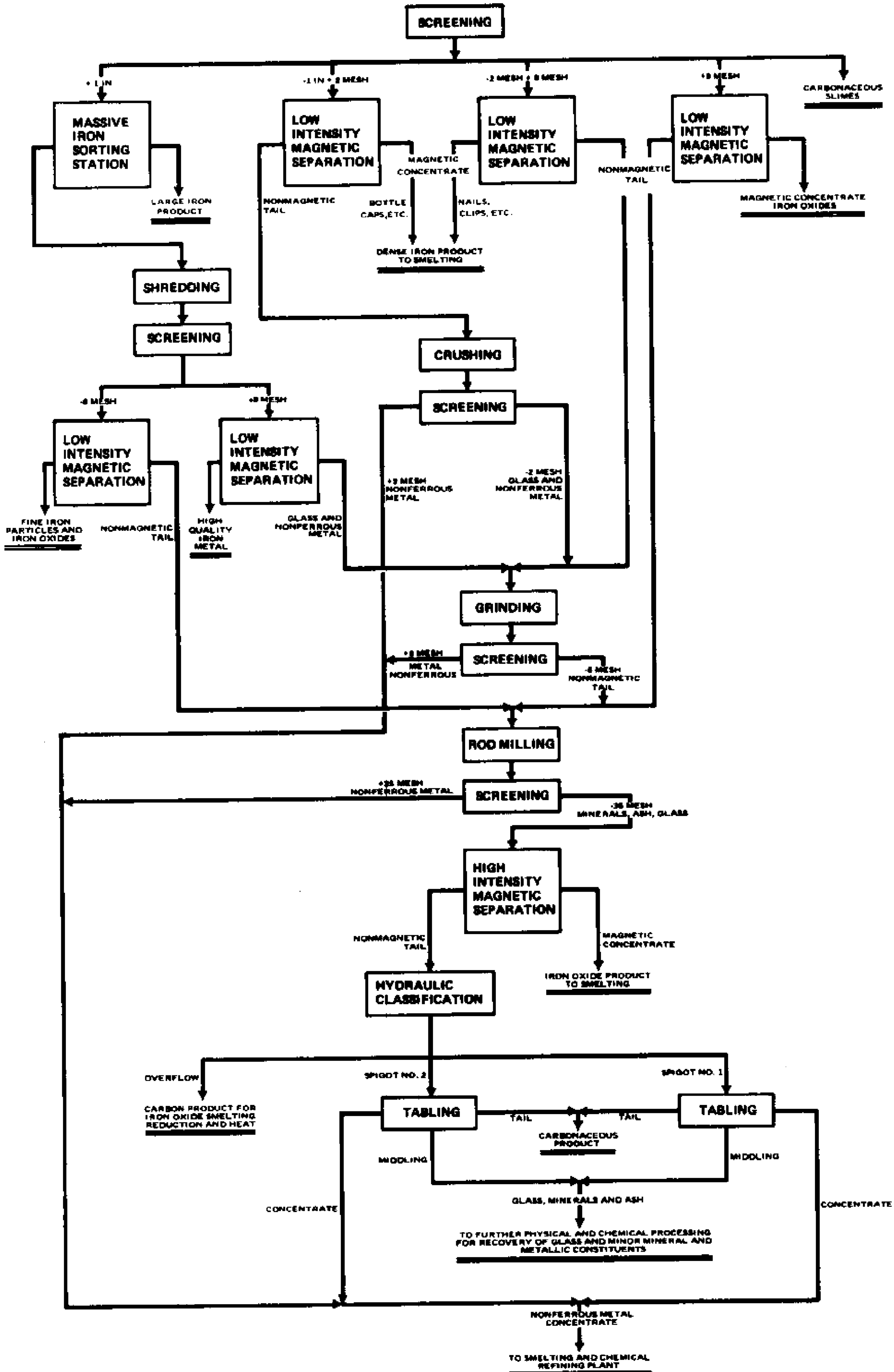


FIGURE 12 BUREAU OF MINES SYSTEM OF SEGREGATION OF INCINERATOR RESIDUE

In general, it makes all kinds of economic sense to make the manufacturer bear the cost of disposal; to, in the economist's jargon, internalize this cost. The obvious fact that the manufacturer will pass this additional cost on to the consumer is not an argument against this arrangement.* For, if a manufacturer produces a product that is cheaper to dispose of than a competitor's product, he will be able to offer his product at a lower cost than his competitor and therefore will be motivated to design for disposal. At present, a manufacturer who designs for disposal merely makes his product more expensive than his competitor's and loses customers. Politically feasible means for effecting this internalization of costs are not always at hand. However, at least for some products, such as automobiles and soft drink containers, workable legislation that accomplishes this end does appear possible.

In summary, we feel that large scale recycling of mixed municipal wastes will not take place in the immediate future. For example, in the Bureau of Mines effort (the most promising we have reviewed), we have a system which is barely out of the laboratory, whose costs have yet to be determined, and which is severely limited in the types of inputs it will accept. Assuming successful solution of these problems, we are still faced with the fact that there appears to be only a limited market for much of the nondecomposable material in the municipal garbage stream.

Composting

Between 80% and 85% of all refuse is compostable (52,3). There are a number of processes to produce compost, but all composting operations can be broken up into three basic steps: refuse preparation, stabliization, and product upgrading.

Refuse preparation includes the receipt of material, sorting, and salvage. Sorting is required in most composting plants to remove non-compostables, bulky items, and material with salvage value. In conjunction with a complete recycling scheme, only non-salvageables would be composted. Some systems include inertial or magnetic separation of refuse, but most rely on handpicking, an expensive, inefficient, and time-consuming method.

* Rather it is an argument for it, since the added cost will motivate the consumer away from purchases with high disposal costs.

** After this was written, the Bureau of Mines publishd preliminary cost estimates indicating $3.50 per ton residue in a 250 ton per day plant.

Grinding is required for efficient composting. There are various grinding systems used with power requirements from 3 to about 30 h.p. per ton-hour grinder capacity (3). Two stages of grinding are normally required.

Stabilization, or aerobic digestion, is usually done by either a mechanical process or by windrows in the open. Five to six days is the average decomposition time for ground refuse in U.S. mechanical plants. Windrow systems require from two weeks to three months for adequate stabilization. Since mixed refuse has a very high paper content, the carbon-to-nitrogen ratio of the ground product usually exceeds 70%. This should be adjusted to approximately 40% for rapid stabilization. This is usually done by adding sewage solids or nitrogen solutions. The moisture content should be approximately 55% and the refuse ground to a particle size less than one inch. Finally, the temperature achieved during composting should exceed 140°F for at least four days (52).

Product upgrading operations which follow digestion consist of some or all of the following: curing, grinding, screening, pelletizing or granulating, drying, magnetic separation, and bagging. Storage of the compost will result in slow decomposition without upgrading of some sort.

The windrow operation requires a good deal of land and is best suited to small cities where a local market for compost exists. Mechanical plants are better suited to large cities. They should be tied into a transportation system that can economically deliver refuse and distribute the compost.

Mechanical plants are fairly expensive. The cost of building the 150-ton/day facility at Gainesville, Florida, was $1,100,000; and the 360-ton/day Houston plant costs $2,000,000.

A table of capital costs, energy, and manpower requirements for various mechanical compost plants is given below. (The table was taken from the Proceedings: The Surgeon General's Conference on Solid Waste Management):

Capacity

Tons/ day	Fairfield			Metrowaste			International Disp. Corp.		
	$\$x10^6$	HP	Labor	$\$x10^6$	HP	Labor	$\$x10^6$	HP	Labor
100	1.4	900	8	0.9	1,250	12	1.4	600	20
200	2.1	1,400	11	1.2	1,700	17	2.1	800	28
300	2.5	1.700	14	1.5	1.900	25	2.7	950	36
400	3.2	2,500	20	1.6	2,000	30	3.2	1,100	45

Operating costs can be taken as a function of the manpower and energy requirements. In 1967, compost was selling for $16/ton and no plant in the United States was making a profit, despite receiving from $3.25 to $3.50 per ton from supporting communities for taking the rubbish (1,3,54).

The major problems seem to be:

1) segregation of non-degradables

2) the size of the market for compost.

If composting were to be adopted on a large scale by a coastal metropolis the output would certainly saturate the market. At that point, the only benefit of the composting would be that it makes a more desirable fill than raw or compacted garbage.

The private market for composting is very small. Compost is not well suited as a fertilizer for heavy agriculture. It is well suited for home gardening, but this market would be quickly saturated. It is also suited as a fertilizer for landscaping and parks. In Europe it has been used for years in vine-yards and "garden agriculture" (small vegetable plots). Again, these markets are usually saturated very quickly.

Compost manufacturers are beginning to think of their product as a filler for heavy agricultural fertilizers. This requires close cooperation with fertilizer manufacturers to create a suitable compost. It also requires a steady and very large supply at somewhat lower prices.

Compost has been used by governmental agencies for large-scale landscaping and filling. The use of compost for landfilling would prolong the life of a landfill. The completed landfill would be a more useful product. Cover would not be necessary during the landfill operation and fire and health hazards would be decreased. In summary, until a much larger market is visable, it appears that the processing costs of composting which have been estimated at about $6.00 per ton would, on a large scale, do nothing more than convert garbage to a more desirable fill material. It would be an unusual situation where a community would be willing to pay this price for this conversion.

In summary, recycling with or without composting is not a feasible alternative for large scale disposal of mixed municipal refuse streams. The rapidity with which this inherently attractive alternative becomes economic will depend as much on the development of markets for the output of the processing as it will on the development of the processing technology itself. Given the increasing scarcity of raw materials and an aggressive research and development effort, we can be sure that both these events will occur in the not too distant future. How soon, however, is a matter of judgment. Our review of the literature indicates to us that recycling of mixed solid wastes will not take place on a large scale for at least a decade. If this is the case, a community can go ahead and invest now in any of the other alternatives, except perhaps incineration, knowing that these systems will not be made obsolescent during their useful lifetime by recycling.

This relatively pessimistic view of recycling is, of course, not an argument against research and development of recycling. Quite the contrary, it points to renewed and strengthened efforts in reclamation technology. Furthermore, we foresee selective implementation of segregation and recycling occurring before this time. And almost every conventional disposal scheme would be aided by such advances. The removal of plastics would markedly aid incineration. The removal of certain metals would reduce some of the biological objections to ocean dumping.

II.5 Summary of Comparison of Land-Based Systems

Our survey of the market costs of land-based systems has indicated:

a) Recycling and reclamation cannot be expected to handle a major portion of municipal solid wastes for some time to come due to both processing problems and lack of markets for the output. It is, of course, a matter of judgment how soon this situation will change. In our opinion, large-scale recycling of mixed municipal wastes,as opposed to incinerator residues,will not take place for at least a decade.

b) The final disposal costs associated with incineration meeting present federal pollution standards appear to be some 30% higher than disposal costs associated with railhaul and sanitary landfill for the large coastal city.

c) Thus, railhaul and sanitary landfills appear to be the land-based alternative of choice in most situations. However, the large coastal city faces very severe political problems in obtaining upland sites for sanitary landfill. In the past five years, many upland communities and regions have enacted broad-based regulations forbidding the importation of solid wastes.

It is not completely clear that such restrictions on upland sanitary landfill of big city garbage are completely consistent with the values of the communities to which the garbage might be imported. Our costs are based on a sanitary landfill meeting rather rigid standards including daily covering of the stacked bales followed by a two-foot mantle. They are not to be confused with the more common open dumps. If a community has an area which has already been despoiled, such as a sand pit or quarry, sanitary landfill of the area can return the land to useful purpose. Further, it is clear that the community receiving the rubbish could potentially extract a fairly handsome fee from the community exporting the garbage. The difference between railhaul sanitary landfill and incineration is about $4.00 per ton. Ruling out other alternatives for the moment, this is the maximum amount which a hard bargaining upland community in a monopoly position could extract from the large city in return for the privilege of receiving its garbage. Of course, in a free market, bargaining among the upland sites will reduce this fee to something closer to the minimum amount of compensation that the community would be willing to accept to take the garbage. It is not clear why upland communities would want to take themselves out of this competition for they could always refuse the compensation offered. Part of this compensation would take place in the form of careful landscaping and restoration of the completed landfill. Westchester County envisions turning Croton Point Landfill into a particularly scenic portion of the Hudson River Bank complete with hills, pools, and even a zoo.

