Resource Recovery: A New Field for Technology Application

This review paper surveys the state-of-the-art of resource recovery from municipal, primarily residential, refuse. Unfortunately, progress in effecting the actual installation of full-sized recovery facilities has been minimal. The work that has been done has been beset with technical, and more often, economic difficulties. However, the rising cost of traditional means of disposal may allow new systems to become economically competitive. Past research and development efforts hold out promise of success and the nation may soon see the application of efficient technological solutions that in some localities will actually reduce the cost of refuse disposal below that of traditional means.

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SCOPE

Since the passage of the Resource Recovery Act of 1970 by Congress, federal attention has been focused on recovery as an alternative, in part or in total, to traditional refuse disposal techniques—incineration or landfill. In the public view, recovery is seldom associated with mechanical separation or refuse processing of any sort but is thought of as voluntary separation in the home, separate pickup of garbage and trash, can redemption centers, Boy Scout paper drives, etc. However, to those that are directly concerned with refuse disposal and its associated costs, resource recovery implies the ability to extract valuable and depletable resources from refuse at a cost less than landfill or incineration. The alternative of higher taxes or higher user charges has not been enthusiastically received by the public.

Technology has been applied so sparingly to the process of resource recovery that the potential return from the efforts of scientists and engineers is great. The chemical engineer's process-oriented perspective makes him particularly well suited to contribute to the development of a new technology-based resource recovery industry.

The text of this review reports on a number of so-called "resource recovery systems." One example is Combustion Power's federally-supported project to recover depletable resources (ferrous metals, nonferrous metals, and glass) as byproducts of freeing the organic fraction which is burned, generating gas to drive a turbine generator. An entirely different approach, inasmuch as utilization of the organic fraction is concerned, is that proposed by the Rust Engineering Company. Here, the inert material is separated from the organic portions, which are then mixed with discarded wood. The end product is a fiberboard material which—among other applications—could be used to form house sidings.

Each of these systems is comprised of unit processes vital to the success of resource recovery. Both systems and unit processes are discussed in this review. Also, an attempt is made to synthesize what can be said about the economics of resource recovery, using as a vehicle an operating statement which purports to illustrate Net Income and Rate of Return on Investment for a hypothetical recovery facility. Some interesting conclusions about the economics of resource recovery emerge both for short run interim materials recovery systems and for more total, and generally more costly, recovery options based on using the organic fraction.

CONCLUSIONS AND SIGNIFICANCE

The considerable effort spent to date promoting resource recovery has had little effect primarily because economically viable resource recovery—from the standpoint of both the operators and the users—generally requires that municipalities pay more than they have traditionally paid for disposing of their refuse. The dump is a cheap, if otherwise unsatisfactory, disposal method. However, one can expect this to change. More stringent health regulations, coupled with more diligent enforcement, are requiring that open dumps be converted to sanitary or other improved methods of landfill with adequate precautions being taken to control leachate by such site designs as diking and the laying of impervious membranes. These expenditures, coupled with rising land prices, have increased disposal cost.

Cities must now pay more for close-in land or face increased refuse transportation costs to more distant, but cheaper, land.

In the past, cities faced with diminishing landfill options turned to incineration as a means of effecting volume (and some weight) reduction, hence minimizing the need for landfill acreage. However, incineration has also seen its costs escalate. This has been due to the general increase in construction costs, and more importantly to the necessity to install expensive air pollution control equipment.

Even a partial resource recovery operation becomes a viable short-term adjunct to the solid waste disposal system of many cities in this high cost environment. Because of the high cost of alternative disposal methods, the way is opened in the longer run to develop relatively sophisticated processing that will increase the amount of recovery at prices competitive with the best available alternative cost structures.

As President Nixon stated in his 1970 Environmental Message, "Solid wastes are the discarded left-overs of our advanced consumer society. Increasing in volume they litter the landscape and strain the facilities of municipal governments . . . If we are ever truly to gain control of the problem our goal must be . . . to reduce the volume of wastes and the difficulty of their disposal, and to encourage their constructive re-use . . ." This paper looks at the potential for recovering resources from mixed municipal—primarily residential—refuse with the aim of conserving our natural resources and lowering our municipal disposal costs.

Litter is not covered in the text. There has been, on occasion, confusion between the problems of litter and solid waste. If solid waste consists of misplaced resources, litter in effect is misplaced solid waste. It is misplaced mostly because of individual carelessness. This is indeed a problem; but the fact remains that the bulk of solid waste is not littered, it is containerized and under the control of either municipally run or private collection and disposal operations. This waste is the main target for resource recovery as the subject is developed here. The topic of reducing waste at its source is not covered in this review. Although it is important, it is beyond the scope of this article. To repeat, this article is directed at the disposal aspect of solid waste management; or, more specifically, toward the potential of introducing efficient resource recovery systems, and thereby producing for the municipally or privately collected portion of our discarded left overs the constructive re-use referred to by the President.

Resource Recovery

The concept of Resource Recovery encompasses:

Reusing such articles as containers, which are recovered in their original form either when emptied or by subsequent effort.

Recovering substances from refuse in a reasonably pure form suitable for use as the raw material for products similar to those discarded; for example, metals, paper fiber, color-sorted glass cullet and plastics.

Recovering materials which because of their previous application or contamination cannot be totally reclaimed but which can be utilized in lower grade applications in the same general product line. Examples of this are fibers recovered from post-consumer paper being used for roofing felt, and bottle glass being recovered for use as insulation material.

Adapting waste products to different applications, such as glasphalt, a new highway paving material made with a crushed glass base.

Altering, in form and substance, large portions of the heterogeneous mass of waste into new products, such as compost or cattle feed.

Burning waste directly to produce energy or converting waste into a storable fuel (gas or oil).

The industrial community as well as the rest of the public has begun to turn an increasing amount of attention to the solid waste problem, but while the breadth of this attention is rather impressive, its depth is less so. Golueke (1971) observed that as a function of time, "the volume of literature on solid waste continues to expand almost exponentially, but the quality is considerably less." According to Golueke, "the failure of the quality to keep pace with the increase in output is not unexpected in view of the fact that many contributions are made by newcomers, or individuals not really conversant with solid waste management, as demonstrated by a naivete which betrays a lack of background on the subject." The same situation exists in the profusion of waste recovery systems that are being proposed, many with panacea-like claims. This creates a problem for a review of this sort. The number of new recovery systems that are being proposed doom to failure any attempt to present an all-inclusive list. Further, most of the systems—with the few exceptions noted—are still in some form of development. Consequently, operational data is lacking and much of the pilot plant data and processes are guarded as proprietary. Thus in this review emphasis is placed on the overall economics of recovery since both the survey and evaluation functions of this review are of necessity limited. [For additional readings that cover a broad range of systems in some depth see Wilson et al. (1972). A shorter survey with some depth is a two part series by Grinstead (1972).]

Resource recovery is unique in that the raw material—municipal refuse—has a negative value. Municipalities are now spending from $1 a ton to over $9 a ton (U.S. EPA, 1971) exclusive of collection costs to dispose of the refuse. The wide range in disposal costs is caused by the differences in geography and available disposal methods. It is doubtful if recovery will ever be competitive as long as $1/ton disposal options are available. However, with the promulgation of more stringent pollution regulations, these options are disappearing and more and more cities are finding the cost of their available options to be in the $5-and-up range. This opens the way for recovery.

In general, the key to competitive resource recovery is efficient and effective sensing and separation techniques. This is not an easy task, yet it is particularly important if the recovered products are expected to find a market as substitutes for virgin materials. The difficulty of separating the refuse in the as received state is illustrated in an example from Wilson and Smith (1972).

A typical item of refuse is a beer can. It may have a paper label or be printed. It may be all aluminum or have a steel body and an aluminum end. It may be half full of beer or water. A strong magnet may decide that this item is ferrous. A meter sensing its surface characteristics only may code it as paper. And a sensor measuring attenuation of radiation passing through the can will probably decide that something having so high a content of water must be fruit. All this is supposing that the can could be measured alone. It may well be wrapped in paper or plastic bag or in a nylon stocking or have some butter paper stuck to it.

The separation problem can be simplified, but far from eliminated, if the beer can is run through a shredder. Even after shredding, many technological gaps must be closed in order to develop separation techniques that will yield a homogeneous, recovered product. For example, most normal shredding will not separate the aluminum ends from the steel sides of bimetallic cans. The point is that waste comes mixed and is difficult to separate. Table 1 provides a frame of reference as to the composition of as-received municipal refuse. In a community that does not have any household separation (followed by separate collection—generally an inefficient practice compared with single collection), the mix goes into the packer truck and is delivered to the disposal site.

Note that paper is by far the largest single component. The bulk is newspapers and magazines. Yard trimmings, the next largest item, are seasonal in most communities, dropping to virtually zero in the winter. Note also that there is extremely little garbage and not enough ash to warrant inclusion in the table. Kitchen garbage disposals have greatly reduced the amount of garbage in refuse. While ash has probably never been a significant component of the waste stream in San Diego (the city whose refuse is described in the table), even in northern cities ash has dropped to relatively insignificant levels. The table illustrates the mixture with which a recovery system must deal.

What is it expected to produce? Table 2 shows the prod-

TABLE 1. TYPICAL SAN DIEGO RESIDENTIAL PICKUP*

Constituent	% by weight as received	% by weight moisture	% by weight, dry basis: with metal & glass	% by weight, dry basis: without metal & glass
Paper	46.16	8.23	42.36	50.40
Yard trimmings	21.14	51.30	10.30	12.25
Wood	7.48	10.50	6.69	7.96
Rags	3.46	7.40	3.20	3.82
Rubber	4.73	9.74	4.27	5.08
Plastics	0.27	0.06	0.27	0.32
Garbage	0.81	57.80	0.34	0.40
Metal	7.64	0	7.64	0
Glass	8.31	0	8.31	0
Moisture	—	—	16.62	19.77
Total	100.00		100.00	100.00

* Source: City of San Diego (1967).

