such a dynamic system of biological cycles for the toxic elements, small disturbances in these cycles will affect the natural equilibriums which will in turn affect the concentrations of toxic intermediates. Great care must therefore be taken in deciding which species of a toxic element should be monitored in the environment, because neglect of these biological transformations can make the development of models for the flow of chemicals through the environment a futile exercise.

References and Notes

1. When a new synthetic compound is produced by the chemical industry and laboratory tests indicate that it is not biodegradable, it is then important to know the solubility of this compound in water and in lipids. The maximum concentration of this new compound in water or in lipids will represent its "bioaccumulation potential." In the environment this potential may never be reached, but "bioaccumulation potential" does give us a good guideline for the concentration of this new compound which should be of concern when testing it toxicologically. Jernelöv has used the term "bioaccumulation potential" to describe this concept [A. Jernelöv, in *Proceedings of the Environmental Protocols Meeting*, San Antonio, Texas, 11 to 16 February 1973 (National Academy of Sciences, Washington, D.C., in press)].
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15. I thank Dr. R. J. P. Williams for stimulating discussions. Supported by PHS grant AM 12599 and NSF grant GB 26593X.

The Economics of Resource Recovery from Municipal Solid Waste

James G. Abert, Harvey Alter, and J. Frank Bernheisel

Environmental concern has drawn attention to means for recovering material and energy resources from urban solid waste, particularly from the household portion (*1*). Recently, federal support has been given for this purpose (*2*). The public viewpoint is that the metal, glass, and other materials found in ordinary refuse are resources to be saved, preserved, and recovered rather than discarded. Recovery, outside of separation by the householder, depends on the availability of suitable separation technology operated at a reasonable cost to the community.

Unfortunately, progress in affecting the installation of recovery facilities to meet the needs of communities has been slow. Much of the work done has been beset with technical, and, more often, economic difficulties. However, the rising cost of traditional and environmentally acceptable means of disposal may allow new systems to become economically competitive. New systems hold promise. The Environmental Protection Agency in late 1972 announced four grants, under Section 208 of the Resource Recovery Act of 1970 (*3, 4*), for the construction of resource recovery plants of at least 200 tons per day capacity to demonstrate new technology. Many unit operations familiar in chemical, mechanical, and minerals processing engineering practice can be, and already have been, applied to refuse processing and resource recovery (*5*). Their final adoption will depend on their costs to the community being competitive with traditional methods of disposal, such as sanitary landfilling or incineration.

Raw Materials

Before considering the costs of resource recovery, one must examine what there is to recover—that is, what is likely to be in the solid waste stream. This article is focused on the household portion of the urban solid waste.

The results of several analyses (*6*) of the composition of household refuse by weight resulted in the values given in Table 1. Unfortunately, there is no such thing as an average refuse composition: The composition varies from city to city—probably geographically and no doubt seasonally and temporally, from year to year and on shorter time scales, all making definitive analysis difficult. There are, however, some general trends in composition that can serve as design input for technical and economic analysis. First, some nominal composition figures can be computed, using one's judgment, from the available data (*7*). Second, it is apparent that municipalities with a "high" refuse assay have an economic advantage in implementing recovery facilities. A high assay means that the content of the valuable, nonferrous metals must be about 1 percent.

Recovery potential falls into two basic groups of materials (see Table 1). The first group of items is labeled "mechanical recovery" and refers to that portion of the refuse stream which is available for essentially mechanical extraction and for reuse as a relatively pure raw material. The second group includes what are primarily organic materials, which, because of their physical characteristics, can only be recovered through conversion. Organic materials are generally suitable for some sort of derived product, such as com-

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post, or a manufactured product, such as fiberboard building material (*3, 5, 8*), or for chemical or biological conversion to a source of energy—either directly, by burning, or indirectly, by converting to a storable fuel (*9*).

Paper is included in both categories: Some is recoverable as a material, but most is not. This is due, in large part, to composite packaging (that is, paper laminated or otherwise attached to plastic or metal) and to the collection process. When mixed with other refuse, paper becomes contaminated with dirt, grease, and other materials that are not acceptable inputs to high-speed papermaking processes and that are difficult to remove, even with special processing (*10*). However, it is probable that some small fraction of paper, most likely bundled newsprint and corrugated board, can be efficiently separated from mixed refuse by hand in a form acceptable for some reuses.

Therefore, based on the composition of the refuse stream, recovery is essentially a two-phase process: First, materials recovery (glass, metals, and some paper); and second, recovery of the organic portion and reuse through conversion, probably as a source of energy.

One scheme for recovering materials and energy from solid waste is shown in Fig. 1. "Front end" refers to materials recovery with disposal of the organic portion by conventional means —for example, by landfill or incineration. This is a suboptimal system because it is incomplete. "Back end" refers to the recovery of the organic portion and its reuse as fuel or as raw material for a product (*11*).