Be that as it may, it is understandable how broadbased restrictions against the importation of garbage are passed. In any political body threatened with importation, a law against such importation is bound to be put forward and anyone who votes against such a law is likely to be characterized as a lover of garbage, a despoiler of the countryside, and probably a pawn of big city interests. Few rural legislators would want to put themselves in such a position. More rationally, a person could feel quite rightly that any law is better than no law and that writing a law which carefully protected local public interests and at the same time allowed for mutually beneficial bargaining between the upland community and the big city is politically infeasible.

In any event, we are faced with the historical fact that most of the coastal communities find themselves legally cut off from the upland disposal sites. A notable exception is New York City where a unique political entity has evolved- the New York State Pure Waters Authority. The New York State Pure Waters Authority is a creature of the New York State Legislature. It may issue bonds and has the right of condemnation throughout the state. Among other things, the Authority is concerned with solid waste disposal for which purpose it identifies marginal land for potential landfill sites throughout the state, approaches the community in question with a plan for filling and restoring the site. Restoration may take the form of a completely developed park or a housing complex on terms very favorable to the community. The Authority can use its condemnation powers to remove the responsibility for allowing big city garbage into the area from the shoulders of the local officials who may feel that the offer is a good one but find it politically risky to be in favor of it. Thus, the New York State Pure Waters Authority is the political vehicle which allows New York City the option of reaching upstate disposal sites. So far, New York is unique in having such a body.

In sum, despite its potential economic viability, the alternative of upland sanitary landfill is not presently open to almost all the large coastal cities, and is unlikely to become more open in the near future. Further, there has been considerable concern expressed about the leachates resulting from a high density landfill, in which garbage is stacked as high as 100 feet. Some sanitary engineers feel that these leachates will have to be collected and treated, which would result in a substantial increase in landfill costs.

CHAPTER III

SEA-BASED DISPOSAL METHODS

This Chapter will examine the present technology of the three following sea-based disposal methods: Ocean Dumping, Incineration at Sea, and Coastal Landfill. The present and proposed operating procedures are detailed for each method. The potential ecological problems inherent in each system are exposed, and the relevant available information is noted. By utilizing a present value determination method, a price per ton disposal cost is computed.

Conclusions are presented in the last section of this Chapter.

III.1 Ocean Dumping of Refuse

In the face of economic and political pressures outlined in the last chapter, the concept of dumping solid wastes at sea in an essentially raw state (allowing for some mechanical treatment but no change in chemical content or composition) has received increasing attention. This section will attempt to analyze the logistics of alternative methods of dumping at sea. However, before doing so, it is necessary, at least, to comment on the non-market effects of disposal at sea.

These effects can usefully be grouped under two headings: ecological and sociological, where ecological refers to the effect on fauna and flora that would be measured by the biologist and sociological refers to effects on the ocean which will have a direct impact on humans. The need for this distinction arises from the fact that the effects which, by any biological measure, are beneficial may be valued negatively by humans. For example, distribution of chopped paper in nutrient-poor surface waters may have a very favorable effect on the ambient fauna but be regarded as quite offensive by the human users of the area.

In the context of this section, consideration of the ecological effects implies that one must be able to guarantee that the value of any deleterious effects on plant and animal life due to dumping at sea will be smaller than the savings achieved by ocean dumping (the differential in costs between ocean dumping and the cheapest feasible alternative). This requires keeping the following two facts in mind. The ecology of the oceans is in a very dynamic and extremely delicate state of equilibrium. This system may be very insensitive to certain perturbations but extremely unstable with respect to others. Second, one must consider the long-term effects of the disposal of solid wastes at sea. Even a disturbance which appears to have a beneficial short-term effect may result in harmful changes in the long-term patterns of growth and distribution.

While we were able to locate one study on the marine-biological effects of solid waste incinerator residue, and a few isolated short-term studies on the decomposition of specific solid waste articles in the ocean environment, no short- or long-term studies on the effects of raw solid wastes deposited in the marine environment are now available. Such a study would include extensive chemical analysis, tank tests, submerged pen tests, and biologically monitoring at the site of the dumping. At present, there are several organizations, universities, government agencies, and combinations thereof capable of conducting such a study, but all related research to date seems to have concentrated on estuarine problems associated with liquid wastes.

Consideration of sociological effects implies that the value of the detrimental effects of ocean dumping on recreational opportunities and enjoyment, on navigation and industry must also be weighed in any complete analysis of disposal at sea. In this context, it is important to remember that we are thinking in terms of rather large volumes of waste. New York City alone generates some 20,000 tons of municipal refuse per day.

The ecological and sociological effects of ocean disposal can be controlled by one of two rather differing philosophies.

1) An area of small ecological-sociological value is selected for a disposal site. Disposal and containment are handled in such a way that biological effects are as small as possible and are guaranteed to be restricted to the boundaries of the site. In this way, a site of low value is essentially "written off" and hopefully the ecology of the surrounding areas is not affected. In general, this philosophy points to disposal in deep waters well offshore, careful packaging of the wastes, and careful control of the dumping operation to insure dumping at the prescribed site. This is the philosophy which has governed most dumping to date.

2) The entire open ocean within range of the refuse generation area is divided into classified sectors, with a classification based on sociological ecological value. (e.g. prime fishing area, recreational area, spawning area, harbor area, ecologically rich area, ecologically barren area, area already used for dumping, etc.). For each area classification, an acceptable concentration of floating, suspended, and sinking solid waste would be computed. Dumping would then occur in each sector throughout the entire open ocean until the limiting concentration in a sector had been reached. Dumping operations in such a sector would then cease until the ecology had absorbed the waste and thereby lowered the concentration again.

This philosophy points toward dispersed dumping in shallow or surface waters of loosely packaged or ground refuse. It almost certainly implies some segregation of the waste stream to avoid particularly toxic or non-degradable materials. It attempts to take advantage of the ocean's biological activity to return the refuse to the life cycle quickly. In so doing, it will often find ecological and sociological values in conflict.

This report makes no attempt to evaluate either of these philosophies. In fact, we are almost certain that any large scale dumping at sea system will find it economic to use them in combination. However, we would be remiss in not at least mentioning their differences, particularly since the latter alternative is sometimes overlooked in discussions of dumping at sea.

We will now review the logistics of several alternative systems which employ dumping at sea.

System A1 - Dumping of Loose Refuse

This system consists of the following:

a) Trash is delivered by primary collection vehicles to dockside transfer station;

b) Loose Refuse is loaded into barges;

c) Barges are transported to sectors designated for that day's dumping and refuse is discharged into water.

Such a scheme could be conducted only under the "concentration" philosophy. This means that a particular area of the ocean is classified according to its sociological and ecological value, and a correspondingly acceptable concentration of refuse is computed. Refuse is then dumped in the area until the limiting concentration is reached.

However, a preliminary estimate of the composition of the incoming refuse reveals that the refuse is approximately 50% (by weight) paper. This fact brings two opposite situations into play.

a) Since almost all of the paper products will either float or remain suspended near the surface, a volumetric concentration level becomes meaningless. Only the volume very near the surface will be utilized.

If one conceded that only the upper 100 feet of the ocean shall be considered for the volumetric concentration, the area required to dispose of metropolitan solid waste becomes enormous.

b) On the other hand, paper products are generally quite easily decomposed by the physical and biological ocean environment, and rather high temporary concentrations may be permissable.

It is our conclusion that consideration (a) combined with the fact that the percentage of non-biodegradable (within reasonable time limits) solid waste is significant, outweights consideration (b), and this method is unworthy of further consideration.

<u>System A2 - Dumping of Bales Compacted Dockside</u>

This system consists of the following:

a) Trash is delivered by primary collection vehicles to dockside transfer stations and compacted into bales.

The primary collection trucks enter an enclosed dumping area and discharge into a storage bin, which should have capacity for one full operating day's (16 hours) accumulation of refuse. An overhead crane picks up the refuse and places it on a conveyor, which feeds the shredding facilities. The refuse passes through the shredding operation onto a second conveyor which feeds the baling press. The trash is compressed by the one-stroke baler into a bale, and strapped in the same operation.

b) Bales are loaded onto barges. The compacted bales are dumped by monorail into a barge. The barge loading facility is entirely enclosed within the station.

c) Barges are transported to disposal sites and bales are deposited on the sea bed.

This system is presented as developed by Metcalf and Eddy Engineers for the New York State Pure Waters Authority (48). The report detailed the specific system necessary to dispose of the solid wastes of Westchester County, New York, but the economics of this part of their system analysis seem relevant for general application. The operating cycle and costs are representative of their design of a system capable of handling 1,000 tons/day (16 hr.).

A major towing company approached Metcalf and Eddy, and quoted a flat rate of $2.60/ton upon the specification of a minimum annual quantity of 264,000 tons from each of three stations. These costs are also contingent upon approval of a dumping site approximately 80 miles off Sandy Hook at the mouth of the Hudson Canyon. A more detailed study of barge haul costs is presented in Appendix 4, together with their effect on overall system costs.

The economic analysis of System A2 is reported in detail in Appendix 2 and leads to the unit costs of $6.78 ($7.09) per ton for interest rates of 5% and 8% respectively.

System A3 - Dumping of Bales Compacted Inland

This system is almost identical to system A1. The only difference lies in the location of the transfer station. System A1 located the transfer station at the barge loading facility, and this seems reasonable for coastal municipalities, where the centroid of the solid waste generation area is near the coast. However, if the system of compaction and dumping at sea becomes economically and/or socially superior to rail haul and sanitary landfill for inland municipalities, this system would provide a feasible solution.

Using the Metcalf & Eddy Report again as a source of cost figures, a system capable of handling 1,000 tons/day for a transfer station located 50 to 150 miles inland is considered. The distance selected affects only the railhaul rate.

This system consists of the following steps:

a) Trash is delivered to inland transfer stations and is compacted into bales. Packer or compaction type trucks enter an enclosed dumping area and discharge into a storage bin. An overhead crane transfers the refuse from the storage bin to a conveyor belt which feeds the shredding units. From the shredding unit the material is transferred by conveyor to the baling unit where it is compressed into high density bales. These baling units include integral automatic strapping equipment. These bales are then placed in the rail car by a traveling crane.

b) Bales are transported by rail to dockside facilities and loaded onto barges. The refuse bales are then transported in specially designed side-loading rail cars to the barge loading site. Refuse would be removed from the rail cars at the unloading area by a high capacity fork lift truck, and placed in the barges by means of a monorail loader.

c) Barges are transported to disposal site and bales are deposited on sea bed. (A major towing company approached Metcalf and Eddy and quoted a flat rate per ton. Details are unavailable, but the rate quoted and minimum desired quantity are given.)

The economic analysis for this system A3 is reported in detail in Appendix 3 and leads to unit costs ($/ton) for interest rates of 5% and 8%, respectively given below:

Inland Transfer Station	i= 5%	i= 8%
50 miles	$10.61	$11.02
100 miles	10.97	11.37
150 miles	11.42	11.82

Barge Transportation Costs

In all of the ocean dumping systems, the cost of the barge-haul and dump procedure constitutes about 25% of the total disposal costs. The available proposals of solid waste disposal systems utilizing barge transportation have all recommended placing responsibility for this phase of the operation in the hands of a private contractor for a fixed fee. If considerations of the economies of scale of barge transportation were made part of the initial design parameters, instead of considering the barge haul operation as an external "black box", the scale of proposed sea-based solid waste disposal systems might be significantly increased.