TABLE 2. PRODUCTS EXPECTED TO BE RECLAIMED FROM RAW REFUSE BY DRY SEPARATION*

Product	Form	Contaminants
Combustibles		
Corrugated board	Shredded, ½ to 3 in. sq., slightly soiled	Small amounts of chipboard, light fabric, light wood and plastic. Trace amount of fine glass
Miscellaneous paper	Shredded, ⅛ to 3 in. sq., slightly soiled; includes chipboard, newsprint, magazine sheet, kraft and other wrapping, tissue, junk mail, etc.	More soiled by food wastes than corrugated. Small amounts of leaves, grass, plastic film & light fabric, trace amounts of glass and dirt
PVC	Shredded, ½ to 3 in. pieces, slightly soiled	Traces of fine impacted glass
Other plastics	Shredded, ½ to 3 in. pieces, slightly soiled; includes film and thin sheet, HDPE, LDPE, P.P., P.S. and miscellaneous plastic types	Trace amounts of fine glass and dirt. Small amounts of miscellaneous light paper and light synthetic fabric
Other combustibles	Shredded, ¼ to 3 in. pieces; includes food wastes, wood chips, thick plastics, leather, rubber, fabric, grass, leaves, yard cuttings	Bones and shells. Trace amounts of all other materials in refuse
Glass		
Colorless cullet	Shattered, ¼ to ¾ in. pieces	2% amber, 3% georgia green
Amber cullet	Shattered, ¼ to ¾ in. pieces	10% colorless, 3% georgia green
Green cullet	Shattered, ¼ to ¾ in. pieces; includes both georgia green and emerald green	10% colorless, 2% amber
Metals		
Light iron	Shredded; includes cans, wire, nails, nuts and bolts, light sheet, other fasteners	Small amounts of paint and rust. Traces of magnetic stainless steel and nonferrous metals coating iron objects
Heavy iron	Nondescript mixture of auto parts, heavy bar, rod and pipe, and other heavy objects	Grease, oil, paint, adhering nonferrous metal, and plated metal coatings
Large aluminum	Shredded sheet, tubing and castings—1 to 3 in.	Small amounts of paint and attached iron and other nonferrous metals
Large copper-zinc	Shredded copper sheet, tubing, wire, motor windings, brass	Small amounts of solder, aluminum and attached iron
Small aluminum	Shredded pieces, ¼ to 1 in. mostly from cans, can ends, pie tins, and fasteners	Small amounts of wood waste and glass
Small copper-zinc	Finely shredded pieces from larger product including coins—¼ to 1 in.	Small amounts of solder and aluminum
Fine waste		
Noncombustible inorganic fines	Finely ground glass, dirt, ceramics, dust from baghouse, etc. less than ¼ in.	Will contain small amounts of unrecovered metals and other materials in refuse

* Source: U. S. Bureau of Mines, Spendlove and Sullivan (1972).

ucts targeted for reclamation from raw refuse by the dry separation system being developed by the Bureau of Mines. Note the wide variety and mixes of materials listed under the main headings of Combustibles, Glass, and Metals. The flow diagram for this system appears later in the text.

RECOVERY SYSTEMS

It is convenient to divide the concept of a resource recovery system into two subsystems. The first is termed the *Front End System* and deals mainly with the mechanical separation of metals, glass, and paper. It is essentially a materials recovery system. The second subsystem involves the use, in some productive form, of the remainder and is called the *Back End System.* The term *remainder* is somewhat of a misnomer since it is really the bulk of the waste material—about 85%. Short of burning for its heat value, it is more difficult and more expensive to recover any value from this portion. Suggested processes for the Back End Systems include converting the bulk of the remainder into building blocks or wall board or converting it to a storable fuel (oil or gas), animal feed, or a soil conditioner.

In general, the technology and the ability to market the recovered materials are more advanced for the Front End System. Some type of Front End recovery, such as magnetic separation of ferrous metals, has been in use for many years, as has hand picking of paper and corrugated. The markets for these products are potentially available through a large secondary materials industry. Markets for composted material, steam produced from burning refuse and other Back End products are not as easily developed, as those who have attempted to do so have found out. A number of examples are described or referred to later in the text of this review.

The importance of developing Back End Systems is pointed out in the last section of this paper on economics. Stated very simply, an 85% remainder is a great economic burden on a recovery system. The Front End subsystem should be regarded as a starting point from which expansion can be made into a more complete resource recovery system. Also, it appears that a Front End System, perhaps not as complete as the illustrative one developed in the next section, is necessary to clean up the refuse for almost all conceivable Back End options. This, as well as the general availability of the technology, led to the selection of the Front End-Back End nomenclature used here in an illustrative context.

FRONT END SYSTEMS

The illustrative Front End system described in the paragraphs that follow is shown in Figure 1. Unit processes included drawing on the experience, both present and past, of a number of sites, including: the shredding, magnetic separation and landfill operations at Madison, Wisconsin; the Metro Waste compost plant at Houston, Texas, although the compost portion of this facility is no longer in operation; the shredding and landfill operation of Waste Management, Inc. at Pompano Beach, Florida; shredding which has recently been combined with a prototype air classification step at Vancouver, Washington; and two facilities operated or being developed by the U.S. Bureau of Mines at College Park, Maryland. The first of these is an incinerator residue separation system and the second

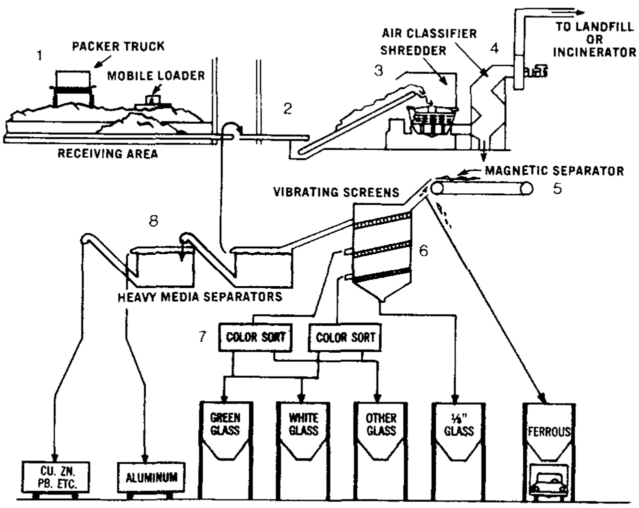

Fig. 1. Typical Front End System.

a raw refuse separation process with particular emphasis on developing improved classification and separation techniques for raw refuse.

Illustrative System

There are a number of steps in the materials recovery system used here for illustrative purposes. These are discussed in turn.

Step 1. The operation begins with delivery of raw refuse to the receiving area, generally by packer vehicles.

Step 2. From the receiving areas, the material is transferred to a size-reduction unit by one of two techniques. In the first instance, the receiving area might be an integral part of the transfer system; that is, collection trucks discharging directly into a pit with hydraulic rams built in the floor which automatically feed another conveyor belt discharging to a shredder. A Front End loader or crane can also be used to move the refuse from the tipping floor onto a conveyor belt and toward the size reduction stage.

Bridging, blockages, and uneven feeding have in the past plagued this initial conveying step. The use of vibrating conveyors to load the main belt (Houston Metro Waste plant) seems to alleviate these problems. A vibrating conveyor installed in the St. Louis facility, however, produced unusual and unanticipated sonic conditions in resonance with the building. A two-conveyor system as installed in Pompano Beach shows promise.

Another problem is the composition of the material fed into the size-reduction equipment. Most operators feel that it is prudent to screen out oversized and hazardous materials. Madison, Wisconsin, discovered that a mortar shell, fortunately a dud, had been fed into its system. Fuel cans and propane containers are also a problem, as are oversized or hardened pieces of ferrous metal. For a shredder designed to handle glass, tin cans, paper and yard clippings, a case-hardened gear can present a problem. Some equipment automatically rejects this type of material, but many operations supplement this protection by positioning a quality control man at the conveyor belt to pull out this material. In the Houston system, hand-picking paper and corrugated serves as an auxiliary task to this screening.

Step 3. While size reduction is shown as a single step operation, it may be desirable to accomplish this process in multiple steps. Most compost plants use at least two stages—coarse and fine—prior to composting. Sometimes a further grinding step takes place prior to packaging the compost product for sale.

The U.S. Public Health Service demonstration compost plant at Johnson City, Tennessee, (now closed) used a rasp mill for initial size reduction. However, about 90% of all municipal solid waste size-reduction operations employ hammermills. The term itself refers to any type of equipment that uses a pivoted or fixed hammer or cutter. This wide classification would include high-speed crushers, chippers, shredders, or grinders. Madison, Wisconsin, at first used a Gondard hammermill and in 1970 added a Tollemach hammermill.

The Bureau of Mines, in its new raw refuse system, uses a chain breaker whose primary function is to tear open the plastic or paper bags as a first step with shredding done after magnetic and primary air separation. Drobny et al. (1971) and Engdahl (1969) contain a relatively complete discussion of size-reduction options, costs (capital and operating), and power requirements.