A flow sheet for a front end recovery process proposed by the National Center for Resource Recovery (*12*) is shown in Fig. 2. The bases for choosing this type of materials recovery plant and details of the various unit operations have been described (*13*), as have other technically feasible processes (*5*). The system shown in Fig. 2 would recover five fractions: bundled paper, ferrous metals, glass, aluminum, and a mixture of other nonferrous metals (including nonmagnetic stainless steel). It would leave as residue the organic fraction (for disposal or recovery) and a small inert fraction consisting of bone, rubber, heavy plastics, grit, sludges, and dust from the processing (for disposal by landfill). An important aspect of "beginning" with the front end system is that the economic analysis does not have to include the normally high cost of marketing new products. This cost would be necessary for many back end systems, such as those which produce new kinds of building materials. Further, the economic viability of the front end system is not hampered by the high capital cost of constructing refuse-burning heat exchangers for energy recovery.

Cost Estimates

The first step in the economic analysis of resource recovery is to determine the capital costs and operating costs of the technology to be installed. A plant processing 500 tons of solid waste per day (like that in Fig. 2, which would serve most of the needs of a community

Table 1. Expected ranges in mixed municipal refuse composition. [Source: (*6*, p. 5)]

Component	Composition (% of dry weight)* Range	Nominal	
Metallics	7 to 10	9.0	
Ferrous	6 to 8	7.5	
Nonferrous	1 to 2	1.5	
Glass	6 to 12	9.0	Mechanical recovery
Paper	37 to 60	55.0	
Newsprint	7 to 15	12.0	
Cardboard	4 to 18	11.0	
Other	26 to 37	32.0	
Food	12 to 18	14.0	
Yard	4 to 10	5.0	Conversion recovery
Wood	1 to 4	4.0	
Plastic	1 to 3	1.0	
Miscellaneous	<5	3.0	

* Moisture content: range, 20 to 40 percent; nominal, 30 percent.

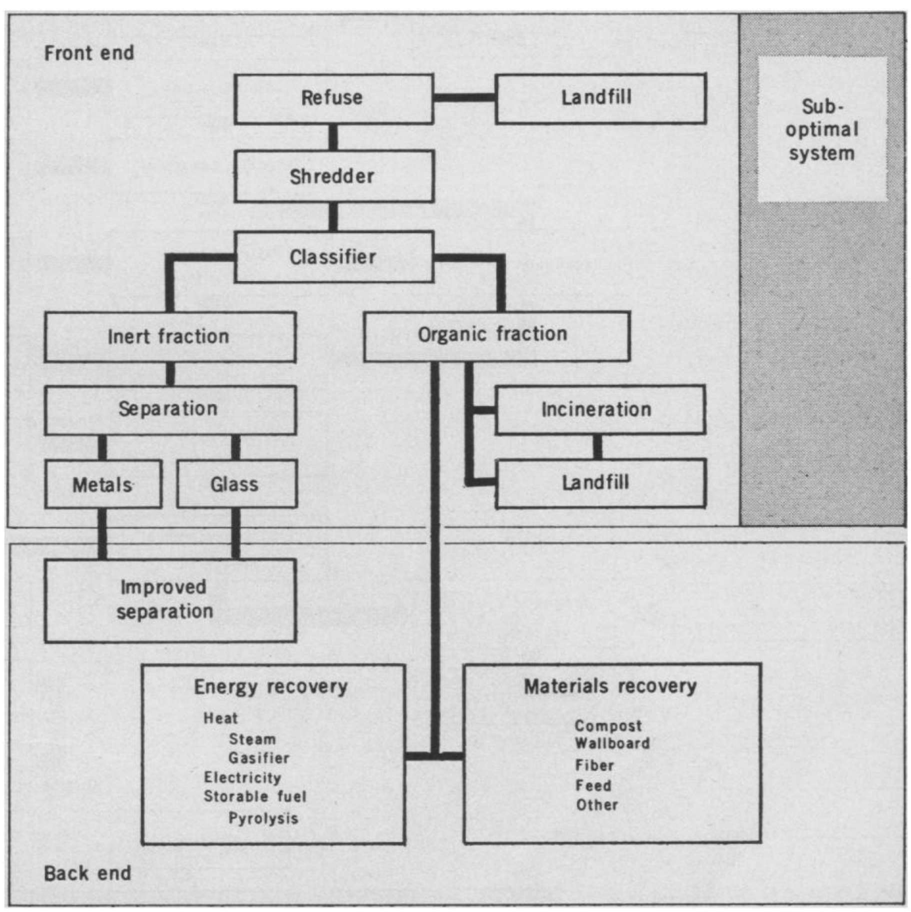

Fig. 1. A modular approach to resource recovery. Front end refers to materials recovery. Back end refers to direct utilization, or conversion, of the organic portion of the waste.

of about 200,000) has been estimated in some detail to have a capital cost of \$2.4 million, exclusive of land (*13*). These costs are explained in Table 2. Operating costs have been estimated (*13*), and are summarized in Table 3, on the basis of a debt-to-equity ratio of 2 : 3. This would apply to the situation in which a private entrepreneur constructs and operates a plant of this kind as a business venture. Public ownership is also possible.