The analysis carried out in Appendix 4 illustrates the economy of scale available in a barge system capable of handling 1,500,000 tons of refuse a year and leads to the following results.

These costs will vary with the interest rate used in the present value calculations. If we assume an interest rate of 5% without an additional inflationary factor, we obtain the following costs.

Summary of Barge Transportation Costs

Towing Distance	Towing Speed	Cost/Ton
20 miles	5 knots	$ .57/ton
50 miles	5 knots	1.30/ton
100 miles	7 knots	2.25/ton

Dispersal Effects of Dumping of Compacted Bales

Both Systems A2 and A3 employ the same ultimate disposal technique, the placing of compacted bales in a selected disposal site. This is an example of the "containment" philosophy, where an area of minimal ecological-sociological value, and hopefully minimal circulation is restricted as a dumping area. This concept places five constraints on the operation of the system.

1. The system must guarantee that each and every bale sinks to the bottom, without reaching a condition of neutral buoyancy. This means the compaction system must produce bales of a density greater than 64 lbs/cu. ft. High density compaction can be attained by the use of converted scrap-metal presses or extrusion-type bales similar to those used in the baling of paper and cotton. One-, two- and three-stroke compactors, both with and without pre-shredding, were investigated. The baler selected for preliminary design studies is a one-stroke baler manufactured by American Baler Company, which also requires a pre-shredding unit. The one-stroke baler was selected on the basis that neither two- nor three-stroke balers appeared capable of producing the required capacity without excessively expensive and cumbersome modifications.

With pre-shredding, the baler unit can guarantee an output of 25 tons/hour. The bale size is roughly 30" x 40" x variable length of from 40" to 80". Bales prepared for tests by the Sandy Hook Marine Laboratory were baled at about one-third normal operating pressure, and had a density of about 68 lbs/cu. ft. Densities of 70 lbs/cu. ft. under better operating conditions seem attainable. However, due to the variation in composition and moisture content of the refuse delivered to the baler, even with pre-shredding, we feel that the baler should have the capability of guaranteeing a minimum density of 70 lbs/cu. ft. on every bale produced.

2) The system must guarantee that the bale maintains its integrity during descent and upon impact on the ocean floor. The system designed around the American Baler mechanism includes a unit to provide automatic wire bale strapping.

Discussion with Mr. Richard Stone of the Sandy Hook Marine Laboratory indicates that the quality of the bales presently being produced may not be high enough to prevent extensive disintegration of the bale both in transit to the site and during the dumping operation. Inadequate preshredding allows many bales to contain whole bottles, magazines, cans, and other whole objects which would easily slough off under the influence of currents or wave action, and during handling procedures.

While the presently available shredding, baling, and strapping mechanisms appear to have the capability of producing bales of adequate integrity, further design improvement and intensive quality control procedures are clearly necessary.

3) The system must guarantee that the bales are deposited within the prescribed site limits. This will require suitable navigation equipment and aids to assure positive location of the barges above the dumping site. It also requires some knowledge of the descent trajectories of the bales under various sea-state conditions. This information is not yet available, but some sort of fathometric trace may provide adequate instrumentation to roughly determine descent trajectories.

4) The system must guarantee that the bales do not disintegrate in the ocean environment. While it appears that the bale will remain intact in its descent and impact phases, quick disintegration due to biological and chemical decomposition may still be a problem. At present no data on this problem is available.

5) The system must guarantee that the bales themselves will not be transported beyond the dumping site limits by current and tidal action. This problem must be solved by a suitable site selection criteria. Experience with incinerator residue indicates that a depth of 200 feet will ensure negligible ocean transport while fifty feet will not.

A Summary Cruise Report of the R. V. Challenger research vessel is presented in Appendix 5 to illustrate the type of information available.

III.2 Incineration at Sea

The concept of incineration and/or the disposal of incinerator residue at sea has only recently been proposed as a sea-based alternative to existing solid waste disposal methods. As sites for the land-filling of incinerator residue become more costly and scarce, and as the need for the construction of new efficient incinerators appears to become more acute, a system for burning and disposal at sea may gather a great deal of backing in both the public and private sector.

Three main system alternatives present themselves for disposal of incinerator residue:

S1) a. Incineration at existing inland incinerators and proposed regional incinerators.

b. Transport of incinerator residue to dock facilities and loading onto sea-transport mechanism.

c. Transport of incinerator residue from dockside to dumping site and placement on sea floor.

S2) a. Transport of raw garbage in primary collection vehicles to dock-side transfer station.

b. Incineration at new incinerator facilities constructed at waterfront sites.

c. Transport of incinerator residue from dock-side incinerator to dumping site and placement on sea floor.

S3) a. Transport of raw garbage in primary collection vehicles to dock-side transfer station.

b. Loading of raw garbage onto a water-borne incinerator, and transport of raw garbage to dumping site.

S3) c. Incineration while en route and/or at dumping site and placement of incinerator residue on sea floor at dumping site.

These systems present alternatives regarding

a. amount of material transported and distance transported;

b. use of already existing facilities;

c. type and cost of initial capital equipment expenditures;

d. system reliability.

Before these alternatives are considered, it is necessary to review the biological effects and the question of dispersion of the residue of incineration.

Biological Effects

Any system which includes the ultimate deposition of incinerator residue on the sea floor, whether in a state of static or dynamic equilibrium, must guarantee a controlled minimal effect on the marine life there, both plant and animal, free-swimming and bottom dwelling. It must be realized that: 1) Many perturbations will appear to have little or no short-term deleterious effects but may have very serious and irreversible long-term (5-25 years) effects on the ecology of the sea bed; 2) Since an extremely delicate equilibrium is in operation in the food chain of the sea floor, the very slightest perturbation, even one which seems to have beneficial short-term effects, may cause violent, irreparable damage; 3) Since the residue of the present state-of-the-art incineration is essentially non-biodegradable, the self-cleansing and renewing mechanisms of the sea ecology will have a long and difficult task in assimilating this residue.

We have been able to uncover only one research program dealing directly with this issue of the biological effects of incinerator residue. However, there are numerous projects in progress on the toxicity of particular chemical compounds which could conceivably be extrapolated and combined to predict the effects of incinerator residue. Working on a Research Grant[1] from the U. S. Public Health Service, the Harvard School of Public Health has published the preliminary results of a study on "Waste Incineration at Sea and Ocean Disposal of Non-Floating Residues." (67)

Experiments to determine the chemical composition of a representative sample of incinerator residue established the percentages of nitrates, ammonia, sulphates and other components of importance in the nutrition of marine plankton. Special attention was also placed on the heavy metal content of incinerator residues, because of their toxicity to marine organisms, and potential concentration in the marine food chain. Bioassays were conducted on a variety of marine species under exposure periods ranging from one day to three years. Although survival rates constituted the main toxicity measurement, sub-lethal effects on hatching and larval processes and long-term growth rates were monitored.

The main thrust of the program was the determination of the level of concentration at which harmful effects were introduced, under the assumption that a residue concentration of 1% would require at least 25 years of very intensive dumping to accumulate. Results indicated that --

a) Quahog, winter flounder, shrimp, adult lobster, and millet were relatively immune to incinerator residue;

b) Menhaden, lobster larvae, and sea scallops showed some significant mortality rate increases due to incinerator residue;

c) Hard shell clams showed lower mortality rates and higher growth rates after exposure to the residue;

---

[1]Research Grant 5 ROI UI 005-57-04 from the Solid Waste Program, U.S. Public Health Service.

d) Results regarding concentration of heavy metals were observed for all species tested, and it is suggested that this factor is unlikely to cause toxicity to exposed marine species; nor is there likely to be significant concentrations of these elements in food fish important to man.

The overall results of this testing program seem to indicate that the short-term effects on marine life outside the prescribed dumping area will be minimal, and no significant long-term effects are apparent.

Dispersion of Incinerator Residue

The second constraint common to all systems depositing incinerator residue on the ocean floor is the need for suitable site selection. Once you feel that you can guarantee minimal deleterious effects on marine life outside the immediate dumping area, you must be able to control the dispersion of the residue and gradual growth of the disposal site.

As part of the Harvard School of Public Study, several tons of actual incinerator residue were deposited at two locations off the southern shore of Rhode Island. A shallow water site, approximately 50 feet deep and 2 miles from shore, was selected as being representative of the minimum feasible depth for disposal. The area was visually monitored by SCUBA divers, and weather, current and wave height measurements were recorded. It was observed that the attenuation of violent free-surface wave effects was insufficient to prevent the motion of some lighter residue, such as tin cans. Heavy storm seas were capable of large mass transport of the residue, and the 50-ft. depth was classified as totally insufficient for the system.

A second deep water site, approximately 200 feet deep and 18 miles from shore, was monitored for a period of several months through the use of a small research submersible and instrumented buoy arrays. The maximum distance a half-gallon can was observed to have moved as a result of severe storm seas was approximately 50 feet. Since the greatest portion of the residue had remained essentially motionless for the entire summer, the study group stated:

"On the basis of these and other observations, it has been concluded that incinerator residues should be deposited in waters at least 200 feet deep to avoid significant migration from the assigned site under the combined effects of wave action plus tidal and bottom currents and that depressions in the ocean floor, where bottom currents are minimal, would be ideal."

We feel that certain logistic consideration-ations must be added to the above conclusion.

1) As one goes to deeper disposal sites (and therefore sites further from shore), the problem of locating the site under poor operating conditions (storm seas, darkness, fog, etc.) becomes extremely difficult.

2) Once one has located the dumping site, the problem of positioning the unloading facility to assure that the trajectories of the falling residue carries it near to the center of a one or two square mile site also becomes exceedingly difficult. There appears to have been no study of the descent rate of the residue.

3) In trying to select a site on the basis of existing current data, one must realize that some migration rates are allowable. Most of the more easily transported residue components, such as tin cans, are also those that are most susceptible to disintegration from the abrasive action of the transport process. Observations of incinerated cans suspended in sea water indicate that within one year the metal disintegrates into a mass of small flat crumbly scale particles.

4) Assuming little or no significant migration occurs, use of existing sites presently designated for the disposal of explosives, dangerous chemicals, and mud, when these areas are within reasonable distance from collection sites, would represent a solution with smaller net ecological effects.

It is therefore our supplementary conclusion that while the 200-foot depth does appear to be a safe minimum depth limit, the costs of surveying prospective sites at this depth, and the costs of navigational aids to ensure dumping within the subscribed site once it has been selected, must be figured into the cost of any sea disposal of incinerator residue system. These costs will increase rapidly with increase in depth.

Analysis of System S1

This part of the analysis is concerned with (a) incineration at existing or proposed land based incinerators, (b) transport of residues to dockside and (c) transport from there to the dumping site. The economic analysis of each step follows.

As shown previously in Section II-1, existing inland incinerators now handle approximately 10% (1) of the total municipal refuse accummulation. The construction of large-scale regional incineration systems as described could:

1) guarantee an 80%-90% reduction by volume of solid waste;

2) incinerate the solid waste at an average cost of $10.50*/ton.

However, in order for this residue to be suitable for sea disposal, we must guarantee that it contains no floatables. Efficient high-temperature incineration (as distinguished from existing local incinerator systems) claims to guarantee that no combustible materials come through unburned. For such a furnace, the only necessary sinkage treatment would be a crush process to get rid of non-combustible floatables such as semi-closed cans. A crusher of the Martin Company design appears suitable for this purpose, and should be included in the incineration plant design. (61)

This brings up the very valid point that the poor quality of incineration available from existing local medium-temperature incinerators would not suffice for guaranteeing the sinking of the residue, even with a crusher treatment added. Too many combustible paper and wood products, whose buoyancy would be essentially uneffected by crushing, are found in the residue of these incinerators. More exotic treatment of the

---

*i = 5%

residue, such as weighted packaging, or compacting, or tarring may be necessary, but the determination of the feasibility of such treatment has not been accomplished and its accomplishment is not within the scope of this report.