Step 4. In the illustrative Front End system shown in Figure 1, the refuse is discharged from the size reduction step to an air classifier. There, the light fraction (primarily organic and, therefore, combustible) and the heavy fraction (mostly inert) are separated. Air classification is a fairly simple, yet efficient, process when used to separate relatively homogeneous materials, even if their densities and aerodynamic characteristics are rather similar. For example, a mixture of aluminum wire and insulation material can be separated after an initial size reduction step and a friction step to physically remove the insulation from the wire. Refuse, however, even after shredding, is extremely heterogeneous and the mixture itself varies from batch to batch. As a result, attempts to achieve a high degree of separation among the various components in the waste stream through air classification have not yet proven successful. Nevertheless, primarily based on the Combustion Power Company's experience at Menlo Park and Vancouver, it appears that expectations of successful gross separations as prescribed in the illustrative Front End system are not unfounded.

Previous work in the area of air classification of solid waste was described by Boettcher (1972) reporting on a study sponsored by the U.S. Environmental Protection Agency. The Stanford Research Institute (SRI) conducted the referred to state-of-the-art investigations. Unfortunately, raw refuse was not included. Processed during the experiment were mixed waste paper, aged compost, and nonferrous trash from auto bodies. In the processor shown in Figure 2, air forced the lighter materials upward through the zig zag chute, while the heavier elements fell to the bottom. The lighter pieces either fell back into a second hopper (as is shown in the diagram) or were carried on to another unit processor. Some success was reported in removing plastics and other light material along with metals and glass from the aged compost, in separating organic materials such as insulation from the nonferrous auto body pieces, and in classifying the paper products. SRI contended, although they do not claim they proved conclusively, that a grade of mixed secondary paper consisting of clean, uniformly shredded newspaper, kraft-paper stock, and corrugated cardboard could be produced commercially from municipal refuse using the zig zag classifier.

The Bureau of Mines is experimenting with a horizontal air classifier, rather than a zig zag, for gross separation, followed by a series of cyclone separators to achieve further differentiation among paper and paper board products. This system is shown in Figure 3 along with the other steps in the Bureau of Mines process. These are similar to those used here in the illustrative Front End System, but

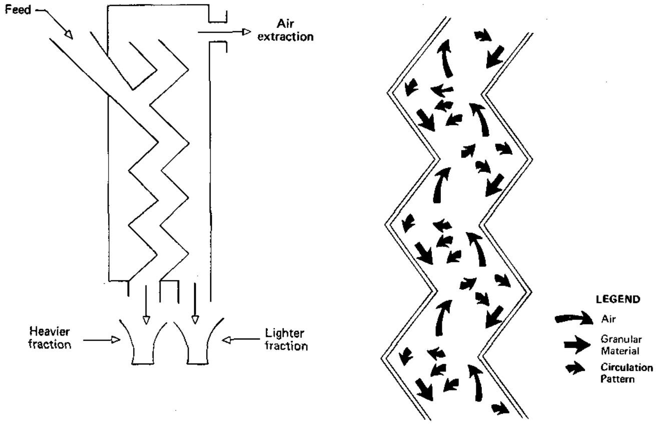

Fig. 2. Zig zag air classifier.

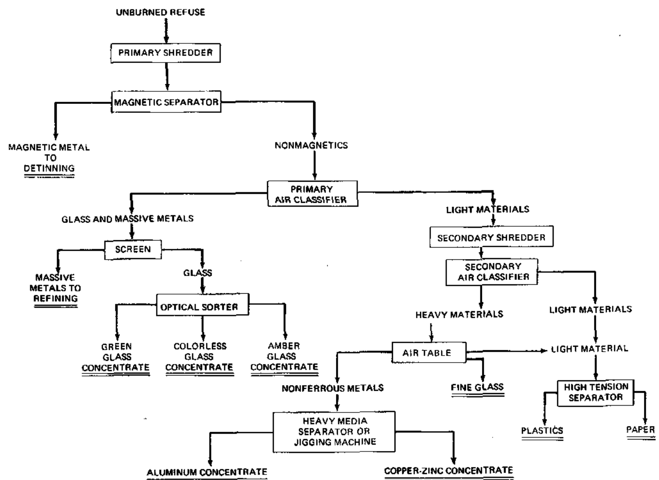

Fig. 3. Bureau of Mines proposed dry separation system.

attempt to obtain better recovery of paper and paperboard as well as some plastic materials. See Table 2.

San Diego has also experimented with a horizontal classifier, while the U.S. Department of Agriculture's Forest Products Laboratory in Madison, Wisconsin, uses that city's shredding facility to supply raw materials for a Bauer Brothers industrial air classifier generally employed as a unit process in the production of commercial chip board. On an experimental basis, some rather fine separation of paper products has been achieved by the Laboratory (Carr, 1970).

Step 5. A number of installations are now magnetically separating ferrous materials, but without air classification. As a result organic materials are carried along with the ferrous. It is anticipated that magnetic separation after air classification will mitigate this problem and also reduce the amount of material that must be scanned to effect the magnetic separation since only the heavy fraction need be processed. Magnetic separation, wherever it appears in the flow diagram, is neither complicated nor expensive. Again, see Drobny et al. (1971) and Engdahl (1969) for a more in-depth discussion of this process.

Step 6. The screening step, as seen in Figure 1, accomplishes size classification and produces a nonferrous metals rich fraction and a glass fraction. The former consists mainly of the larger sized nonferrous particles, the bulk of which will be aluminum beverage cans along with some plastic, rubber (which is difficult to shred), leather, and wood. Particles that pass through the screens will be mainly glass plus ceramics, rock and ash, and small pieces of plastic and wood. Vibrating screens which are relatively simple devices, are part of the Bureau of Mines raw refuse separation process in College Park, Maryland. They are also used in Combustion Power's pilot plant operation in Menlo Park, California, and at the Forest Products Laboratory facility in Madison, Wisconsin. Extensive use was also made of vibrating screens and gravity tables in the Metro Waste facility in Houston. [See Prescott (1967) for a description of Houston Metro Waste as it was during the years it was producing compost.]

Step 7. It can be expected that the glass-rich fraction will require considerable clean up to make it suitable for reuse in primary glass making. One such step illustrated on the diagram is color sorting. Palumbo et al. (1971) of the Bureau of Mines has conducted a number of tests in sorting glass from both raw refuse and from incinerator residue using an optical sorting device. In the test, an optical color sorting machine was used to recover colorless glass from a mixed glass fraction. Using an unincinerated glass sample containing 54% colorless glass, they were able to recover 62% of the colorless glass in a single pass. However, the recovered fraction was not entirely clean as colored glass and other impurities represented 14% of the sorted fraction.

For glass manufacturing this is not a pure enough fraction. To improve this material the Glass Container Manufacturing Institute has received a grant from the U.S. Environmental Protection Agency to develop a system for glass fraction clean up and color sorting in conjunction with the Black-Clawson fiber reclaiming facility in Franklin, Ohio. While not yet in operation, the system is designed to produce usable glass and aluminum in proportion to their presence in the rejected material of the liquid cyclone system.

The first step in the proposed system is the removal of whatever magnetics remain in the magnetically scalped mixture. Immediately after this step, a drying operation is incorporated after which three beneficiation steps are performed. These are zig zag air classification, cyclonic air separation, and electrostatic separation, after which color sorting is performed. The target is a clear glass fraction with less than 2% colored glass, essentially free of organic and metallic and other nonglass contaminants.

Step 8. The make up of the larger pieces coming off the screen has previously been described. To effect separation here, the illustrative Front End System suggests a series of media steps. These would start with water flotation to separate the remaining organics from the metals, followed by heavy media separation of the aluminum and other heavier nonferrous (Cu, Zn, etc.) metals. Various solutions or pulps are available for this purpose, with specific gravities ranging from 1.25 to 3.4. The material immersed in the heavy media will either float or sink, depending on its specific gravity. In this case, the sink fraction would be a heterogeneous mixture, primarily nonferrous metals. [Roberts et al. (1970) describe heavy media and other processes, such as jigging, that might be used to accomplish this separation step.]

Unless the facility is very large, it would probably not be feasible to further process this mixed nonferrous residue at the recovery site. This fraction is likely to be less than 1% of the raw refuse input. Hence a 1,000 ton/day plant (roughly the refuse from a half million people) would only produce 10 tons a day maximum. Presumably, rather than installing further classification equipment on site, it would be more efficient to transport the mixture to secondary metals firms who specialize in separation of this material.

Concluding Comments on the Front End System

It should be noted that an independent Front End system will not solve the total disposal-recovery problem. From the standpoint of disposal, it offers very little waste reduction (roughly 10 to 20% by weight). The rest, barring a Back End option, must be disposed of by traditional means. On the positive side, however, the separated organic residue is shredded into a relatively homogeneous form which appears to offer some disposal economics. If it is correctly incinerated, there will be little residue, which will significantly reduce costs in some cities. This is because of the lack of inerts. Also, there should be less wear and tear on the incinerator since the main abrasive objects have been removed prior to the refuse being placed on the grates. If the shredded residue is landfilled, there should be less requirement for land, cover dirt, manpower, transportation, and site equipment due to the densification and decrease in the health hazard resulting from shredding. Also, since compaction potential is somewhat greater for a given amount of effort expended, it should increase the life of the landfill representing a postponement in future outlays for the purchase of new landfill acreage (Duszynski, 1971). Neither of these presumed benefits has been established empirically, although work on the landfill cost is underway at Madison, Wisconsin.

BACK END SYSTEMS

From a total systems standpoint, a subsystem accomplishing only the separation outlined above is clearly suboptimal. The key to substituting recovery for disposal is to effectively utilize the potential economic values in the organic or light fraction. This has not gone unnoticed by systems developers, and a great many options have been proposed. As mentioned earlier, in large measure they are simply add-on's to the Front End system described above. Most require a cleaned up organic fraction. However, it should be noted, Back End options, with the exception of certain types of burning for energy recovery, are still essentially in the proposal stage.