The costs of back end processing facilities are more difficult to obtain or analyze because the technology is generally new and often proprietary. However, it seems that the most efficient and inexpensive (in terms of capital) means of extracting energy from the organic fraction would be to use it as a supplementary fuel in existing coal-fired boilers for generating electricity, as is now being done in St. Louis (*14*). The cost of modifying the plant and any increase in the cost of operation of such a utility boiler may be paid for by the value of the organic fraction as a fuel.

General Economic Considerations

A great deal has been written about the economics of environmental quality, with discussions of internalization of costs, redistribution of income, costs and benefits to society, and so forth (*15*). It is not our intent to review or enter into these arguments here. Rather, we seek to determine the cost to a community of adding resource recovery to its solid waste management system. Put another way, we apply the "indifference principle"; the indifferent community is one for which the added resource recovery would cost the same as its present solid waste management practice. In this day of environmental concern, the indifferent community may also be one to which the extra cost of having resource recovery is acceptable as a means of participating in materials conservation programs.

A cost center concept is the basis for evaluating the recovery facility. Refuse is accepted for processing for a fee paid to the facility, and unrecovered byproducts and residues are disposed of for a fee paid by the facility. It is assumed that the facility is privately owned and is operated at a profit. If the facility is economically feasible under private ownership, it may be less expensive to implement under public ownership because a public body does not require a profit and can often borrow capital at lower interest rates.

For purposes of analysis, the characteristics of a prototype facility are assumed to be the same as those described in Tables 2, 3, and 4, with a profit before taxes or return on an equity of 15 percent, which is assumed to be the minimum that would attract private capital (considering present interest rates on certificates of deposit and other relatively safe, often tax-free, investments).

The fraction of incoming refuse recovered as salable material (Table 4) is determined by the expected efficiency of an operating plant and by the average expected composition of the incoming refuse (*13*).