For the transport of incinerator residue to dock facilities the residue is (under normal operating procedures) quenched by a water spray or bath as the residue leaves the incinerator. Sufficient water is absorbed or retained to increase the weight of the residue from 40% to 70% above its dry weight. Records of refuse disposal operations in Washington, D. C., Arlington County, and Alexandria (10) show these general relationships of incinerator residue to raw refuse for existing incinerator plants.

1) The wet bulk density of residue averages about 1000 lbs. per cubic yard.

2) Approximately 0.35 to 0.5 tons of wet residue results from burning one ton of raw refuse.

In the Solid Waste Disposal Study for the Washington Metropolitan Region already cited (10), the following cost figures for a haul involving 20 miles of expressway travel and 5 miles of non-expressway travel are presented

10-Cubic Yard Vehicle	35-Cubic Yard Vehicle
$3.50/ton of residue	$1.25/ton of residue

Since the larger 35-cubic yard vehicle will be more compatible with the proposed large regional incineration plants, we have chosen to use the cost of $1.25/ton in the subsequent analysis.

Conversion of this cost per ton of residue to a cost per ton of untreated refuse yields a price of

$$\frac{\$1.25}{1 \text{ ton residue (wet)}} \times \frac{0.425 \text{ ton residue (wet)}}{1 \text{ ton solid waste}} = \$0.53/\text{ton}$$

The transfer of the residue from the trucks to the barges should be accomplished directly at a paved loading dock area. The relatively high density (and therefore small volume) of the residue should minimize congestion problems.

Using a barge transportation cost analysis similar to the one presented in Appendix 4, we can establish the following costs:

Miles to Dump Site	Cost/ ton residue	Cost/ ton solid waste
20	$ .65/ton	$ .28/ton
50	$1.00/ton	$ .43/ton
100	$1.27/ton	$ .54/ton

For the sake of comparison with the other systems involving a sea dump operation, the 50-mile distance to the ocean dump site is used in determining an overall price for disposal.

This leads to an overall cost figure for system S1 as follows:

a)	Incineration	$10.50/ton	$11.00/ton
b)	Transport to Dock	0.53/ton	0.53/ton
c)	Sea Transport & Dump	0.43/ton	0.43/ton
	TOTAL	$11.46	$11.96

Analysis of System S2

This system concept differs from System S1 in only one essential area -- the location of the incinerators. And in this one area S2 is inferior on two counts:

1) Regional inland location is designed to minimize the distance traveled by (and thereby the costs of) the primary collection vehicles. By locating the incinerator in the port complex, one both increases the distances and costs of primary collection, and forces the collection vehicles to operate in the already congested and inadequate (usually) dock transfer area.

2) Regional inland location allows some latitude in finding suitable land at a reasonable cost, and minor deviations to capitalize on local geographic and economic conditions. Dockside location forces the purchase of easily accessible (both by land and sea) waterfront property, which is at somewhat of a premium.

Therefore, we conclude that System S2 is both economically and logistically inferior to System S1, and unworthy of further consideration.

Analysis of System S3

This system represents a radical departure from any existing solid waste incineration techniques, both in overall system concept, and in a large part of the necessary equipment. The only completed study on this area consists of a report prepared by Abraham Michaels for the City of New York City Planning Commission entitled, "Feasibility Study of a Water-Borne Incinerator." (61) In the preliminary design considerations, the main system functions were characterized by the following mode of operation.

Transfer stations are designed and constructed to accept garbage from existing primary collection vehicles. The refuse is compacted into storage containers, and these containers are then placed in special racks in the ship's hold. These containers are designed to allow ram discharge into the incinerator. The size and rated capacity of the transfer system is a function of the cycle time (seebelow).

The filled containers are unloaded using a bridge crane and track extension to remove the filled container from the dock and place it in its assigned rack position. The garbage is then transported and burned on the basis of either a 2-day or 3-day cycle. (see below). The cycle time determines ship size and incinerator capacity, as well as transfer station size.

Incineration may occur while en route provided that all burning takes place at least 10 miles offshore (or at the dumping site) to ensure adequate air pollution control. (see 1965 N.Y.C. Department of Sanitation Report, "Survey, Study, and Report on the Disposal of Oversized Burnable Waste.")

The following general components were formulated for the incinerators.

1. A continuous feed-water cooled chute

2. A hung and tied-back refractory lined furnace

3. A separate refractory lined combustion chamber for complete gas burn out

4. A travelling or reciprocating feed grate

5. Combustion air fans

6. An insulated metal stack

7. A crusher-type, wet quench residue removal system

8. No separate air-pollution control devices will be included.

Residue leaving the incinerator will pass through crushers into a water-quench hopper. It is then pushed out of the hopper onto a conveyor belt, carried to the top deck, and dumped into an open well located amidships. This will provide for the separation of flotables and non-flotables in the residue. The non-flotables sink through the well to the ocean bottom. Any flotables remaining on the surface will be periodically skimmed off and recycled through the incinerators.

The equipment and operating costs of such a system have been computed for three different operating scale and/or cycle time arrangements given as follows:

1) Two-day cycle system:

All refuse received in a two-day period is initially stored at a transfer station, then loaded on board and transported to the burning and dumping site. The capacity of this system is approximately 650 tons/day, (two 500 ton/day furnaces used) operating 6 days/week.

2) Three-day cycle system:

All refuse received in a three-day period is initially stored at a transfer station, then loaded on board and transported to the burning and dumping site. The capacity of this system is approximately 780 tons/day, (two 500 ton/day furnaces used), operating 6 days/week.

3) Liberty-ship conversion system:

Due to ship size constraints, the Liberty-ship incinerator will operate on a two-day cycle. The capacity of this system is approximately 433 tons/day (two ton/day furnaces used) operating 6 days/week.

The details of these analyses are reported in Appendix 6 and yield the following results:

	Cost in $/tons for interest rate of	
	5%	8%
Two-day cycle system	11.33	12.39
Three-day cycle system	10.10	11.08
Liberty-ship conversion system	14.97	16.08

Backup Capability Required by Weather Considerations

The figure of $10.10 for an incineration-at-sea cost is undoubtedly very optimistic in that it does not take into account the effect of days in which operation is not possible due to weather conditions. Discussions with the Perini Corporation of Boston and Moran Towing Corporation of New York indicate that a sea disposal system should expect to be inoperative due to weather conditions 1-2 days per month in the summer and 3-6 days per month in the winter. Moreover, these days should be anticipated to occur in blocks.

Since the solid waste flow is essentially continuous, this condition places major backup requirements on any sea-based system, and especially on the waterborne incinerator system due to the specialized nature of the equipment. While the dumping-at-sea system can hire additional barges on a short-term basis from other dumping operations to dispose of a backlog of solid waste, the water-borne incinerator system must bear the full costs of additional capacity.

A reasonable design criterion might be the requirement of disposal of material backed up by a three-day storm in two weeks. (It should be noted that any actual implementation of an incineration-at-sea system would require a careful study of local weather patterns to determine an appropriate back-up capability level.)

This design criterion would probably require additional incineration capacity as well as storage space, since, if a seven-day week is worked after storms, it would take three weeks for the three-day cycle to adjust. Disruption of the normal operating schedule during the three weeks may entail further operating problems.

A conservative estimate of the necessary back-up requirements implies a 25% increase in incineration capability and suitable buffer storage. The rough costs of such back-up capability would entail a 25% increase in incinerator and housing costs, a 50% increase in container cost, and a 50% increase in storage costs. When these estimates are placed back into the present-value cost determination, the final cost for the most efficient water-borne incinerator is shown to be

$10.89 (i=5%)

$12.00 (i=8%)

Weather is not the only problem faced by the water-borne incinerator. Any solid waste disposal system must have the ability to function during, or at least quickly recover from, any sort of system disruption.

Ocean dumping of the residue of landbased incinerators is clearly superior to a water-borne incinerator due to the former's system configuration of a large number of low-complexity barges. A damaged barge could be fairly easily repaired or replaced, and the total system could operate effectively with one or two barges down. Only failure of your main propulsion tug(s) would represent complete system failure and these too are quickly replacable. However, due to the system configuration associated with sea-borne incineration, namely one ship of high complexity, container manipulating components, etc., failure of any major component would probably result in the abortion of the trip and a complete slippage of the two- or three-day cycle time. Differences in system reliability have not been allowed for in our cost per ton figures.

III.3 Coastal Landfill

Almost all the large coastal cities with which we are concerned in this report have in the past placed heavy reliance on landfills, (some sanitary, most not) along their shoreline. In some cases, such as New Orleans, use of this alternative continues unabated. However, most such cities have found it increasingly difficult to locate politically feasible shoreline sites for landfill. The San Francisco Bay area communities are now prohibited by law from developing new disposal sites in the bay. New York City regards itself as unable to locate any new coastal landfill sites. Boston not only cannot locate a coastal site for landfill, but is even unable to find a politically feasible site for an incinerator along its long shoreline. This rapidly increasing opposition to use of the shoreline for disposal is a product of both the realization of the ecological importance of such traditional sites as marshes and flats and, more significantly, of the rapidly rising value of present shoreline real estate which would be removed from the shore by landfill. Nonetheless it is not clear that complete prohibition of coastal landfills is consistent with the values of the community involved.

The problem of how much of the coastal zone should be devoted to sanitary land fills is a special problem in the economic allocation of the shoreline which problem is more generally treated in considerable detail in Volume II of this series. Therefore, we will not consider the problem further in this volume other than to note that whether or not the large coastal cities have run out of coastal fill sites from the point of view of the economists, it appears that most of them believe they have run out of politically feasible sites. From a pragmatic standpoint then, it appears that coastal landfill will not play a major role in the future in the disposal of municipal solid waste.

A potential varient of shoreline landfill which avoids some of its political problems involves the construction of artificial islands using, in part, municipal wastes. We have not been able to give this alternative any analysis during this study. However, especially in areas which are considering the construction of such islands for such reasons as to accommodate the rapidly increasing drafts of bulk carriers (e.g. the Gulf Coast ports), it appears to deserve careful attention.

III.4 Conclusions with Respect to Disposal at Sea

There are two rather distinct philosophies which can be followed for dumping refuse at sea. One approach is to accept the ecological destruction of a designated area and attempt to confine all the effects of the refuse to that area. One, then, chooses areas which are judged to be ecologically unimportant. This has been the prevailing philosophy among marine biologists who argue for dumping off the continental slope at depths greater than 1,000 fathoms with the waste suitably contained to keep it from spreading. The other philosophy is to view the ocean as a link in the natural process of returning the wastes to the life cycle. Holders of this point of view point out that the ocean has considerable regenerative powers, that in proper concentrations much waste material can be regarded as useful nutrients for the lower levels of marine life. They point to even such unattractive materials as the acid mine wastes dumped in outer New York Harbor, noting that in the center of this dump the water is biologically dead while around the edges marine life flourished at levels higher than those in the undisturbed waters.

Obviously, there are very substantive differences in these two philosophies. The first calls for dumping in very concentrated areas, the second calls for a much more even distribution of the wastes. Holders of the first view point out that almost no bacterial action takes place at such depths. The apple on the ALVIN after being submerged at 4,500 feet for close to a year was perfectly edible when the boat was raised, as was the meat in the bologna sandwich. Thus, holders of the second view are led to recommending near-surface dumping in shallow water or at least in the photic zone. These are just the areas most valuable to man, and this places a much heavier burden on holders of the second philosophy since they must be much more concerned with the sociological effects of the garbage than those who call for confinement in deep waters. Their information requirements are much higher and presently this information does not exist.