Burning the Organic Fraction

The most promising short-term approach to recovering value from the organic fraction appears to be in burning it for its energy content. It may even be the most efficient utilization in the long run. Raw refuse of average moisture content on an as-received basis runs about 4,450 B.t.u./lb. With the ferrous metals removed, its value increases roughly 6 to 10% (Niessen and Chansky, 1970; Wisely et al., 1971). There are a number of ways the utilization of heat value can be accomplished. Incinerators, for example, can be constructed or adapted for hot water or steam production. Alternatively, refuse can be used as a supplemental fuel in regular or modified heat exchangers along with fossil fuels to produce steam for heating or cooling or even burned as a supplementary fuel in utility grade boilers for the production of steam to drive turbine generators. Another possibility is to substitute refuse burning auxiliary equipment for particular stages in an otherwise traditional thermal electric plant (Cohan and Fernandes, 1967). Another option is that proposed by the Combustion Power Company and supported by EPA to burn the refuse in a fluidized bed incinerator using the products of combustion to power a gas turbine generator. A final source of options for utilizing refuse's fuel value lies in developing storable and transportable fuels from raw refuse. Techniques are being developed to convert raw refuse into storable fuel gases, oils, and lump coal substitutes. Companies involved in these conversion processes include Union Carbide, Garrett Research, and National Recycling Corporation.

Water-Wall and Other Steam Producing Incinerators. The idea of recovering useful energy from refuse is not new. As early as 1889, a refuse burning steam generator was built in New York (Stephenson, 1970). U.S. practice, until recently, has been to use refractory furnaces with either internal or external boiler tubing, while the European trend is to use water-wall furnaces. Some examples of U.S. steam generating refractor furnace incinerators are: Atlanta, Georgia's Mayson plant that produced steam and sold it to a local steam heating system (the facility closed early in 1972 due to air pollution problems); Miami, Florida, where steam was produced and delivered to an adjacent hospital, but because of air pollution problems, has since been closed; and Hempstead, New York, which has two steam generating incinerators. Wilson et al. (1972) lists incinerators with significant heat recovery capability. Water-wall construction has the advantage of being able to operate at higher temperatures than refractory-wall construction, with the attendant benefit of being able to operate at substantially reduced excess air levels. The first American application of waterwalls to an incinerator boiler plant burning essentially municipal refuse was a 360-tons/day plant that went into operation at the Norfolk, Virginia Navy Yard in 1967. Each of the two 180-ton units was designed to produce 50,000 lb. of steam/hour. The steam is used in the naval base's steam supply system. Other American water-wall steam-producing plants now under construction include those in Braintree, Massachusetts, and Hamilton and Montreal, Canada.

However, perhaps the most publicized water-wall incinerator in the United States is the Chicago Northwest facility. The incinerator has four boilers, each with a steaming capacity of 440,000 lb./hr. It is expected that at full capacity the incinerator will consume 1,600 tons of refuse/day. In the process it will utilize 2,240,000 lb. of steam for internal purposes; the rest is expected to be sold to nearby industries (Pikarsky, 1971).

For the most part, incinerators with steam generation capacity use the steam entirely for in-plant use (Stephenson and Cofiero, 1966). External uses are the exception rather than the rule. One problem with selling steam to commercial users is that the generation of steam in a municipal refuse incinerator cannot be reasonably varied to meet load conditions. To handle cases where the steam generating capacity of the refuse needing to be burned exceeds the demand, the plant must be provided with a boiler bypass flue or steam condensing equipment. Conversely, for those times when demand is higher than can be met by burning available refuse, the plant must be provided with an auxiliary fuel-firing system. However, experience has shown that the additional cost of this equipment is justified only where firm markets can be obtained for all of the steam produced. In general, markets as assured as this have not materialized. Alternatively, a cheaper bare bones plant could be constructed which would be part of a larger steam-generating system, rather than the sole provider.

The ideal use in this instance would be to sell the steam to a large electrical utility company. In such a case, when the incinerator plant had steam to sell, it would be able to feed it into the system. But, when it did not have sufficient refuse, or the heating value of the refuse was low due to adverse weather or composition, it could be relieved from having to produce steam. However even in this case, it does not appear that the economics are favorable. For example, Day and Zimmerman (1968) report on an inquiry made to Potomac Electric Power Company in Washington, D.C., with respect to a new incinerator then in the design stage:

> The Potomac Electric Power Co. operates a steam turbine powered electric generating station adjacent to the plant site. They were contacted to determine if they could use a supply of steam from the incinerator plant at the 225 p.s.i.g. dry saturated conditions, available from an incinerator boiler. We were advised that they could use 200 p.s.i.g. steam in their older turbines but that superheated steam was preferred. The minimum cost of steam generation at the incinerator plant plus pipeline charges is in excess of the steam generating costs for low pressure steam at the utility power plant.

This is a good illustration of why there have been no major examples in this country of incinerator production of steam for electric utility use.

One reason for the cost differential is the matter of economics of scale. Efficient thermal electric plants are extremely large, burning upwards of 5,000 tons of coal/day or an equivalent in B.t.u. value of oil or gas. Except in rare circumstances (New York City, for example), it would be extremely difficult to reach the required scale of operation with refuse as a primary fuel without escalating the cost of solid waste management by increasing transportation costs. The Chicago Northwest Incinerator at 1,600 tons/day is the largest in the country. Yet a 2,000-ton/day plant would only produce about 40 MW of electricity, while labor costs for a plant of this size would be almost the same as one of a 1000-MW facility.

However, recently the State of Connecticut announced a competitive procurement to develop a plan to deal with Connecticut's long range solid waste disposal problem. This is to be followed by the award of implementation contracts to put into production the recommended system or systems. It is clear from the procurement letter that the state has in mind an energy conversion approach. Attached to the basic letter is a memo entitled "Utilization of Solid Waste for the Generation of Electricity" and a pledge of not only cooperation but also "substantial effort" from Northeast Utilities, a consortium of light and power companies serving the state (Connecticut, 1972).

The Vertol division of the Boeing Company has proposed an incinerator steam plant for Philadelphia and two surrounding counties. The steam generated from the waste is to be sold to the Philadelphia Electric Company to be used in an existing center-city steam heating system. The plant is designed to accommodate 3,000 tons of waste/day. Unfortunately, net disposal costs even after credit for energy recovery are projected at $8.40/ton (Boeing, 1972). This does not show much promise for reducing the cost of disposal.

Refuse as a Fuel in Utility Grade Boilers. Two types of on-site burning of refuse have been considered; first, as a primary fuel but burned in auxiliary equipment, and second, as a supplementary fuel fed into the main combustion chamber of the boiler either in combination with the primary fuel or through a separate inlet.

Cohan and Fernandes (1967) suggested using incinerator generated steam in the regenerative feedwater heating portion of the power plant cycle, or using refuse-fired air heaters or economizers rather than as a combined fuel in the main chamber.

Roberts and Wilson (1971) also examined the question of utilizing refuse as a low sulfur boiler fuel and concluded that the most cost-effective approach is to use the refuse in a preheating role; that is, to fire refuse on reciprocating grates in a water-walled furnace to produce high enthalpy feed water. This feed water is then sent to a tandem fossil-fuel-fired steam generator of conventional design. Also considered were various alternatives, such as firing refuse and coal in separate furnaces with the flue gases combined and passed over a common convective surface, combined firing, separate firing to provide partial superheated steam, etc. No utility in the United States has adopted any of the alternative approaches.

Approximately three years ago EPA (then Bureau of Solid Waste Management, DHEW) awarded a grant to the city of St. Louis, Missouri, for construction of what is essentially a minimum recovery Front End system. The raw refuse is shredded and the ferrous materials removed. The main focus of the project, however, is to evaluate the value of burning solid waste as a supplementary fuel in the main combustion chamber of a conventional coal fired boiler.

In carrying out this experiment, the Union Electric Company, which serves the greater part of the St. Louis metropolitan area, modified two boilers in their Meramec plant. Each of these boilers has a generation capacity of 125 MW. The boilers are normally tangentially fired by a series of pulverized coal inlets in each corner of the installation, supplemented by natural gas burners. For the experiment, a gas nozzle in each corner of the boilers was replaced with a refuse inlet. Initially refuse will be fed to provide 10% of the heat requirement. At full rating this is equivalent to 12.5 tons of refuse plus 56.5 tons of Illinois bituminous coal/hour. The ultimate goal is to use a 20%/80% refuse to coal mixture.

In the electric plant itself, funds for the installation were completely supplied by Union Electric (approximately $600,000). For the city facility which costs about $2 million, EPA contributed approximately 1.7 million. This included the building, conveying equipment, the shredder, magnetic separator, storage facilities at the city's site, transfer vehicles, and unloading and transfer facilities on ground leased by the city at the Meramec plant.

Refuse is dumped on the tipping floor at the city facility and then loaded on a conveyor by a Front End loader. The conveyor feeds the shredder. From the shredder, the ferrous materials are extracted after which the refuse drops into a storage bin. Discharge is by conveyor to a stationary packer which loads transfer trailers for the 18-mile trip to the power plant. There the refuse is unloaded into another storage receptacle (city owned). It is removed from storage by a pneumatic system and transferred several yards to another storage area (Union Electric owned). From this storage bin, the refuse is conveyed to four outfeed chutes through a like number of air locked pneumatic feeders with associated piping to the corners of the boilers.

During a 10-month operating period, shredded refuse will be supplied at no cost by the city. Even giving the material away, that is, disregarding its value as a fuel, represents a saving to the city of St. Louis because the city can shred and deliver the refuse to Union Electric for $5.00/ton. The alternative is to burn the raw refuse in its present incinerator, but this costs $7.00/ton.