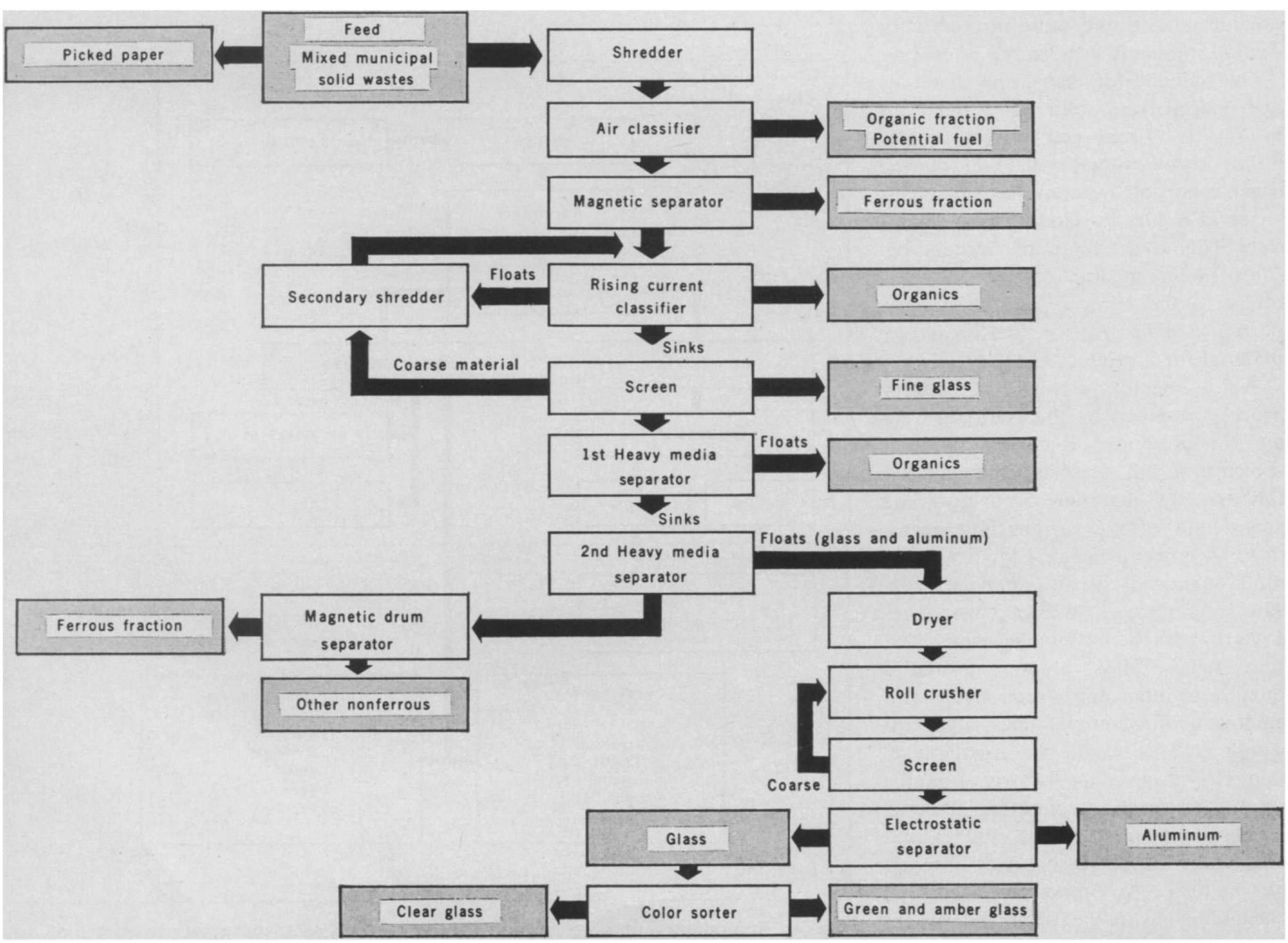

Fig. 2. Processing scheme for separating materials from mixed refuse.

The Operating Statement

Under the cost center concept, a prototypical operating statement can be used in economic analysis. Such a statement must include entries for all operating expenses and revenues for the stated equity, as well as target return on this equity. An example of an operating statement is shown in Fig. 3.

Net operating income provides the return on equity previously discussed. Total operating expenses are the sum of annual operating costs (derived as shown in Table 3) and waste product costs, which are costs resulting from the disposal of unrecovered material. By-product revenues are net proceeds from the sale of recovered fractions (*16*). The dumping revenue is a per-ton fee paid by the community or by private haulers to the facility for disposing of the refuse.

The by-product revenues are based on the expected annual recovery rate for each potentially recoverable resource and on the anticipated selling price for each material. The expected recovery of each material is listed in Table 4; the engineering estimates made to arrive at these figures have been described elsewhere (*13*). The expected selling price for each material is a judgment based on examination of analogous scrap prices quoted in trade publications (*17*), conversations with potential buyers, and freight charges over a likely distance.

The following net prices were arrived at: ferrous metals, at $15 per ton (based on a No. 2 scrap bundle price of about $35 per ton, delivered to the steel mill and allowing $20 per ton for transportation); glass, at $7 per ton (based on 12 percent of the glass output being sorted as flint at $12 per ton and the remainder being color-mixed at $8 per ton and allowing only for local transportation costs); paper, at $10 per ton (mostly No. 1 news, a standard paper stock—price estimates vary greatly with area of the country); aluminum, $200 per ton net (quote from an aluminum producer); and nonferrous metals, excluding aluminum, $120 per ton (based on prices paid per ton for metal contained in some nonferrous concentrates from automobile-shredding operations). The likely by-product revenues for the operating statement, calculated on these estimates, are listed in Fig. 3, with entries for all the costs and revenues established so far (*18*).

Table 2. Summary of capital costs. [Source: (*13*, pp. 9-1–9-53)]

Item	Cost ($)
Building	173,000
Electrical equipment	192,300
Water and sewage	124,000
Auxiliary equipment	119,830
Processing equipment	914,300
Subtotal	1,523,430
Architecture and engineering (10%)	152,343
General contracting and architect-engineer field supervision costs (23%)	350,389
Contingency (19%)	289,452
Working capital	100,000
Total	2,415,614

Figure 3 illustrates the oft-heard argument, and a correct one, that the by-product revenues from resource recovery cannot support the cost of separation. By-product revenues are listed as $562,000, falling short of expenses ($819,000) by $1.65 per ton of input. These arguments are incomplete, however, because they do not take into account other entries to the operating statement that must be added in order to determine the economics of such a facility.

First, the prototype plant discussed here processes 500 tons per day, 6 days a week. Of this input, 19 percent is recovered, and hence does not generate a disposal cost for the facility. In order to balance the operating statement and to determine the point of indifference mentioned earlier, the credit for the dump revenues and the debit for the waste product disposal costs must be such that the net operating income equals the target rate of return, $216,000 per year. This may be stated as:

$$156{,}000(DR) - 126{,}360(WPC) = \$473{,}000 \qquad (1)$$

Table 3. Annual operating costs of a plant processing 500 tons per day, 6 days per week. Basis: 40 percent of capitalization debt; 60 percent equity. [Source: (*13*, pp. 9-1–9-53)]

Operating costs	Expenditure ($)
Variable	
Labor*	258,425
Maintenance materials	74,327
Utilities	64,800
Total variable	397,552
Fixed	
Depreciation†	306,530
Real estate taxes and insurance‡	39,429
Interest§	75,000
Total fixed	420,959
Total net	818,511

* Labor costs are based on paying time-and-a-half for the sixth day. †Depreciation is straight line based on 20 years for buildings and 7 years for equipment. ‡ Land assumed to be provided rent-free by the municipality. § Based on borrowing 40 percent of capital cost at 8 percent simple interest, paid quarterly for 20 years on building and 10 years on equipment. Interest shown for the first year of operation.