There are a variety of ways of dumping solid wastes at sea:

1) Surface dump of the raw garbage

2) Surface dump of ground garbage

3) Compaction and dump of compacted bales with and without packaging

4) Pump raw garbage to depths where natural compression renders all the garbage denser than the sea water.

The first alternative was at one time practiced by New York City among others. However, New Jersey was able to obtain an injunction on any dumping which might result in the garbage returning to shore and New York found it uneconomical to take the garbage far enough to prevent its return. The economics have changed in favor of longer trips. However, this alternative is dominated by compaction because the shorter trip which compaction allows more than compensates for the costs of compaction. Thus, dumping raw garbage appears neither feasible nor economic.

The second alternative is the one most consistent with the philosophy of using the oceans biological powers to return wastes to the life cycle. It will run about 1.00 more per ton than the first alternative and probably require as long a trip. Therefore, at present it also appears to be dominated by alternative (3) with respect to costs of transportation. However, if the validity of the dispersal philosophy can be substantiated, then it will deserve serious attention.

Compaction of garbage to densities higher than that of sea water is presently at the edge of the state-of-the-art. Bales have been produced from municipal garbage with densities in the 70-75 pound per cubic feet range. However, in our view, no one has demonstrated the ability to consistently produce heavier than water bales over a range of garbages. We feel that this ability can be achieved at little more than present baling costs as soon as the need is demonstrated.

Baling is the technological advance that has made dumping at sea feasible. No experimentation on the ecological effects of the dumped bales other than very short-term observations of a few bales on the bottom in shallow water have been undertaken. Nor has the differential in these effects associated with different packaging materials been studied. Covering the bales with polyethelene would cost about 1.00 per ton (40). Given a deep water dump, this would have little effect other than to prevent surface spauling during decent.

In summary, dumping of compacted bales at sea appears to be the most attractive of the marine alternatives with respect to solid waste disposal from the point of view of market costs. However, before it or any other sea based disposal system is placed in operation, we should know much more than we presently do about the ecological effects associated with this activity.

APPENDIX I

Sample Economic Analysis for System R-1 for Rail-Haul Sanitary Landfill

The figures quoted are those reached by Metcalf & Eddy in the design of a particular station with a capacity of 1,000 tons/day for 260 days/year = 260,000 tons/year (48).

Capital Expenditures

a)	Land (5-7 acres)	$ 450,000
b)	Transfer Station Building Cost	1,228,000
c)	Equipment Cost	

Item	Quantity	Unit Cost	Total Material Cost
Scale & recorder	1	10,000	$ 10,000
Bridge Crane 10 ton	3	135,000	405,000
Apron Conveyor	2	24,000	48,000
Shredder	2	102,000	204,000
Shredder motor & Accessories	2	37,000	74,000
Shredded refuse Conveyor	2	15,000	30,000
Baler	4	48,000	192,000
Baler Motor & Accessories	4	3,125	12,500
Strapping Unit	4	20,000	80,000
Traveling Crane 2.5 ton	1	21,300	21,300
Traveling Crane for Bulky Wastes	1	7,700	7,700
Miscellaneous Hoppers		15,000	15,000
Transformers		26,000	26,000
			$ 1,125,500

Operating Costs

A) Overhead

Shredder Power	$ 65,800
Baler Power	19,100
Crane Power	17,100
Lighting & Ventilation	12,600
Heating	5,000
Strapping Bales	91,000
Hogger Blade Replacement	130,000
Maintenance on Equipment	44,000
Maintenance on Building	17,000
Total	$401,500
Contengencies 15%	60,000
Total Annual Cost	$461,500

b) Labor

	Number/Day	Yearly Salary	Total
Weigh Master	1	6,700	$ 6,700
Mechanic	3	9,000	27,000
Crane Operator 10 ton	4	10,000	40,000
Superintendent	2	10,500	21,000
Laborer	5	6,700	33,500
Baler Operator	2	8,000	16,000
Shredder Operator	2	8,000	16,000
Bale Stacker	2	8,000	16,000
Bulky Waste Loader	1	8,000	8,000
Total			$184,200
(Pension, Taxes, Payroll, Office, etc.) 50%			92,100
Total Annual Cost			$276,300

c) Transportation Costs

These figures are based on 100 tons/car loading density in cars attached to regular trains and railroad owned cars (46).

Shipping Distance	Dollars/Ton
50 miles	2.65
100 miles	3.00
150 miles	3.45

d) Sanitary Land-Fill Charges

These figures are based on a site capable of handling 3,300 tons/day of high-density compacted bales. Costs per ton are significantly below normal Sanitary land-fill costs because,

1) Uniform weight and shape of bales eases handling problems.
2) High density of bales prolongs (usually doubles or triples) the life of the land-fill operation.
3) High density bales reduce need for bulldozers and rollers to ensure stabilization of land-fill site.

	Cost/Ton
Land	$0.06
Site Development	0.09
Equipment Cost	0.14
Operating Cost	0.16
Labor Cost	0.21
Total	$0.66/Ton

Present Value Determination:

Capital Costs

Item	Cost	Life	Total Cost
Land	450,000	20 Years	$ 450,000
Transfer Station Building	1,228,000	20 Years	
Roads, Sidings, etc.	200,000	20 Years	
	1,428,000		
ENR correction	x 1.575		
	2,249,100		2,249,100
Equipment	1,125,500	20 Years	
30% installation	337,650		
	1,463,150		1,463,150
			$4,162,250

Operating Costs (Annual)

Transfer Station	461,500
Labor	276,300
Transportation by Rail*	689,000
Sanitary Land Fill Charges**	171,600
	1,589,400

* Based on 260,000 tons/yr. being hauled 50 miles
** Based on 260,000 tons/yr.

The determination of the present value price as outlined in Chapter I is worked out in detail to demonstrate the methodology.

P_t = price per ton charged on annual basis

X_n = number of tons moved each year

i = interest rate

n = year of operation = (1,2,3, , , , 19,20)

Therefore the total annual charge the community must pay each year is $(P_t X_n)$. As stated in the introduction, under the assumption of equal annual payments over the 20-year life span of the operational equipment, the present value of these payments is given by

$$\sum_{n=1}^{20} \frac{1}{(1+i)^n} [P_t X_n] = \text{P.V. of payments}$$

Since P_t is an unknown constant and X_n is a known constant = 260,000 tons, they may be factored out of the expression, yielding

$$(260{,}000)\, P_t \sum_{n=1}^{20} \frac{1}{(1+i)^n} = \text{P.V. of payments}$$

for i = 5%,

$$\sum_{n=1}^{20} \frac{1}{(1+i)^n} = 12.462$$

for i = 8%,

$$\sum_{n=1}^{20} \frac{1}{(1+i)^n} = 9.818$$

As shown in the introduction, the present value of the costs of the operation, C, is given by

$$\hat{C} = \sum_{n=1}^{20} \frac{1}{(1+i)^n} C_n$$

where C_n = Costs (capital & operating) incurred in year n

i = interest rate

n = year of operation = (1,2,3, , , 19, 20)

In this particular case,

	4,162,250	capital costs
	+1,589,400	operation costs
C_1 =	5,751,650	total costs in year 1

	0	capital costs
	+1,589,400	operating costs
C_2 =	1,589,400	total cost in year 2

$C_2 = C_3 = C_4, \; , \; , = C_{20}$

Therefore $\hat{C} = \frac{1}{(1+i)^1}(5{,}751{,}650) +$

$$\frac{1}{(1+i)^2}(1{,}589{,}400) + \frac{1}{(1+i)^3}(1{,}589{,}400)$$

$$+ \; . \; . \; . \; . \quad + \frac{1}{(1+i)^{20}}(1{,}589{,}400)$$

$$\hat{C} = \frac{1}{(1+i)^1}(5{,}751{,}650) + \sum_{n=2}^{20} \frac{1}{(1+i)^n}(1{,}589{,}400)$$

$$= [5{,}325{,}452.74] + [14{,}133{,}103.74]$$

$$= 19{,}458{,}556.48 \text{ (for } i = 8\%)$$

Finally, by setting the present value of the payments equal to the present value of the costs

$$\sum_{n=1}^{20} \frac{1}{(1+i)^n}[P_t X_n] = \sum_{n=1}^{20} \frac{1}{(1+i)^n} C_n$$

where P_t is the only unknown, we can solve for the annual price per ton charged to the community. In this case

for $i = 5\%$, P_t = \$7.34/ton;

for $i = 8\%$ P_t = \$7.62/ton.

APPENDIX II

Economic Analysis of Dumping at Sea for Bales Compacted Dockside

The figures quoted are those reached by Metcalf and Eddy in the design of a particular station with a capacity of 1,000 tons/day for 260 days/year = 260,000 tons/year

Initial Capital

a) Land (3-4 acres) — $ 120,000

b) Transfer Station Building Cost

1)	Pile Foundations & Sheeting	$ 200,000	
2)	Main Building	1,190,670	
3)	Barge House	229,512	$1,620,182

c) Equipment Costs

Item	Quantity	Unit Cost	Total Material Cost
Scale & Recorder	1	10,000	10,000
Bridge Crane, 10-ton	3	135,000	405,000
Apron Conveyor	2	24,000	48,000
Shredder	2	102,000	204,000
Shredder Motor and Accessories	2	37,000	74,000
Shredder Refuse Conveyor	2	15,000	30,000
Baler	4	48,000	192,000
Baler Motor and Accessories	4	3,125	12,500
Strapping Unit	4	20,000	80,000
Monorail	1	27,800	27,800
Traveling Crane for Bulky Wastes	1	14,600	14,600
Miscellaneous Hoppers		15,000	15,000
Transformers		26,000	26,000
TOTAL			$1,138,900

Operating Costs

a) Overhead

Shredder Power	$ 65,800
Bailer Power	19,100
Crane Power	17,000
Lighting & Ventilation	12,600
Heating	6,500
Strapping Bales	91,000
Hogger Blade Replacement	130,000
Maintenance on Equipment	45,000
Maintenance on Building	21,300
TOTAL	$408,300
Contingencies 15%	61,200
TOTAL ANNUAL COST	$469,500

b) Labor	Number/ Day	Yearly Salary	Total
Weigh Master	1	6,700	6,700
Mechanic	3	9,000	27,000
Crane Operator,10-ton	4	10,000	40,000
Superintendent	2	10,500	21,000
Laborer	5	6,700	33,500
Baler Operator	2	8,000	16,000
Monorail Operator	2	8,000	16,000
Bulky Waste Loader	1	8,000	8,000
(Pension, Taxes, Payroll, Office, etc.) 50%			92,100
TOTAL			$276,300

Transportation & Disposal Cost

(Quoted by Moran Towing Corp.) $2.60/ton

For 260,000 tons/year = 676,000 total.

Present Value Determination

Capital Costs

Item	Cost	Life	Total Cost
Land	$ 160,000	20 yrs.	$160,000
Transfer Station Building	1,620,182	20 yrs	
Roads, Dredging etc.	170,000	20 yrs.	
	$1,790,000		
ENR correction	x 1,575		
	$2,819,537		$2,819,537
Equipment	1,138,900	20 yrs	
30% installation	341,670		
	1,480,570		$1,480,570
			$4,460,107

Operating Costs (Annual)

Transfer Station	469,500
Labor	276,300
Disposal	676,000
	1,421,800

Solution of the present value price determination

$$\sum_{n=1}^{20} \frac{1}{(1+i)^n} P_t X_n = \sum_{n=1}^{20} \frac{1}{(1+i)^n} C_n$$

equation by the methods given on pages I-4, I-5 yields a price per ton charged to the community:

for i = 5% P_t = \$6.78

for i = 8% P_t = \$7.09

APPENDIX III

Economic Analysis of Dumping at Sea for Bales Compacted Inland

The figures quoted are an estimate taken from those reached by Metcalf & Eddy in the design of a system with a capacity of 1,000 tons/day for 260 days/year = 260,000 tons/year.