If the experiment succeeds, it will validate using refuse as a heat source and raise the question of payment for the refuse to the city of St. Louis and other cities who may establish such an arrangement. Clearly, utilities have potential fuel cost savings over their alternative of coal, oil or gas, as does the city over its disposal alternatives—ordinary incineration and landfill.

Refuse as a Fuel for Gas Turbine Generation of Electricity. A rather novel technique of converting refuse to electrical power is being developed by the Combustion Power Company, Inc., of Menlo Park, California, as reported by Bergin et al. (1970). This project, funded by EPA, utilizes a refuse-fired gas turbo-electric generator plant. The system is now entering the final stages of R&D with a complete 1/5-scale pilot plant scheduled to be operational by the end of 1972. The process is shown schematically in Figure 4. Refuse is shredded into particles of approximately two inches and dried and classified by the means discussed under Front End systems. The combustible portion of the refuse is transferred to a storage unit which meters the shredded waste to an air lock. Passing through the air lock, the refuse is mixed with 100 lb./sq.in. gauge, 600°F air as it enters the fluid bed combustion chamber. The combustion chamber, which is 8 ft. in diameter, contains sand which has assumed fluid characteristics due to the high degree of agitation caused by the high-pressure air flow. The high heat transfer rates promote rapid and complete combustion of the refuse. The bed is expected to operate at about 1,650°F. The entrapped particles in the hot exhaust gases are removed by a two-stage, inertial separator before the gas is used to drive the turbine. The turbine exhaust gas, which is approximately 930°F and at atmospheric pressure, can be passed through an optional waste heat boiler.

The full-scale plant as conceived by Combustion Power will consume 400 tons of solid waste/day and produce approximately 9,000 kW of electrical power. According to the company, it is expected that the CPU-400 facilities will produce electricity at prices competitive with large fossil fuel steam plants. Yet because of the relatively small size of the CPU-400, the plants could be decentralized to allow the refuse-fired system to be located to minimize refuse hauling costs.

An added advantage is the fact that turbines can be put on and off line rather rapidly. Hence, a number of such installations can be effectively integrated into an existing system with the fossil fuel plant carrying the base load in the power net.

Storable Fuel Systems. Clearly, the latent energy value

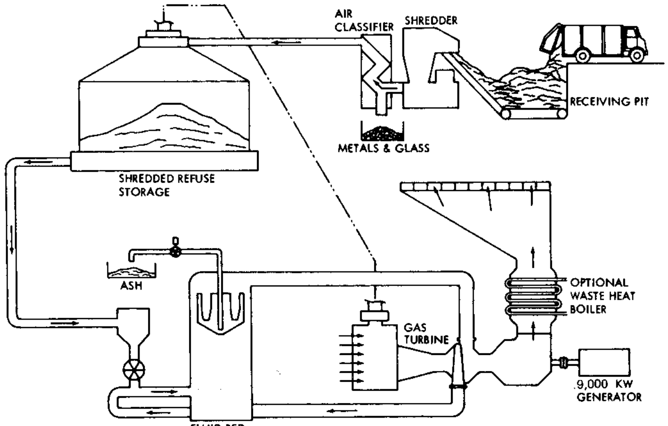

Fig. 4. Flow chart of the CPU-400 system.

of refuse could be more effectively realized if it could be stored. Because of odor and health hazards, this is hardly possible with the basic raw material. Further, it is hydroscopic which lowers the effective B.t.u. value. Transportability is another important element. A number of ways to obtain storability and transportability have been proposed. These include shredding followed by separation of the noncombustibles after which the material is cubetted into a lump coal substitute; subjecting the refuse, with or without shredding and inert removal, to pyrolysis in order to produce burnable oil and burnable char along with a usable gas; burning in a fluidized bed incinerator to produce a burnable gas, and chemical/biological processes designed to obtain methane gas with high potential B.t.u. yields.

Solid Waste Cubette Fuel. Cubes of approximately 1½ in. consisting of compressed organic solid waste matter are being developed as supplementary fuel by National Recycling Corporation (NRC) of Fort Wayne, Indiana. The inert fraction of the municipal refuse is separated from the organic fraction (Hollander et al., 1971). The organic fraction is then compressed and extruded into the cubes in a proprietary process. In order to allow for limited testing of the cubettes, NRC produced 37 tons which were burned with lump coal at a 3:1 ratio of coal to cubettes on a conventional stoker grate in the Fort Wayne, Indiana, municipal power generation station with no station modifications. No adverse effects of burning the cubettes along with the coal were encountered. Two calorimetric tests of the cubettes indicated they had a heating value of 6850 and 8530 B.t.u./lb. The National Recycling Corporation believes that cubettes can be utilized in most existing lump-fired boilers, although modification may be necessary in some cases. The city of Fort Wayne has applied to EPA for a grant to investigate the economic and technical applicability of the cubettes, both as a supplemented fuel and as a total fuel for their municipal power station.

Conversion of Solid Waste to Oil and Char. Garrett Research (Mallan, 1971) reports on a proprietary pyrolysis process to treat the organic fraction of municipal solid waste and recover its energy as a storable fuel. The process is based on experience gained by Garrett in destructive distillation of coal to produce oil. The main product of the pyrolysis when used on the organic fraction of the municipal solid waste is a liquid which, Garrett claims, has an average heating value of approximately 12,000 B.t.u./lb. In addition to the liquid, a low sulfur char with a heating value of around 9,000 B.t.u./lb. is produced as well as a gas stream with a heating value of about 600 B.t.u./ft^3. In the Garrett process this is used as an in-plant heat source. Overall, the products of the pyrolysis process on a weight basis are 35% char fraction, 40% oil fraction, 10% gas fraction, and 15% waste water fraction. The system was originally developed on a laboratory pyrolysis reactor that had the capacity of 5 lb. of municipal refuse per hour. With the success of the laboratory tests, a four ton/day pilot plant was constructed and is now being operated.

The process consists basically of five steps: (1) shredding the refuse down to approximately two inches; (2) drying, air classifying, and screening the shredded refuse to remove both the moisture and inerts; (3) secondary shredding; (4) pyrolyzing the finely shredded organic refuse; and (5) collecting the pyrolysis products. Solid char is removed from the hot gas stream by a series of cyclones. The volatiles in the gas stream are condensed and the organic liquid as well as the waste water are separated out.

Garrett in conjunction with San Diego County was awarded an EPA grant in September, 1972, to construct and operate a 150-ton demonstration plant.

Conversion of Solid Waste to a Burnable Gas. Union Carbide's Linde Division is developing a product that utilizes limited amounts of oxygen rather than air to oxidize some of the refuse, generating the heat to sustain a pyrolysis process. The gas produced is mainly hydrogen and carbon monoxide and has flame temperatures and heat transfer characteristics that are similar to natural gas. The process, as now configured, requires neither initial shredding nor separation of the refuse before it is fed into the pyrolysis unit. Union Carbide reports that the volume of solid waste is reduced 95 to 98%. Further, because it is a pyrolysis unit, without the excess air of standard incinerator processes, Union Carbide reports that air pollution problems are minimal. A pilot demonstration plant of 5 tons/day has been operated for a year at Union Carbide's technical center in Tarrytown, New York.

Anaerobic Digestion to Generate Methane Gas. Anaerobic digestion is being used in various parts of the country as a means for treating sewage sludge. The principal products of the anaerobic digestion processes are methane gas, a commercially useful product and a solid residue that can be used as a soil conditioner or put in a landfill without cover. It appears that the process could have significant merit in treating the organic fraction of the solid waste stream. This is particularly true when it is noted that since the advent of the kitchen grinder disposal unit, sewage sludge contains significant amounts of garbage. The University of California has been doing experimentation on the use of anaerobic digestion for the treatment of raw refuse with encouraging results (Goleuke-Vol. I, 1970). Approximately 6 cu.ft. of methane gas/pound of organic solid waste have been generated accompanied by a volume reduction of about 50%.

High Temperature Incineration

While not strictly resource recovery oriented, a number of systems strive for maximum volume reduction. Some claim heat recovery as an adjunct to the reduction process. Most suggest utilization of the residual inert material in the construction area, primarily as a gravel substitute.

High temperature (3,000 to 3,200°F) incineration offers several advantages over conventional incineration (1,600 to 1,800°F). These are volume reduction of 95 to 97% compared with 65 to 75% for a conventional incinerator. Also, excess air requirements are 25 to 30% compared to 200 to 300% for a conventional incinerator, with the resultant reduction in the amount of flue gases that must be filtered by air pollution equipment, although greater amounts of oxides of nitrogen are expected to form at the higher combustion temperatures. In addition, the residue, initially a molten slag, consists almost totally of minerals and metals. The conventional incinerator residue on the other hand contains approximately 20% unburned but potentially combustible solid waste (Henn and Peters, 1971).

Melt-Zitt Process. One example of a high temperature incinerator is the Melt-Zitt process being developed by the American Thermogen Incorporated (Illinois, 1972). Refuse in an as received condition (this includes bulky items such as appliances, tires, etc.) is fed into the furnace where the combustibles are ignited and the first burning occurs. The hot combustion gases (2,500 to 2,900°F) are passed through a waste heat boiler where steam for internal and external use (if a demand exists) is generated. After leaving the boiler heat exchanger, the combustion gas, which is about 650°F, is passed through the air pollution equipment to remove particulates and noxious gases before being exhausted into the atmosphere.

The refuse that is not combusted moves to a second furnace area where the temperature is maintained at approximately 3,000+ °F by the addition of auxiliary fuel. In this portion of the furnace, the remaining combustibles are ignited while the minerals and metals liquify and are continuously drained off through a slag tap to a quench tank. It is possible to separate the quenched and dried residues to make various products such as structural blocks, slag wool, pipe, tool blanks, etc., as described in the publication previously cited.