The $473,000 are operating costs plus profit, minus by-product revenues. Dump revenues (DR) and waste product costs (WPC) are expressed in dollars per ton.

The equation can be solved for both DR and WPC if a relation can be established between the two unknowns. A plausible one is

$$0.75(DR) = (WPC) \qquad (2)$$

Dumping revenue		$ ___	
By-product revenues (net)			
Ferrous metal	$ 159		
Glass	$ 76		
Aluminum	$ 218		
Paper	$ 62		
Other nonferrous metal	$ 47		
Total		$ 562	
Total operating revenues			$ ___
Waste product costs		$ ___	
Annual operating costs		$ 819	
Total operating expenses			$ ___
Net operating income			$ 216

Fig. 3. Protypical operating statement showing the format and fixed entries, of a resource recovery facility (annual rates in thousands of dollars; equity, $1.44 million; return on investment, 15 percent).

In other words, there is a 25 percent discount in the cost of disposing of the waste products after processing (shredding and removing of the inert material).

It is believed that this discount can be justified if the processed refuse is disposed of in a landfill, particularly in areas where land is expensive and dirt to cover the refuse is scarce. With the same mechanical effort, shredded refuse can be made more compact than unshredded refuse; it therefore requires less land for disposal. In addition, there is substantial evidence that shredded refuse does not need daily earth cover and thereby saves on clean fill, often a scarce and costly material (*19*). Shredded refuse without cover requires fewer earth-moving machines and compactors for landfilling than does unprocessed refuse. The lower requirement saves capital investment and daily operating costs. Finally, because shredded refuse as fill stabilizes more rapidly, compared to unshredded material, the filled land is available sooner for capital improvement. This is often an income-producing item for the municipality. The potential savings in each of these various categories have been estimated (*13, 19*) and are summarized in Table 5. In the case of landfill without daily cover, Eq. 2 seems justified, if not conservative.

It is more difficult to make a similar case for Eq. 2 when the unrecovered fraction is disposed of by incineration. Although the burning of shredded wastes, such as bark and bagasse, has been practiced for years, it has only been in the last 2 years or so that municipal incinerators operating on shredded refuse have been put into operation. One such plant is in the city of Hamilton, Ontario. In the Hamilton plant, there are several design innovations aimed at reducing costs of incineration. Among these are conveyor belts, rather than overhead cranes, for handling refuse. Also, because of suspension burning, the combustion chamber is smaller than a conventional incinerator of the same capacity. Finally, there is no need for water quench of the ash; it is cooled in suspension by the air flow. Because the Hamilton plant is new, data on actual costs are not yet available. However, it is likely that the operating costs for the complete facility are slightly less than those for conventional incinerators using unshredded feedstock. In time, the coefficient in Eq. 2 will be determined for incineration of shredded refuse. Until then, 0.75 will serve as an estimate.

When Eqs. 1 and 2 are solved, the indifferent community is one where the cost of disposing of unprocessed raw refuse (*DR*) is $7.72 per ton and the cost of disposing of the shredded refuse (*WPC*) is $5.79 per ton. A completed operating statement is shown in Fig. 4.

It is important to point out the three sources of revenue for the front end recovery facility. First, it can sell the recovered materials; second, it does not have to dispose of the recovered materials; third, it can charge a fee for the service of preparing refuse for the landfill. (In the example here, the facility can charge 25 percent of the raw refuse disposal cost, or $1.93 per ton for this service.)

Dumping revenue			
(156,000 tons per year, at $ 7.72 per ton)		$ 1,204	
By-product revenues (net)			
Ferrous metal	$ 159		
Glass	$ 76		
Aluminum	$ 218		
Paper	$ 62		
Other nonferrous metal	$ 47		
Total		$ 562	
Total operating revenues			$ 1,766
Waste product costs			
(126,360 tons per year, at $5.79 per ton)		$ 733	
Annual operating expenses		$ 819	
Total operating expenses			$ 1,552
Net operating income			$ 216

Fig. 4. Protypical operating statement, for materials recovery alone, of a resource recovery facility (annual rates in thousands of dollars).