<u>Initial Capital</u>

A. Inland Rail Transfer Station*

a) Land		450,000
b) Transfer Station Building Cost		1,128,000
c) Equipment Cost		1,125,500
		2,703,500

B. Barge Transfer

a) Land (5-6) acres		150,000
b) Building Cost		
Pile Foundations & Sheeting	140,000	
Barge House	230,000	
		370,000
c) Unloading Area Cost		
Apron	16,000	
Rail Spur	150,000	
		166,000

d) Equipment Costs

Item	Quantity	Unit Cost	Total Material Cost
20-Ton Fork Lift	2	210,000	420,000
Close-Coupled Engine	1	35,000	35,000
Conveyor	2	24,000	48,000
Monorail	1	27,800	27,800
TOTAL			530,800

*These figures are exactly the same as presented under Rail Haul - Sanitary Land Fill, page I-1 , and are only summarized here.

Operating Costs

A. Inland Rail Transfer Station*

a) Overhead	461,500
b) Labor	276,300
	737,800

B. Barge Transfer Station

a) Overhead

Conveyor & Monorail Power	6,000
Heating, Lighting, Ventilation	13,000
Fuel	6,000
Maintenance on Equipment	20,000
Maintenance on Building	11,000
TOTAL	56,000
Contingencies 15%	8,400
TOTAL ANNUAL COST	64,400

b) Labor

	Number/Day	Yearly Salary	Total
Supervisor	2	10,500	21,000
Mechanic	2	9,000	18,000
Fork Lift Operator	2	8,000	16,000
Monorail Operator	2	8,000	16,000
Laborer	4	6,700	26,800
			97,800
(Pension, Taxes, Payroll Office, etc.) 50%			48,900
TOTAL			146,700

c) Transportation

These figures are based on 100 tons/car loading density in cars attached to regular trains and railroad-owned cars.

---

*These figures are exactly the same as presented under Rail Haul - Sanitary Land Fill, page I-1 and are only summarized here.

Shipping Distance	Dollars/Ton	Yearly Cost*
50 miles	2.65	689,000
100 miles	3.00	780,000
150 miles	3.45	897,000

*Yearly cost for 260,000 tons/year

d) Disposal

(Quoted by Moran Towing Corporation) $2.60/ton

Total Cost for 260,000 tons/year 676,000

Present Value Determination

Capital Costs

Item	Cost	Life	Total Cost
Land - R.T.S.	450,000	20 years	450,000
Transfer Station Building - R.T.S.	1,228,000	20 years	
Roads, Sidings, etc.	200,000		
	1,428,000		
ENR Correction	x 1.575		
	2,249,100		2,249,100
Equipment - R.T.S.	1,125,500	20 years	
30% installation	337,650		
	1,463,150		1,463,150
Land - B.T.S.		20 years	150,000
Transfer Station Building - B.T.S.	370,000	20 years	
Roads, Dredging, etc.	170,000	20 years	
	540,000		
ENR Correction	x 1.575		
	850,500		850,500
Equipment	530,800	20 years	
30% installation	159,240		
	690,040		690,040
TOTAL CAPITAL COST			5,852,790

Operating Costs (Annual)

Rail Transfer Station	461,500
R.T.S. Labor	276,300
Barge Transfer Station	64,400
B.T.S. Labor	146,700
Disposal	676,000
	1,624,900

Rail Haul Distance	Charge	Total Operating Costs
50 miles	689,000	2,313,900
100 miles	780,000	2,404,900
150 miles	897,000	2,521,900

Solution of the present value price determination equation

$$\sum_{n=1}^{20} \frac{1}{(1+i)^n} [P_t X_n] = \sum_{n=1}^{20} \frac{1}{(1+i)^n} C_n$$

by the methods demonstrated previously yields a price per ton charged to the community.

Transfer Station Inland

	P_t i = 5%	P_t i = 8%
50 miles	$10.61	$11.02
100 miles	10.97	11.37
150 miles	11.42	11.82

APPENDIX IV

Analysis of Barge Transportation Costs

This analysis is based on a system which has the capability of handling 1,500,000 tons of waste per year. As such, it operates at a considerably higher scale than the systems compared in Table 1.1.

The costs are based primarily on data received from Mr. Cullion at the Perini Maritime Corporation, although other sources were consulted. The costs were calculated for a set of three ranges.

The ranges were: 20 miles
50 miles
100 miles

It was assumed that 1,500,000 tons of garbage would be generated over a year-long period. This rate would increase at 5% per year. The tug-barge system was assumed capable of operating at least 300 days/year.

One tug is capable of towing two barges out to sea. These barges are of the bottom dump type used in dredging, and dump automatically.

Non-transit time per round trip was as follows:

	3 hours	part time for loading, etc.
	1 hour	at sea-dumping time
Total	4 hours	non-transit time/round trip

The calculations for each of the given distances follow.

20 miles: Towing Speed = 5 knots

Transit time required =	4 hours
	4 hours in
Total transit time	8 hours
	+ 4 hours non-transit time
	12 hours/round trip

Each barge has a capability of 1,300 tons.

Therefore, a 2-barge and one tug combination can make 2 trips per day with capacity 5,200 tons/day.

The tug is capable of producing 1,800 BHP and towing at 5 knots.

Capital Costs:

1 tug	$ 500,000
2 barges	1,000,000
TOTAL	$1,500,000

Operating Costs:

Tug Operating Costs	$2,000/day	
Barges:		
2 deck hands	240/day	
Maintenance & repairs	200/day	(60,000 yearly / 300 days/year)
System Daily Operating Costs	$2,440/day	

System Annual Operating Costs:

(Daily Costs x 300 Days) = $732,000/year
Interest Rate = 8%
Life of Equipment = 20 years

Present Value of 20-year Operating Costs = $\$7.28 \times 10^6$

Capital Cost = $\$1.5 \times 10^6$
20-year System Cost $\$8.78 \times 10^6$

Discounted Solid Waste Flow at 5% over 20 years = 18.7×10^6 tons

Cost/ton = $0.47/ton

50 miles: Towing speed = 5 knots

Transit Time:
10 hours out
10 hours in
20 hours
\+ 4 hours non-transit time
24 hours/round trip

To meet our goals of a capability of 5,000 tons/day we need 2 tugs and 4 barges.

Daily Operating Costs:

$2,400/tug x 2 tugs	= $4,800
$ 200/barge x 4 barges	= 880
TOTAL	$5,680/day

Capital Costs:

2 tugs (1800 BHF)	$1,000,000
4 barges (1300 tons)	2,000,000
TOTAL	$3,000,000

Operating Costs Discounted at 8%

For 20 years	$\$16.7 \times 10^6$
Capital Costs	$\$3.0 \times 10^6$
TOTAL	$\$19.7 \times 10^6$

Discounted Garbage Stream at 5% = 16.7×10^6 tons

Cost/ton = $1.05/ton

100 Miles:

Towing Speed = 7 knots requiring larger tugs

Transit Time:

14.5	hours out
14.5	hours in
+ 4	hours non-transit time
33	hours/round trip

Operating 300 days/year = 7200 hours/year.

Therefore, one tug-two barge system can make 219 round trips a year.

Assuming that on each round trip, it carries 2,500 tons to be dumped, one such system can carry 550,000 tons/year.

Therefore, we need three such systems to meet our requirements of 1,500,000 tons/year.

Capital Cost of System:

3 tugs	$3,000,000
6 barges	3,600,000
TOTAL	$6,600,000

Round Trip Operating Costs for one tug-two barge system:

Tug costs/R.T.	\$ 3,300
Barge costs/R.T.	660
	\$ 3,960/R.T.
	x 220/Round Trips/year
	$\$8.7 \times 10^5$/year
	+ 0.8×10^5/year
	$\$9.5 \times 10^5$/year
	x 3 such systems
System Yearly Operation Costs	$\$2.85 \times 10^5$

Annual Operating Costs

Discounted at 8% over 20 years	=	$\$48.0 \times 10^6$
Capital Costs	=	6.6×10^6
Total System Cost over 20 years	=	$\$34.6 \times 10^6$

which yields \$1.85/ton to dump 100 miles out.

Summary of Calculations - for Barge Transportation Costs only (no shore-handling or transfer costs included):

Basic Assumption:

1) 1.5×10^6 tons to be dumped per year: this comes to 5000 tons/day for 300 days.

2) One tug tows two barges each with a capacity of 1300 tons. Thus, one tug barge train has a capacity of 2600 tons.

3) System operates 300 days/year.

4) Non-Transit Time/round trip:

   1 hour for dumping at sea
   3 hours loading in port
   4 hours non-transit time/round trip

Summary of Costs:

Towing Distance	Towing Speed	Cost/Ton
20 miles	5 knots	$ .47/ton
50 miles	5 knots	$1.05/ton
100 miles	7 knots	$1.85/ton

The cost of barge transportation on inland waterways of the United States for 1969 was $0.0033/ton-mile.

Towing at sea is more expensive with costs substantially rising with the distance from shore. In these cost calculations, the system was assumed to be able to operate reliably only 300 days/year, since rough weather will inhibit ocean dumping.

These costs will vary, of course, with the interest rate used in the present value calculations. If we assume an interest rate of 5% without an additional inflationary factor, we obtain the following costs.

Summary of Costs

Towing Distance	Towing Speed	Cost/Ton
20 miles	5 knots	$ .57/ton
50 miles	5 knots	$1.30/ton
100 miles	7 knots	$2.25/ton

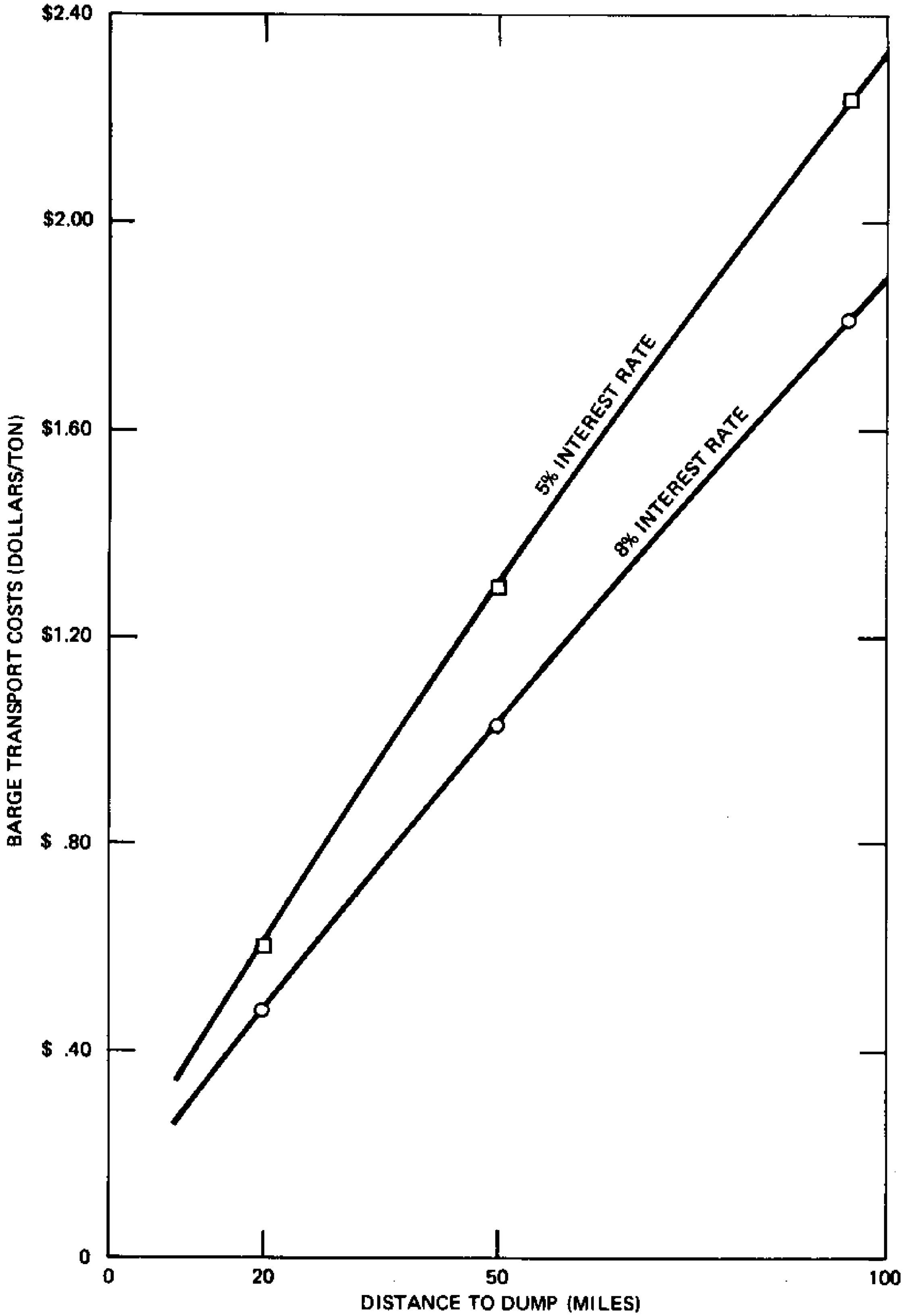


FIGURE IV-1 COST OF BARGING AS A FUNCTION OF DISTANCE

APPENDIX V

(COPY)