A 3-ton/hour Melt-Zitt pilot plant went into operation in Whitman, Massachusetts, during 1966. Kaiser (1969) evaluated the process.

Torrax. A second example of high temperature incineration is a 75 ton/day experimental pyrolytic unit developed by Torrax System, Inc., now being constructed in Orchard Park, N. Y. with the assistance of a $1 million EPA grant. The system, which processes unshredded refuse, consists of an air blast heater, gasifier, off-gas igniter, and bag filter. Incoming combustion air is filtered and heated to 2,000°F by means of auxiliary fuel in the blast heater. The hot gases are fed into the bottom of the gasifier unit which is charged at the top with refuse.

The hot gas, rising, pyrolyzes most of the organic material before it reaches the high temperature zone at the bottom of the gasifier. Difficult-to-burn objects, pyrolysis char, and noncombustibles are liquified to a mixture of inorganic and metallic material at 2,600 to 3,000°F and flow from the gasifier into a water quenching chamber. The gases, mainly carbon monoxide, hydrocarbons and nitrogen, although carrying some carbon and flyash, are mixed with ambient air in the igniter where complete combustion takes place.

The process produces a sterile residue which has potential value as an aggregate, a source of crude metal, glass wool, or other application. It is claimed that steam can be produced as a byproduct of the system.

Other high temperature incinerators discussed by Zinn et al. (1970) include the DRAVO/FLK incinerator, Sira System, Ferro-Tech System, Electric Furnace System, and Oxygen-Enrichment System.

Landgard System. The Landgard System developed by the Monsanto Enviro-Chem System, Inc., is a hybrid system based on the principle of pyrolysis and ordinary incineration. Waste heat generated by incineration of the gases generated during the pyrolysis process is available for steam generation. Ferrous metals are also recovered.

All incoming wastes are shredded and fed to a rotating kiln in an oxygen-deficient atmosphere (the pyrolysis principle). This decomposes the organic matter and reduces the waste to about 6% of its original volume, and 25% of its original weight. The system is not complete pyrolysis since controlled amounts of air are introduced through the primary burner into the kiln. The air is used to burn some of the refuse. The heat of combustion is used to sustain the pyrolysis process. Products of the pyrolysis are gases, which are burned in a combustion chamber followed by an afterburner, cleaned and exhausted, and a glass and metal residue. Auxiliary heat requirements range from none with dry refuse to 10^6 B.t.u./ton under most adverse conditions (Rochester, 1972).

A demonstration plant was in operation in St. Louis County, Missouri, for two years, with a processing rate of 35 tons/day of municipal waste (Pyrolysis, 1971). An application made to the EPA for support of the construction of a plant in Baltimore, Maryland, was approved in September, 1972. Negotiations with New York City to build a 1,000 ton/day plant on Staten Island have been underway for some time.

Bureau of Mines Incinerator Residue System

No discussion of incineration recovery—whether high or low temperature—would be complete without a description of the Bureau of Mines incineration residue recovery system. For several years, the Bureau of Mines has conducted a research program aimed at the recovery of resources from municipal incinerator residue (Sullivan and Stanczyk, 1971). This program centers around the reclaiming, refining, and recycling of metals and minerals from the residue of conventional incinerators. The process includes continuous screening, grinding, magnetic separation, shredding, gravity separation, and other purification steps to recover iron concentrates, aluminum copper-zinc mixtures, clear and colored glass fractions and carbonaceous ash tailings. Table 3 indicates the composition of incinerator residue on a dry basis. A pilot plant with a capacity of ½ ton/hour has been operated successfully but intermittently for over a year, as the Bureau is not funded to operate continuously. It is located at Edmonston, Maryland, just outside of the College Park campus of the University of Maryland, where the Bureau has a laboratory.

Although the system is undergoing constant modification, currently initial size classification of the incinerator residue is accomplished with a trommel and several screens (see Figure 5). Ferrous materials are removed magnetically. Large nonmagnetic materials are screened. The nonferrous fraction which is primarily glass is further ground in a rodmill with the glass, being friable, reduced to the consistency of sand. After screening out the nonferrous, the glass is separated into colored and colorless elements by use of a high intensity magnet. The nonferrous metals are separated either using a heavy media separator, or a jig, either of which extracts the aluminum from the other nonferrous metals. Table 4 indicates Bureau of Mines expectations for the value of the recovered products. These values compare with estimated capital cost of $1.9 million and operating costs of $13.30/ton for a 400 ton/day plant operating on a single shift.

The city of Lowell, Massachusetts, in conjunction with Raytheon Corporation, was given an EPA award in September, 1972, to construct a 250 ton/day incinerator residue plant based on the bureau of mines system.

Wet Separation and Fiber Reclaim

One alternative to burning of the total organic fraction is recovery and reuse of some of the fiber it contains. Already mentioned are several attempts to develop dry separation techniques: SRI, Bureau of Mines Raw Refuse, Forest Products Laboratory. Another approach is the wet separation process for mixed refuse advanced by the Black Clawson Company of Middletown, Ohio. Their hydrapulping and fiber reclaim system first went through a pilot testing stage after which with funds from EPA an operating plant was built and opened in Franklin, Ohio, during the summer of 1971. The system is projected to reclaim 50% of the city's refuse, burn 45% without pollution in a fluidized bed incinerator, and landfill the remaining 5%.

A schematic of the plant is shown in Figure 6 and consists of three parts: The Hydrasposal, the material recovery

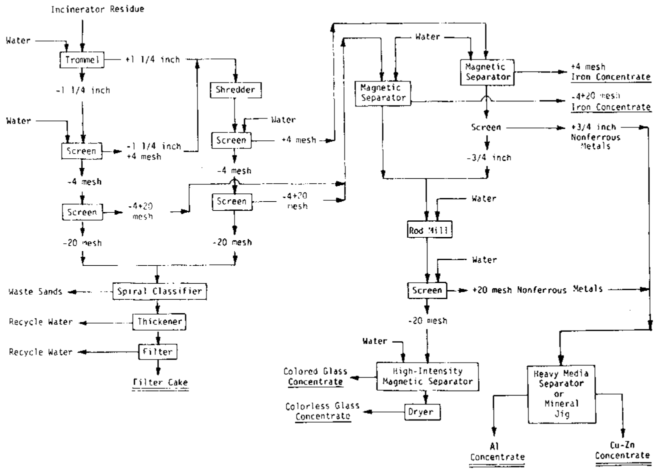

Fig. 5. Incinerator residue processing flow sheet.

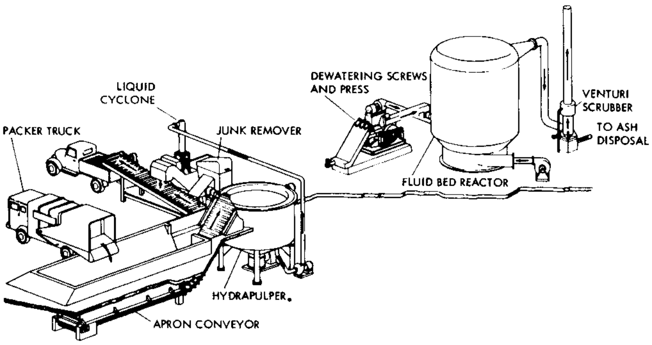

Fig. 6. Flow chart of the Black-Clawson Hydrasposal solid waste disposal system.

system, and the fiberclaim system. The Hydrasposal system prepares materials for further recovery and the fiberclaim system recovers fiber in a reusable form. Other waste components are treated in the material recovery system. At present, only ferrous metals are recovered, but an additional grant previously mentioned from EPA is expected to extend this to nonferrous metals and glass.

In the plant as it is now configured, waste is first dumped into a hopper and then fed into a hydrapulper. There the solid waste is converted to a liquid slurry. Pulpable materials such as paper, yard trimmings, food and friable materials, including ceramic and glass, are reduced to a size which will pass through ¾ to ½ inch holes located under a high speed cutting rotor in the bottom of the hydrapulper. The cutting rotor shatters the glass into small particles and breaks up organic and inorganic materials alike. Heavy metal objects are rejected through an opening in the side door of the hydrapulper while light pieces of material are removed by screening. Remaining in the slurry are pulp, particles of glass, small bits of metal, plastic and bones. This slurry is then pumped through a cyclone separator, which removes the bulk of the remaining solid material. About 80% of the material from the reject stream at this stage is glass, and a large percentage of the remainder is aluminum.

The slurry now contains mainly organics, such as paper and food waste, along with some plastics. It next goes to a classifier that has a high speed defibering rotor operating against a plate with ⅛ in. diameter perforations. This serves to flush out large pieces of plastics and other residue after which the organic material is ready for a series of

TABLE 3. ANALYSIS OF THE INCINERATOR RESIDUE, DRY BASIS*

Residue	%
Wire and large iron	3.0
Tin cans	13.6
Small ferrous metal	13.9
Nonferrous metal	2.8
Glass	49.6
Ash	17.1
Total	100.0

* Source: Henn and Peters (1970).

TABLE 4. ESTIMATED PRODUCT VALUES*

Product	$ Value	Quantity, lb/ton residue	$ Value/ ton residue
Ferrous metal	10/ton	610	3.05
Aluminum	0.12/lb	32	3.84
Copper-zinc	0.19/lb	24	4.56
Colorless glass	12/ton	552	3.31
Colored glass	5/ton	398	1.00
Total Value			15.76

* Source: Henn and Peters (1971).

screening processes. These screening processes extract paper fiber leaving a nonusable sludge. The paper fiber is then dewatered, thickened, and transported to user industries, in the Franklin case, a roofing materials manufacturer. The largest single piece of equipment in the Franklin plant is a fluidized bed reactor to burn the partially dewatered sludge. This incinerator has been modified by the addition of 5,000 nozzles so that in addition to burning the in plant waste sludge, it can also act as a disposal site for other liquid wastes. The plant is also designed to operate in conjunction with a sewage treatment facility now being constructed, burning the sewage sludge while using the ash resulting from the incinerator as a settling material in the adjacent water treatment facility.