Dumping revenue			
(156,000 tons per year, at $3.96 per ton)		$ 618	
By-product revenues (net)			
Ferrous metal	$ 159		
Glass	$ 76		
Aluminum	$ 218		
Paper	$ 62		
Other nonferrous metal	$ 47		
Total		$ 562	
Total operating revenues			$ 1,180
Waste product costs			
(24,960 tons per year, at $5.79 per ton)		$ 145	
Annual operating costs		$ 819	
Total operating expenses			$ 964
Net operating income			$ 216

Fig. 5. Protypical operating statement, for materials and heat recovery, of a resource recovery facility (annual rates in thousands of dollars).

The Indifferent Community

A resource recovery facility of the sort described would be economically feasible when the cost of operating the landfill, or incinerating raw, unprocessed refuse, is the $7.72 per ton calculated above and when disposing of the shredded, unrecovered residue is, accordingly, $5.79 per ton. If these figures are exact, then the community is indifferent; resource recovery costs no more or less than present disposal practices. If the community is paying, or expects to have to pay, more than this in the near future, obviously resource recovery would save it money. If current (or projected) costs are less, then a front end resource recovery system would be an add-on incremental cost.

This last circumstance warrants further discussion.

If the community is paying less than \$7.72 per ton to dispose of its refuse, it is not indifferent, because recovery would cost more than the community would otherwise have to pay. The community would have to decide the worth of resource recovery in light of other demands such as those for schools, medical care, and housing. However, an example may place this new demand in perspective. A family of four generates aproximately 2 tons of refuse per year. An incremental cost of \$2 per ton could be incurred as a result of a decision to construct and operate a front end resource recovery system. The \$2 per ton figure is not exact, but is the likely size of the increment. The point is that, on a per family basis, this is not a very large incremental cost.

Utilization of the Organic Fraction

Figure 4 shows that 47 percent of the total operating expenses of the facility is the so-called waste product disposal cost; for the most part, this unrecovered residue is organic and, therefore, combustible. A more beneficial course would be to recover this residue for use as energy.

Consider the cost of burning the combustible portion of household refuse in an electric utility boiler, along with coal, to generate electricity. In order to prepare an operating statement for a facility in which the organic fraction is so utilized, certain assumptions must be made about the amount of combustible residue, the costs of utilizing this fuel, and the costs of disposing of the wastes.

Not all of the residue can be burned. In the example represented by Fig. 4, it is estimated that approximately 16 percent of the residue (24,960 tons per year) will not be combustible and, therefore, must be disposed of in a landfill. Assume also that the cost of disposing of the residue is the same as in the case of Fig. 4—that is, \$5.79 per ton. Finally, assume that the value of the organic fraction as a fuel exactly offsets the cost to an electric utility for capital modifications necessary to accept and burn it (judged to be about \$1 million) and any added operating costs, such as for ash handling, air pollution control, added maintenance, and so forth (*14, 20*). In other words, assume that the organic fuel fraction is delivered to the utility boiler at no net cost to the recovery facility. Under these assumptions, the prototypical operating statement of Fig. 4 is modified to Fig. 5, and the dump fee is reduced to \$3.96 per ton. This illustrates the large economic advantage of such energy recovery. Disposal costs are obviously reduced. The indifferent community of the previous example, whose disposal costs for raw, unprocessed waste were \$7.72 per ton, now saves \$3.76 per ton on its disposal system.

The indifferent municipality is replaced by one whose alternative disposal costs are \$3.45 per ton (*21*). This lower figure greatly expands the number of communities in which resource recovery is economically viable, provided that the community has an electric utility which can utilize the organic fraction and that all other assumptions hold.

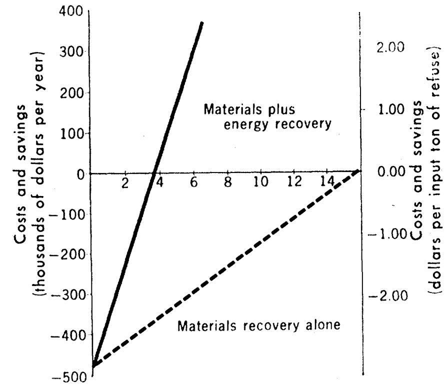

Fig. 6. Graph of incremental costs and savings for implementing resource recovery. No discount in the cost of waste disposal is assumed.

Table 4. Characteristics of prototype facility: size, 500 tons per day (156,000 tons per year input); capital cost, \$2.4 million (exclusive of land); debt, \$0.96 million; target return, 15 percent of equity (\$216,000 per year).