SANDY HOOK MARINE LABORATORY
U.S. Bureau of Sport Fisheries and Wildlife
Highlands, New Jersey

Summary Cruise Report R. V. Challenge

Dates: October 16, 17 and 25; November 25, 1968.

Purpose: To investigate the possibility of utilizing compressed solid wastes and garbage as reef material.

Procedure: On October 16, we obtained a test bale of compressed solid waste and garbage from the Moran Towing Corporation. The bale had been prepared by the American Baler Company, Bellevue, Ohio, specifically for this test at sea.

The bale, which we loaded on the *Challenger* (Fig. 1) was 30-1/2" x 40-1/2" x 48" and weighed 2,225 pounds. This bale occupied 34.3 cu. ft. and had an indicated density of 67.75/cu. ft. on the day it was baled (see enclosed letters from American Baler Co. for detailed information on the contents of the bale).

On October 17, divers located and buoyed off a relatively flat area of bottom about 100 feet west of the Shrewsbury Rocks' bell buoy in 45 feet of water. The bale was dropped on this spot from the stern of the *Challenger*. It floated at the surface for several minutes, then sank to the bottom. We then tied the bale to the bell buoy anchor with a tag line to facilitate finding the package on future inspection dives.

Results: Five to ten minutes after the bale reached bottom, we observed several areas on the bale which appeared somewhat loose (Fig. 2). However, most of the bale remained intact (Fig. 3) and soon attracted a few small cunner, *Tautogolabrus adspersus*. The cunner (Figs. 4 & 5) did not appear to be feeding on the compressed garbage but merely attracted to the unusually high relief offered by the bale on the relatively flat bottom.

On October 25, the bale was again inspected by diver biologists. They indicated that the bale appeared very much the same as the day it was put down with the exception of a slight rounding of the edges. There were a few pieces of material scattered around the bale and the surface area was slightly soft after the eight days of submergence. However, the bale was still compact and felt quite solid when a diver attempted to stick his knife into it.

Our next attempt to observe the condition of the test bale was delayed by weather until November 25. This dive came shortly after an intense northeast storm which had developed a sizable storm surge. Divers were unable to locate the bale and we assume the storm surge moved the compressed garbage some distance from our test site.

At present, we do not have enough information to make a statement concerning the possibility of utilizing such bales as reef material. However, I believe we should make another attempt to study the fate of similar bales in deeper water where there would be less chance of damage or loss by storm surge. Since ocean disposal is becoming increasingly more popular, we should be able to comment intelligently on the feasibility of using compressed solid wastes and garbage as reef materials. We need to understand the effect of these wastes on the ecology of the marine environment.

The American Baler Company indicated they used only one-third of the possible operating pressure in preparing this test bale. In view of ocean disposal it may be better to make the bales denser. A bale produced by utilizing two-thirds to full operating pressure of the compressing unit would probably sink quickly in salt water, and reduce the chance of bales dispersing away from a dump site by drifting.

Report prepared by:

Richard B. Stone
February 27, 1969

Approved:
L. A. Walford
Laboratory Director

APPENDIX VI

Economic Analysis for Incineration at Sea

Case 1: Two-Day Cycle System

Case 2: Three-Day Cycle System

Case 3: Liberty Ship Conversion System

APPENDIX VI

CASE 1. TWO-DAY CYCLE SYSTEM
(Calculations based on six-day working week)

Initial Capital Costs

(1) Vessel

Division	Material	Labor
Hull Steel	840,000	1,800,000
Hull Outfit	145,000	170,000
Incinerators & Housing	4,000,000*	Incl'd
Hull Engineering Items	525,000	465,000
Machinery & Propulsion	1,235,000	445,000
TOTAL	6,745,000	2,880,000

Total Material	= 6,745,000
Total Labor	= 2,880,000
Total Cost (1) Ship	9,625,000

(2) Transfer Station

Building Structure	300,000
Ramp	200,000
Compactors - 7 @$40,000 (installed)	280,000
Crane	100,000
Storage Racks, Winches, etc.	250,000
Scale	20,000
TOTAL Cost (1) Transfer Station	1,150,000

*This figure represents our own analysis and not that of the New York City Planning Commission

(3) Container

Containers -110 @ $8,000	880,000

Total Initial Cost:

Vessel (1)	=	9,625,000
Transfer Station (1)	=	1,150,000
Containers	=	880,000
		11,655,000

Operating Costs (Annual)

(1) Vessel

Wages	562,000
Sustenance	34,000
Stores and Supplies	15,000
Insurance on Crew	38,000
Fuel @ 340 days	164,000
Maintenance and Repair	85,000
Insurance on Ship	54,800
Overhead & Misc.	87,000
	1,039,800

(2) Transfer Station

Total Personnel Cost	188,000
Heat, Power, Water, etc.	9,400
Maintenance	40,600
	238,000

Estimated Unit Cost

It is estimated that the waterborne incinerator will be out of service for maintenance work two weeks out of each year.

Therefore, total annual tonnage would be 650 tons/day x 6 days/week x 50 weeks/year = 195,000 tons/year.

Present Value Determination

Capital Costs

Item	Life	Total Cost
Vessel	20 years	$ 9,625,000
Transfer Station	20 years	1,150,000
		$10,775,000
Containers	10 years	$ 880,000

Operating Costs (Annual)

Item		Cost
Vessel		$ 1,039,800
Transfer Station		238,000
		$ 1,277,800

Solution of the present value price determination equation

$$\sum_{n=1}^{20} \frac{1}{(1+i)^n} [P_t X_n] = \sum_{n=1}^{20} \frac{1}{(1+i)^n} C_n$$

by the methods demonstrated previously yields a price per ton charged to the community:

	P_t
for i = 5%	$11.33/ton
for i = 8%	$12.39/ton

CASE 2. THREE-DAY CYCLE SYSTEM

All refuse received in a three-day period is initially stored at a transfer station, then loaded on board and transported to the burning and dumping site. The capacity of this system is approximately 780 tons/day, (two 500 ton/day furnaces used), operating 6 days/week.

Initial Capital Costs

(1) Vessel

Division	Material	Labor
Hull Steel	1,032,000	2,300,000
Hull Outfit	145,000	170,000
Incinerator & Housing	4,000,000*	Incl'd
Hull Engineering Items	525,000	465,000
Machinery & Propulsion	1,235,000	445,000
TOTAL	6,937,000	3,380,000

Total Material = 4,937,000

Total Labor = 3,380,000

Total Cost (1) ship 10,317,000

*This figure represents our own analysis and not that of the New York City Planning Commission.

(2) Transfer Station

Building Structure	300,000
Ramp	200,000
Compactors 7 @ $40,000	280,000
Crane	100,000
Storage Racks, Winches, etc.	350,000
Scale	20,000
TOTAL cost (1) transfer station	1,250,000

(3) Containers

Containers - 190 @ $8,000	1,520,000

Total Initial Cost

Vessel (1)	=	10,317,000
Transfer Station (1)	=	1,250,000
Containers	=	1,520,000
		13,087,000

Operating Costs (Annual)

(1) Vessel

Although slightly larger than a two-day cycle vessel, manpower requirements and other operation costs are estimated at approximately the same as the two-day cycle vessel 1,039,800

(2) Transfer Station

Total Personnel Cost	188,000
Heat, Power, Water, etc.	9,400
Maintenance	55,400
	252,800

Estimated Unit Cost

Total Annual Tonnage

780 tons/day x 6 days/week x 50 weeks/year = 234,000 tons/yea

Present Value Determination

Capital Costs

Item	Life	Total Cost
Vessel	20 years	$10,317,000
Transfer Station	20 years	1,250,000
TOTAL		$11,567,000
Containers	10 years	$ 1,520,000

Operating Costs (Annual)

Vessel	$1,039,800
Transfer Station	252,800
TOTAL	$1,292,600

Solution of the present value price determination equation

$$\sum_{n=1}^{20} \frac{1}{(1+i)^n} [P_t X_n] = \sum_{n=1}^{20} \frac{1}{(1+i)^n} C_n$$

by the methods demonstrated previously yields a price per ton charged to the community:

	P_t
for i = 5%	$10.10/ton
for i = 8%	$11.08/ton

CASE 3. LIBERTY SHIP CONVERSION SYSTEM

Due to ship size constraints, the liberty ship incinerator will operate on a two-day cycle. The capacity of this system is approximately 433 tons/day (two ton/day furnaces used) operating 6 days/week.

Initial Capital Costs

It is assumed that a municipality can obtain liberty ships from the Reserve Fleet at no cost by Federal action.

(1) Vessel

Division	Material	Labor
Drydocking Sandblasting & Repairing Hull	incl'd	150,000
Removal of Machinery and Interior Steel	incl'd	
New Hull Steel	80,000	220,000
New Hull Outfit	22,000	33,000
Incinerators and Housings	3,200,000*	incl'd
Hull Engineering Items	525,000	465,000
Machinery and Propulsion	1,235,000	445,000
TOTAL	5,062,000	1,313,000

Total Material = 5,062,000

Total Labor = 1,313,000

Total Conversion Cost = 6,375,000

---

*This figure represents our own analysis and not that of the New York City Planning Commission.

(2) Transfer Station

Building Structure	250,000
Ramp	200,000
Compactors 5 @ $40,000	200,000
Crane	100,000
Storage Racks	250,000
Scale	20,000
	1,020,000

(3) Containers

Containers - 106 @ $8,000	848,000

Total Initial Cost

Vessel (1)	=	6,375,000
Transfer Station (1)	=	1,020,000
Containers	=	848,000
		8,243,000

Operating Costs (Annual)

Although slightly smaller than a two-day cycle vessel, manpower and other operating costs are estimated at approximately the same as the two-day cycle vessel

1,039,800

(2) Transfer Station

Total Personnel Cost	188,000
Heat, Power, Water, etc.	9,400
Maintenance	37,400
	234,800

Estimated Unit Cost

Total Annual Tonnage

433 tons/day x 6 days/week x 50 weeks/year = 129,900 tons/year

Present Value Determination

Capital Costs

Item	Life	Total Cost
Vessel	20 years	6,375,000
Transfer Station	20 years	1,020,000
		7,395,000
Containers	10 years	848,000

Operating Costs (Annual)

Vessel	1,039,800
Transfer Station	234,800
TOTAL	1,274,600

Solution of the present value price determination equation

$$\sum_{n=1}^{20} \frac{1}{(1+i)^n} [P_t X_n] = \sum_{n=1}^{20} \frac{1}{(1+i)^n} C_n$$

by the methods demonstrated previously yields a price per ton charged to the community:

	P_t
for $i = 5\%$	\$14.97/ton
for $i = 8\%$	\$16.08/ton

Therefore, using this economic evaluation, the three-day cycle at a unit cost of

i	P_t
5%	\$10.10/ton
8%	\$11.08/ton

is shown to be the most economic of the three possible systems, and is the only one water-borne incinerator considered in the reliability analysis.