Construction cost of the Franklin plant was about $2 million. The EPA demonstration grant supporting the project shows an estimated total project cost of $2,471,858. The system's design capacity is 150 tons of mixed refuse/24-hour-day. Currently the system is operating at about 50 tons/8-hour-day.

Fiberboard

The Rust Engineering Company has proposed a waste recovery system that it claims will produce a variety of useful products using as its main raw material municipal refuse plus the wood discards of the Metropolitan area (Rust, 1971). One major midwestern city indicated that they collected as much as 300 tons a day of felled trees and an equal amount of tree trimmings which are now chipped or ground and dumped into a landfill.

According to the Rust plan, municipal refuse, excluding bulky items such as appliances, and the scrap wood will be ground and dried. The ground material will be classified and separated into its various components. Combustible materials that cannot be used for useful products along with off-gases generated during the drying process will be burned and the heat recovered and utilized for in-plant processes.

Possible products, depending on market conditions are:

- Fiberboard (50% reclaimed fiber, 50% wood fiber)
- Fiberboard (25% reclaimed fiber, 75% wood fiber)
- Fiberboard (100% reclaimed fiber)
- Paper (100% reclaimed fiber)
- Bricks (70% reclaimed glass, 30% brick clay)
- Bricks (94% reclaimed glass, 6% hydrated lime)
- Fiber glass (80% reclaimed glass, 15% dolomite, 5% fused borax)
- Rock wool (50% reclaimed glass, 50% dolomite)

Compost

Composting is another alternative Back End system. Technically it is feasible. Economics, however, appear to be another matter. Composting is a process in which microorganisms destroy such material as paper, food scraps, and other organic materials. This destruction process normally occurs under aerobic conditions, with temperatures of 140° to 160°F. After a period of time (from five days to three weeks depending on the process) the material cools and becomes compost which is reputed to have both soil conditioning and plant nutrient characteristics (Wiley and Kochtitzky, 1965).

Unfortunately, attempts to sell the compost either as a soil conditioner or as a fertilizer have, except in isolated small scale instances, not been successful. Ecology, Inc., of New York, operating a plant rated at 150 tons/day has reported success in selling 28-lb. bags at $5.95 each in the metropolitan area. However, wide-spread agricultural applications have failed to materialize. This is true even though tests have shown that application of compost can significantly reduce losses from erosion. Studies have also shown that compost significantly increases the water-holding capacity of soil and thus makes it very useful for crops such as sorghum (Terman, 1970). Yet, even with these qualities, the cost of application is usually prohibitive, unless the land has significant productive value such as the growing of grapes for wine production (Carlson and Menziers, 1970).

In 1971, the Environmental Protection Agency published a list of 18 municipal solid waste composting plants in the United States (Breidenbach, 1971). Of this list, nine were closed and three were operating only intermittently. The reasons for closing were many, but primarily they were the result of excessive operating costs and lack of substantial markets. The U.S. Public Health Service-TVA composting plant at Johnson City, Tennessee, closed down after its four-year test period as nearby markets simply could not be developed. The costs of shipping and applying the material ruled out widespread use on field crops, strip mine banks, highway cuts and grasses. Metro Waste's plant at Houston, Texas, was forced to close down as they were unable to sell as much of their compost as they had forecasted. The St. Petersburg, Florida, plant which attempted to upgrade the nutritional value of compost could not achieve the desired result at a price competitive with other commercial fertilizers.

In spite of these experiences, there still may be a future for composting, even though it may be only for limited local applications. However, changing environmental philosophies, government regulations, economics and expanding uses may one day make composting a more broadly applicable method of solid waste disposal. Several systems currently being proposed are heavily oriented toward composting for special markets. The following are two proposed systems based mainly on composting.

All American Environmental Control Corporation. The All American Environmental Control Corp. (AENCO) is a firm with a rather unusual approach to the solid waste disposal problem. Their idea is to turn Craigsville, Virginia, into a major trash processing center for the Washington, D.C. and Baltimore metropolitan areas. Although Craigsville has a population of only 1,000 and is about 150 miles from Washington, it does have an abandoned cement plant which, according to AENCO, can be used as a processing facility plus large quarries for disposing of the unrecovered residue.

The basic plan is for all trash to be shredded and compacted in the metropolitan area and then delivered by rail to Craigsville. The first plant site process would be further grinding followed by separation of the ferrous material, with the remaining refuse, over 90%, going to a bioprocessing pad for aerobic digestion and conversion to compost. The compost would then be screened, and nonferrous metals, plastics, and rubber removed for immediate sale, stockpiling, landfilling, or fuel.

AENCO has tested a 50 ton/hour refuse shredder and a machine to handle the bioprocessing pad. They have also tested the compost for growing mushrooms and have expectations of using part of their plant space for this purpose. A roasting process is also proposed to convert the separated ferrous alloys to magnetite (Fe_3O_4), which if produced successfully has a market value of about $25/ton.

The company states that they will be able to dispose of solid wastes at a $9.16/ton charge to municipalities in the Washington area. This price includes $2.66 for railhaul and $6.50/ton as a disposal fee. Their expectation is that there will be a rebate of about $2.00/ton coming from sale of recovered goods. [For a more complete description of this proposal, see Montgomery (1971)].

Delaware Project. Late in 1970 Hercules, Inc., of Wilmington, Delaware, received a contract from the State of Delaware to design what Governor Russell W. Peterson called "the most advanced solid waste reclamation plant ever devised" (Hercules, 1970). The project design is now about 65% complete, and Delaware has submitted the plan to EPA for matching funds on the construction and initial operation of the plant.

The plant has been designed to handle two major solid waste problems. Current plans call for a plant that would initially process 500 tons of solid waste/day and 230 tons of 8% solid sewage sludge. Operating capacity will be 1,000 tons of refuse and 460 tons of sludge.

The system's four major processing steps are pretreatment, composting, separation, and pyrolysis. There are many specialized pieces of equipment in these steps, which are considered proprietary at this time. The proposed plant process flow is depicted in Figure 7.

The refuse will be magnetically separated, shredded, mixed with the sewage sludge, and aerobically digested. The composted mixture will be separated into three fractions: humus, nondigestible organic, and inorganic materials. The nondigestible organics are conveyed to the pyrolysis subsystem to produce carbon and hydrocarbon gases. The hydrocarbon gases will be scrubbed to remove pollutants and then recycled to supplement the fuel used for plant operation. Inorganic material is separated into glass and nonferrous metals. Full truck loads of selected industrial waste, including clean paper, tires, and plastics will be weighed and accepted at point 6 of Figure 7. The paper will be baled and sold.

The humus product which is produced in the plant can be tailored to meet market demands. The plant has the processing capability to manufacture two grades of essentially debris-free humus in five different sizes by grinding and screening. Table 5 lists the expected output from a 500-ton/day operation in Wilmington, Delaware.

Other Proposals

A number of unit processes that have promise in utilizing the latent resources in solid wastes are being developed in laboratories throughout the country. These processes are for the most part either biological or chemical conversions of the organic fraction. If found technically and economically feasible, they will no doubt be incorporated into future resource recovery systems. A few of the more interesting processes are briefly described below.

Wet Oxidation. Wet oxidation consists of processing the organic fraction of solid waste in an aqueous solution at a high pressure (500 to 1000 lb./sq.in.) and high temperature (200° to 260°C) where partial oxidation occurs. The University of California estimates that for every 100 tons of solid waste treated the process would yield 10 tons of waste residue, 45 tons of carbon dioxide and water, and 45 tons of commercially useful chemicals (Golueke, 1971). Boegly et al. (1971) indicates that wet oxidation is being currently used in several cities to treat sewage sludge.

Partial Oxidation. Experiments aimed at partially combusting finely divided organic waste in an oxygen-nitrogen atmosphere with insufficient oxygen to sustain total combustion were described by Shuster (1970). A number of commercially valuable chemicals such as acetic acid, formic acid, formaldehyde, methanol, acetone, etc., are formed by this process.

Controlled Pyrolysis. Appell et al. (1970) reports experiments generating low-sulfur oil through pyrolysis of wet refuse at temperatures of 350 to 400°C and pressure near 400 lb./sq.in.gauge of carbon monoxide. Cellulose conversions of 90% or more have been achieved. Some alkaline catalytic material, such as that from sewage sludge, or bicarbonate, is added to the cellulosic waste.

Protein Production. Meller (1969) performed an economic evaluation of the conversion of solid wastes into

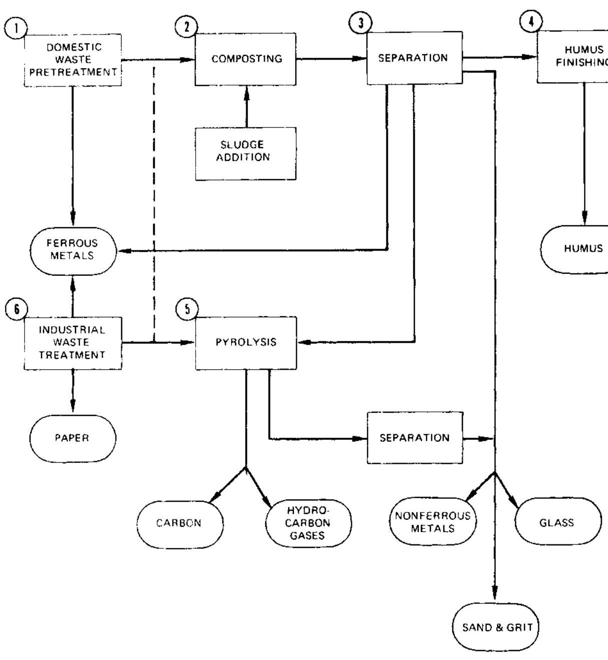

Fig. 7. Delaware reclamation plant process flow.