Material	Weight recovered (%)
Ferrous metal	6.80
Glass	7.00
Aluminium	0.70
Paper	4.00
Other nonferrous metal	0.25
Total	18.75

Public Ownership

The same type of operating statement analysis can be used in cases where the facility would be publicly owned. The net operating income figure of \$216,000 is not required, since most public bodies seek only to recover costs. In addition, the interest and depreciation entries must be modified for public financing. Also, the real estate tax entry is dropped. However, the community now loses this revenue, so, strictly speaking, in a total calculation of costs and benefits, real estate tax should be included as a cost (revenue decrease). Public financing may be through a revenue bond or general obligation bond (*22*). A 6-percent interest, 10-year bond with a level annual payment is assumed to supply the total capital requirement of \$2,415,614 for the facility (Table 2). This results in a reduction of the community's disposal cost to \$5.78 per ton for the materials recovery case and \$2.09 per ton for materials plus energy recovery. Thus, resource recovery is possible for greater numbers of communities when some form of public financing is used.

Incremental Costs and Savings

The potential incremental costs or savings per ton for private resource recovery facilities are plotted in Fig. 6. The abscissa shows the disposal cost in dollars per ton. Both the materials recovery case and the materials plus energy recovery case are shown. In this case, no added value for the shredding process is assumed (in other words, $DR = WPC$). Hence, Fig. 6 represents a "worst possible case"—that is, the case in which the cost of disposing of shredded refuse is the same as the cost of disposing of raw, unprocessed refuse.

For the materials recovery case, the graph illustrates that, unless disposal costs are high (greater than \$15.90 per ton), there is an incremental cost asso-

Table 5. Potential savings, by cost category, resulting from the use of milled refuse.

Cost category	Saving (%)
Land	62
Capital improvement	Varies
Equipment	42
Operating	42
Materials	11

ciated with resource recovery. For the community discussed previously, with a \$7.72-per-ton disposal cost, the incremental cost is \$240,000 per year, or \$1.54 per ton. However, the line for materials plus energy recovery crosses the abscissa from cost to saving, indicating the indifferent community, at a disposal cost of \$3.60 per ton. If current or near-term projected costs (say the average for the next 5 to 10 years) are above this value, there is a savings to be realized by installing materials and energy recovery. Figure 6 can be used to estimate the course a community might follow in planning a solid waste management system.

Summary

A prototypical operating statement similar to that used by business firms has been shown to be a useful decision-making tool for a community choosing a solid waste management system. When applied to resource recovery, it highlights the economics of recovery and the values of the input parameters necessary to achieve economic viability, whether in the case of public or private ownership (*23*).

In most communities, refuse processing to recover material resources must be based on more than one source of revenue. In addition to the revenues from the sale of by-products, there must be revenues from processing the incoming refuse and from a user, or dump, fee. In the first case discussed, that of materials recovery by a front end system, resource recovery is shown to be economically feasible for those communities in which the present cost of disposal is relatively high. The indifferent community was one having a current cost of \$7.72 per ton; more accurately, this would be the cost for the near-term future. It is not necessary that current costs be used, since many communities are merely "dumping" their refuse. The indifference decision should be based on the cost of an environmentally sound alternative.

Energy recovery from municipal solid waste can increase the number of communities in which resource recovery will be an economic adjunct to a solid waste management system. The analysis presented here was based on the assumption that the value of the fuel recovered exactly offset the additional capital and operating costs of the utility which burns it. There could be costs above and beyond this; similarly, there could be a saving by taking into account the economic value of the organic fraction as fuel. However, it is believed that the assumption under which the materials-plus-energy case was analyzed seems to be realistic at this time.