APPENDIX VII

REFERENCES

General Solid Waste Disposal Studies

1. Technical-Economic Study of Solid Waste Disposal Needs and Practices, U.S. Dept. of Health, Education and Welfare, Public Health Service, Bureau of Solid Waste Managment, 1969.

2. Status of Solid Waste Managment in California, U.S. Dept. of Health, Education, and Welfare, Public Health Service Solid Wastes Program, Sept. 1968.

3. Proceedings- The Surgeon General's Conference on Solid Waste Managment for Metropolitan Washington, July 1967, U.S. Dept. of Health, Education and Welfare, Public Health Service, 1968.

4. Solid Waste Disposal Study for Washington, D.C. Metropolitan Area, U.S. Dept. of Public Health Service, 1969.

5. Collection and Disposal of Solid Waste for the Des Moines Metropolitan Area, An Interim Report, U.S. Dept. of Health, Education, and Welfare, Public Health Service, 1968.

6. Policies for Solid Waste Management, National Academy of Engineering, National Academy of Sciences, 1969.

7. Solid Waste Handling in Metropolitan Areas, U.S. Dept. of Health, Education and Welfare, Public Health Service, Jan. 1968.

8. Summaries, Solid Waste Demonstration grant Projects - 1968 for grants awarded during the period June 1, 1966 - December 31, 1967, U.S. Dept. of Health, Education and Welfare.

9. Solid Wastes Demonstration Grant Abstracts, for grants awarded Jan. 1 - June 30, 1968, U.S. Dept. of Health, Education and Welfare.

10. Solid Waste Disposal Study for the Washington Metropolitan Region, prepared by Black Veatch - Consulting Engineers, 1967.

11. Refuse Collection and Disposal for the Small Community, A Joint Study and Report of U.S. Dept. of Health, Education and Welfare, Public Health Services and American Public Wor s Association, November 1953.

12. The Role of Packaging in Solid Waste Management - 1966 to 1976, U.S. Dept. of Health, Education and Welfare.

13. Technical Services Report (SW-6ts) Comprehensive Solid Waste Study Johnson City, Tennessee, U.S. Dept. of Health, Education, and Welfare, Public Health Service, May 1968.

14. Quad-City Solid Wastes Project, An Interim Report, June 1, 1966 to May 31, 1967, U.S. Dept. of Health, Education and Welfare, Public Health Service, 1968.

15. Summaries of Solid Waste Program Contracts, July 1, 1965 - June 30, 1968, U.S. Dept. of Health, Education and Welfare, Public Health Service, 1969.

16. A Systems Study of Solid Waste Management in the Fresno Area, Final Report on a Solid Waste Management Demonstration, U.S. Dept. of Health, Education and Welfare, Public Health Service, 1969.

17. Summaries of Solid Wastes Research and Training Grants, 1968, U.S. Dept. of Health, Education, and Welfare, Public Health Service.

18. What Can You Do with Refuse?, Caterpillar Tractor Company.

19. Solid Waste Management, A Comprehensive Assessment of Solid Waste Problems, Practices, and Needs prepared by Ad Hoc Group for Office of Science and Technology, May 1969.

20. Waste Management: Generation and Disposal of Solid, Liquid and Gaseous Wastes in the New York Region, prepared for the Regional Plan Association by: Blair T. Bower, P.E. Gordon P. Larson, Abraham Michaels, P.E. Walter M. Phillips, March 1968.

21. WHO International Reference Center for Wastes Disposal, Federal Institute for Water Supply, Sewage Purification and Water Pollution Control, Zurich, Switzerland, 1968.

22. An Interim Report -- 1968 National Survey of Community Solid Waste Practices, Ralph J. Black, Anton J. Muhich, U.S. Dept of Health,Education, and Welfare, Public Health Service, 1968.

23. Final Report, What Methods of Solid Waste Disposal Should be Used in San Francisco Bay Area --Landfill, Incineration, Export Out of Area, Other? Commonwealth Club of California, July 7, 1969.

24. Who Should Pay for Hospital Waste Disposal? Land Pollution Reporter,Freed Publishing Company, Sept. 1969.

Incineration

25. Evaluation of the MELT-ZIT High Temperature Incinerator, Operation Test Report, August 1968, U.S. Dept. of Health Education and Welfare, Public Health Service, Bureau of Solid Waste Management, 1969.

26. Special Studies for Incinerators--for the Government of the District of Columbia, U.S. Dept. of Health, Education and Welfare, Public Health Service, Solid Wastes Program, 1968.

27. Combustion Power Unit CPU-400, A Technical Abstract, U.S. Dept. of Health, Education and Welfare, Public Health Service, 1969.

28. Incinerator Guidelines 1969, U.S. Dept. of Health, Education and Welfare, Public Health Service, 1969.

29. Municipal Incineration, M. DeVon Bogue, U.S. Dept. of Health, Education and Welfare, Public Health Service, Dec.1,1965.

Land Disposal

30. Abstract - Controlled Tipping of Solid Urban Refuse, George J. Kupchik, Dr. Eng., New York City

31. An Accounting System for Sanitary Landfill Operations, Eric R. Zausner, U.S. Dept. of Health, Education and Welfare, Public Health Service, 1969.

32. Sanitary Landfill Facts, Thomas J. Sorg, H. Lanier Hickman, U.S. Dept. of Health, Education and Welfare, Public Health Service, 1968.

33. Development of Construction and Use Criteria for Sanitary Landfills, An Interim Report, U.S. Dept. of Health, Education and Welfare, Public Health Service, 1969.

34. Land Reclamation Project, An Interim Report, U.S. Dept. of Health Education and Welfare Public Health Service, 1968.

35. Solid Wastes Landfill Stabilization, An Interim Report, U.S. Dept. of Health, Education and Welfare, Public Health Service, 1968.

36. The Tezuka Refuse Compression System, A Preliminary Report, U.S. Dept. of Health Education and Welfare, 1969.

Ocean Dumping

37. The Tezuka Refuse Compression System, A Preliminary Report, U.S. Dept. of Health, Education and Welfare, 1969.

38. Undersea Vehicles for Oceanography, Interagency Committee on Oceanography of the Federal Council for Science and Technology, 100 pamphlet No. 18, October 1965.

39. Proceedings of the First International Conference on Waste Disposal in the Marine Environment, University of California, Berkeley, July 22-25, 1959.

40. Delaware Valley Industrial Wasteline, First Year's Study, July 1969, Daniel Pindzola, Robert A. Erb.

41. Marine Disposal of Solid Wastes, Charles G. Gunnerson, F. ASCE, Robert P. Brown, and David D. Smith, U.S. Dept. of Health, Education and Welfare, Public Health Service, Dec. 1969.

42. Institute of Ocean Law, Coastal Zone and Ocean Law: Problems of the User, Dec. 10-12, 1969, University of Miami Law Center.

43. Marine Disposal of Solid Wastes, An Interim Summary, Robert P. Brown and David D. Smith (Dillingham Corporation)

44. Collection and Removal of Municipal Solid Wastes by Pneumo-Slurry System, Iraj Zandi, University of Pennsylvania.

Rail Haul

45. The Tezuka Refuse Compression System, A Preliminary Report, U.S. Dept. of Health Education and Welfare, 1969.

46. Rail Transport of Solid Wastes, A Feasibility Study --interim report; phase one, U.S. Dept. of Health, Education and Welfare, Public Health Service, Bureau of Solid Wastes Management, 1969.

47. Status Report (April 1 to December 31,1967) on Project 67-1 (PHS: 1-D01-U1-00073-01), The Potential Benefits of Rail-Haul as An Integral Part of Waste Disposal Systems, January 1968.

48. Report to the New York State Pure Waters Authority on Rail-Haul Disposal of Solid Wastes for Westchester County, New York, February 27, 1969, Metcalf & Eddy.

49. Rx For Disposal of Metro Area Solid Wastes: Shredding-Compaction-Railhaul- Sanitary Landfill, Arthur Handlen and John P. Annicelli, New York State Pure Waters Authority, April 21, 1969.

Recycling

50. Solid Waste Reduction/Salvage Plant, An Interim Report, City of Madison Pilot Plant Demonstration Project, June 14 to December 31, 1967, U.S. Dept. of Health, Education and Welfare, 1968.

51. Gainesville Compost Plant, An Interim Report, U.S. Dept. of Health, Education and Welfare, Public Health Service, Bureau of Solid Waste Management, 1969.

52. Solid Wastes Management/Composting European Activity and American Potential, Samuel A. Hart, University of California, 1968.

53. A Modern Municipal Waste Disposal Process, Metropolitan Waste Conversion Corporation.

54. Composting Developments in the United States, John S. Wiley, O.W. Kochtitzky - U.S. Dept. Of Health, Education and Welfare and Tennessee Valley Authority.

55. Resource Recovery From Incinerator Residue, A Report for the Bureau of Mines, U.S. Dept. of the Interior, American Public Works Association, November 1969.

56. Report for the Bureau of Mines Solid Waste Research Program, by F. J. Cservenyak and C.B. Kenahan.

57. Reclaiming and Recycling Metals and Minerals Found in Municipal Incinerator Residues by Carl Rampacek for Bureau of Mines, U.S. Department of the Interior.

58. Wealth Out of Waste, Bureau of Mines Programs in Solid Waste Utilization, U.S. Dept. of the Interior, Bureau of Mines.

Incineration at Sea

59. Evaluation of the MELT-ZIT High Temperature Incinerator, Operation Test Report, August 1968, U.S. Dept. of Health, Education and Welfare, Public Health Service, Bureau of Solid Wastes Management, 1969.

60. Special Studies for Incinerators--for the Government of the District of Columbia, U.S. Dept. of Health, Education and Welfare, Public Health Service, Solid Waste Program, 1968.

61. City of New York City Planning Commission, Feasibility Study of a Water-Bourne Incinerator, Abraham Michaels, March 1968.

62. Undersea Vehicles for Oceanography, Interagency Committee on Oceanography of the Federal Council for Science and Technology, ICO Pamphlet No. 18, October 1965.

63. Proceedings of the First International Conference on Waste Disposal in the Marine Environment, University of California, Berkeley, July 22-25, 1959.

64. Combustion Power Unit CPU-400, A Technical Abstract, U.S. Dept. of Health, Education, and Welfare, Public Health Service, 1969.

65. Incinerator Guidelines 1969, U.S. Dept. of Health, Education and Welfare, Public Health Service,1969.

66. Municipal Incineration, M. DeVon Bogue, U.S. Dept. of Health, Education and Welfare, Public Health Service, Dec. 1965.

67. Waste Incineration at Sea and Ocean Disposal of Non-Floating Residues, Melvin W. First, Department of Environmental Health Sciences, Harvard School of Public Health, 1969.

Coastal Landfill

68. San Francisco Bay Plan, S.F. Bay Conservation and Development Commission, January, 1969.

69. Ibid.

70. Bay Area Regional Planning Program Refuse Disposal Needs Study, Association of Bay Area Governments, July 1965.

71. Institute of Ocean Law, Coastal Zone and Ocean Law: Problems of the User, Dec. 10-12, 1969, Univ. of Miami Law Center.