References and Notes

1. Urban solid waste refers to all material collected in a community and consists of portions from households and commercial and industrial establishments, as well as construction and demolition rubble.
2. Resource Recovery Act of 1970, Public Law 91-512 (26 October 1970). Also S. 498, an extension of that act, passed 26 January 1973.
3. The awardees of Section 208 grants and the prime contractors or processes to be installed are State of Delaware—Hercules, Inc.; Baltimore, Landgard pyrolysis—Monsanto Enviro-Chem Systems, Inc.; Lowell, Mass.—Bureau of Mines Incinerator Residue; San Diego County, Calif.—Garrett Research and Development Company, Inc. For a description of the processes, see (*4*).
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6. N. L. Drobny, H. E. Hull, R. F. Testin, *Recovery and Utilization of Municipal Solid Waste* (Publ. No. Sw 10c, Environmental Protection Agency, Solid Waste Management Office, Washington, D.C., 1971). The authors cite several sources of data.
7. The judgment exercised in developing nominal figures for discussion is stressed. In contrast, if a specific resource recovery plant is to be built, exact numbers must be obtained for that community. One method of doing this is described by E. R. Kaiser, C. Zimmer, D. Kasner, in *Proceedings of the National Incinerator Conference* (American Society of Mechanical Engineers, New York, 1970), pp. 25–31.
8. *A Study to Identify Opportunities for Increased Solid Waste Utilization*, report to National Association of Secondary Materials Industries, Inc., (Battelle Columbus Laboratories, Columbus, Ohio, 1972).
9. Storable fuel may be created from waste by several methods. Pyrolysis and anaerobic digestion processes are described in (*4*).
10. See, for example, J. F. Laundrie and J. H. Klangress, *Pap. Trade J.* **157** (No. 16), 34 (1973).
11. Many wastes do not have a use or have a very low economic use and, therefore, are not suitable for recovery. Hence, there will always be a need for some kind of landfill as an ultimate disposal method.
12. R. L. Lesher, *Environ. Sci. Tech.* **6**, 1078 (1972).
13. *Materials Recovery System, Engineering Feasibility Study* (National Center for Resource Recovery, Washington, D.C., 1972).
14. D. L. Klumb, *Solid Waste Disposal Seminar, Proceedings* (Union Electric Company, St. Louis, Mo., 1972).
15. For a recent discussion, see J. D. Headley, *J. Environ. Qual.* **1**, 377 (1972).
16. We do not intend to discuss the availability of markets and similar topics. These are covered adequately elsewhere—for example, in testimony before the Joint Economic Committee, subcommittee on fiscal policy, *The Economics of Recycling Waste Materials* (92nd Congr., 1st sess., 1971). It is obvious that recovered materials will have to be sold according to specifications, like any other commodity. It is our experience that, under such conditions, buyers can be found when there is, or is to be, an assured source of reasonable tonnages of appropriately processed products.
17. See, for example, publications such as *Iron Age*, *Waste Product Journal*, and *Official Board Markets*.
18. Perhaps the only other material thought to be recoverable is plastics, for which no revenue is shown here. Although some plastics can be recycled if separated and cleaned, at present there are no efficient means of separating them from mixed municipal refuse in a sufficiently clean form for reuse in new products. It appears that the best use for plastic waste is as fuel. Some plastics have a high heat of combustion; that of polyethylene, for example, is 46×10^6 joules per kilogram. [J. Brandrup and E. H. Immergut, *Polymer Handbook* (Wiley-Interscience, New York, 1966), p. VI–44].
19. J. Reinhardt, "A report on the demonstration of the Gondard grinding mill for pulverizing refuse and landfilling milled refuse without daily cover," final report to the Department of Health, Education, and Welfare, grant 5 001 U1 00004, undated.
20. R. A. Lowe [*Energy Recovery from Waste* (Publ. No. SW-36d.ii, Environmental Protection Agency, Washington, D.C., 1973), p. 13] states that solid waste as a fuel contains 0.1 percent sulfur and has a fuel value of about 11×10^6 joules per kilogram. Our own experimental studies (unpublished) indicated that, when air classified, the waste has a fuel value of about 19×10^6 joules per kilogram, dry weight basis. Therefore, at about 25 percent moisture, as received, and sold for \$0.40 per 10^6 joules, the processed waste would be worth in excess of \$5 per metric ton as a fuel.
21. To identify the indifferent community, Eqs. 1 and 2 must be restated. In Eq. 1, the waste product tonnage for materials plus energy recovery, 24,960 tons, is substituted for 126,360 tons of the materials recovery alone. Equation 2 remains the same. The result is:

$$156{,}000(DR) - 24{,}960(WPC) = 473{,}000 \quad (1)$$

$$0.75(DR) = (WPC) \quad (2)$$

The solution is $DR = \$3.45$ per ton and $WPC = \$2.59$ per ton.
22. The Pollution Control Bond is a form of the tax-free Industrial Development Bond, first sanctioned by the Internal Revenue Service in 1957. These bonds are issued by local governments to buy or build equipment and plants that are then leased to private corporations. This kind of financing resulted in a significant loss in tax revenue; as a type of tax reform, Congress passed in 1968 the Industrial Revenue Bond Act, which stipulates that no individual offering could be larger than \$5 million. However, an exception was made for industrial revenue issues that were intended to finance pollution control equipment. There is no limit on the size of these issues. Early beneficiaries of this exemption were corporations installing air and water pollution facilities. In April 1970, the Internal Revenue Service approved tax-exempt bonds for solid waste recycling facilities. To qualify, the processed material must be of no value to the producer; that is, it cannot be used or sold by the producer at the location of processing or at the time the bonds are issued. In addition, 65 percent of the input must fit this definition. A broad interpretation appears to have been given to the term "solid waste facility." According to the Internal Revenue Service, solid waste facility means any property used for the collection, storage, treatment, utilization, and processing of solid waste that results in the reconstitution or final disposal of such waste [sec. 103(C) 4 (E), U.S. Internal Revenue Code].
23. There have been, of course, recent dynamic changes in the nation's price structure. Building and equipment, as well as labor, costs have increased. However, secondary materials prices have risen as well. Therefore, an updating of the figures given here would be in order before any final decision to enter into resource recovery is made. Nevertheless, the method of analysis and, in general, the conclusions of this article are valid over a broad range of price structures.