TABLE 5. HERCULES RECYCLING PLANT—500 TONS/DAY

Material	Tons	% of Usable Output
Humus	156	50
Ferrous	34	12
Nonferrous	4.5	1
Carbon	20	6
Paper	5	2
Glass cullet	36	12
Fuel gas	54	17
Moisture and nonrecoverable material	190.5	

yeast. He considered the hydrolysis of cellulosic wastes to produce fermentable sugars and subsequent fermentation. The kinetics of this hydrolysis process, and hence the plant's design are based on data assembled in the late 1940's at the Forest Products Laboratory. The proposed design of the fermentation unit is traditional. The author recognized that new technologies could have a significant influence on the fermentation, which is the costliest step. The market analysis presented for the yeast, when used as a vitamin and protein supplement in human and animal feeds, concludes that the process is not yet competitive. For yeast to compete in the feed supplement market, it must sell for 10¢ to 12¢/lb. of protein product. However, the author's estimate is that yeast produced from organic urban refuse would have to sell for from 14.7¢ to 18.9¢/lb. of protein in order to cover costs.

Separation of Plastics. There have been several studies of plastics and rubber in solid waste management, but more from the standpoints of the management problem (Warner et al., 1970), the environmental impact of the plastics (Franklin and Hunt, 1972), and reuse (Pettigrew and Roniger, 1971) than from separation. Current attempts to separate various metals and nonmetals from urban refuse at the Bureau of Mines (Dean et al., 1971) include plans for further separation of the plastics portion into major categories by chemical type (Holman et al., 1972).

In the Holman study, plastics hand separated from municipal refuse were used as the feed stock. Their composition was 74% polyolefins, 19% polystyrene (PS), 5% polyvinylchloride (PVC), and 2% others. The plastic pieces were granulated, then separated into fractions of polypropylene, high and low density polyethylene (PE), PS and PVC by float-sink, using tap water, salt water, and aqueous alcohol as the liquid media. Results obtained on initial runs with granulated virgin materials (PE, PS, and PVC) produced separated fractions with less than 1% contamination.

Alter (1960) described the rapid oxidation of polyethylene wastes using oxygen or ozone and Co, Cr, or Mn salts as catalysts. The products were low melting waxes with infrared spectra suggesting they may be useful as feed for single cell protein-producing animals.

Banks et al. (1971) studied the theoretical product composition distribution from the pyrolysis of PS, PE, and PVC. Their analysis is largely thermodynamic, using a computer calculation of the thermochemical equilibrium on which is superimposed a kinetic analysis based on published data. The total analysis predicts useful product streams of mixed organic chemicals and suggests the calculated product compositions should be verified experimentally.

Table 6. Resource Recovery Facility
Prototypical Operating Statement
($ millions/annual rates)

Dumping revenues $7.71 tons, 500 tons/day, 260 days yr., 130,000 tons/yr.		$1.002	
Byproduct revenues			
Ferrous fraction 6%, 7,800 tons/yr., $15.00 ton (net)	$0.117		
Aluminum fraction ½%, 650 tons/yr., $200.00 ton (net)	$0.130		
Glass fraction 5%, 6,500 tons/yr., $9.25 avg. (net), 4,875 ton/yr. cullet at $12.00 ton (net) and 1,625 tons/yr. fines at $1.00 ton (net)	$0.060		
Fiber fraction 4%, 1/3 corrugated at $10.00 ton (net) and 2/3 mixed at $6.00 ton (net)	$0.038		
Systems residue (other nonferrous) ¼%, 325 tons/yr., $300.00 ton (net)	$0.098		
Gross byproduct revenues		$0.443	
Total gross operating revenues			$1.445
Waste product costs $5.78 ton, 15.75% reduction, 421 tons/day, 109,525 tons/yr.		$0.633	
Operating and maintenance costs		$0.338	
Depreciation		$0.198	
Interest expenses		$0.060	
Total operating expenses			$1.229
Net operating income			$0.216

Equity: $1.200 million   Return on investment: 18%

ECONOMICS OF RESOURCE RECOVERY

Ideally, resource recovery would see a situation wherein there was a one-to-one correspondence between the amount of material disposed of by the public—the discards of society—and the amount recovered and offered for re-use in some form by a recovery facility. However, it is unlikely that this ideal will be achieved. Only when the technology of resource recovery provides recovery and conversion processes that yield usable and competitive outputs from the large amounts of organics in municipal waste will recovery be adopted on any broad scale as an efficient disposal alternative.

Front End System: Materials Recovery

At present, resource recovery based on the reclaiming of traditional secondary materials must be seen as an adjunct to—rather than a substitute for—traditional disposal methods. Even then, unless there are exceptional circumstances, such an add-on is only economically feasible for municipalities where the cost of disposal is $7.00 or more per ton. Efficient recovery can only take place under the $7.00/ton disposal costs figure if there are a number of other favorable circumstances, such as a much higher than average level of recoverable aluminum and other metals in the solid waste stream or unique local markets for at least a portion of the fibrous waste.

The relationship among the variables that affect the economics of resource recovery can be seen in Table 6. The operating statement in Table 6 is a useful device for highlighting those factors that bear on the economics of resource recovery. The statement is hypothetical although believed reasonable. The reader should understand that there is at present no operating plant by which its assumptions can be verified. Engineering estimates place the cost of a facility such as envisioned here at approximately $2 million. In the calculations of the entries on the Prototype Operating Statement, a debt equity ratio of 0.66 is assumed. The Prototype Operating Statement lists five so-called "byproducts": ferrous, glass, paper, aluminum, and other nonferrous. The projected recovery rate is approximately 16%. Put differently, 84% of the refuse must be disposed of by traditional means—incineration with landfill of the residue or landfill alone. It should be noted that there is a good deal of technical risk involved in producing material of sufficient quality to find a viable market at the prices shown in the statement.

The first byproduct shown is the ferrous fraction. This is estimated to be 6% of the 500 tons/day of raw refuse. The recovered ferrous fraction will consist mainly of steel cans—approximately 80% by weight.

For many years cans have been recovered from both raw refuse and incinerator residue. According to *Solid Waste Report* (1971), Atlanta, Georgia, has been recovering cans for 35 years and currently sells approximately 80 tons each week for $13.50/ton. These cans are magnetically separated from incinerator residue. The same article points out that Oakland, Sacramento, and Martinez, California, are recovering cans from raw refuse. These cans are magnetically separated after a course shredding operation. Along with Atlanta's 100 million and the Oakland area's 260 million, Chicago is estimated to recover 730 million cans, Franklin, Ohio, 10 million, with citizen groups accounting for about 600 million in 350 cities.

There are essentially three uses for these recovered cans. The greatest quantity, over 100,000 tons, is used by the copper industry in the leaching process (Cannon, 1972). In this process, copper tailings are leached with sulfuric acid to obtain copper sulfate. Copper is then precipitated out of the leach solution by substituting iron for copper at a rate of from 1.2 to 2.5 tons of iron/ton of copper (Dean et al., 1968).

The basic steel making process accounts for some of the recycling of both incinerated and nonincinerated cans. The recycling of scrap tin cans and other ferrous scrap from incinerators has been demonstrated using limited quantities in virtually all processes of steel making, using blast, BOP, open hearth and electric furnaces. Tests were performed using regular steel cans, tin-free cans, and steel cans with aluminum ends and other ferrous metallic scrap incinerator residue (Ostrowski, 1971). Experimentation with tin-free steel cans established that this material can be recycled into raw steel from which prime mill products can be produced. The tests on recycling of scrap tin cans showed that the included tin may build up with repeated recycling to an undesirable level for manufacture of high grade mill products. The lead present in the soldered seams of the cans is recovered as an oxide in the dust generated in the process. These experiments, some on a large scale approaching production conditions, indicate that the potential for utilizing ferrous scrap from municipal incinerators is high.

Utilization of cans and other ferrous scrap separated directly from municipal waste (not incinerated) has also been studied (Ostrowski, 1972). The one sample of such material used contained undesirable combustible materials as well as an unacceptably high moisture content. Before large scale utilization is possible, low temperature incineration may be needed to clean such scrap.

There is reason to believe that there is potential in utilization of this type of ferrous scrap in the foundry industry. Rosenthal et al. (1970) reported that there has been a premature rejection of the idea and that further detailed studies must be made not only on the scrap but also on the end product as affected by the contents of the scrap. Their research has been primarily concerned with ferrous recovered from incinerator residue where the high temperatures cause the other metals in the refuse to form a complex residual alloy on the surface of the can scrap. This causes problems in utilization that are not expected to occur with cans extracted from raw refuse.

With respect to the Operating Statement, the market price of the recovered ferrous material is difficult to determine. Its highest value at present is in the copper leachate process where it is estimated to be $40 to $60/ton delivered to the leachate facility—generally in Arizona, Utah, New Mexico, Nevada, and Montana. Transportation costs become a significant factor, however, as does the ability of the copper industry to absorb the potential supply. Because of transportation costs, it is unlikely that the major eastern cities would find a viable outlet for their ferrous materials in this market. In terms of use in the steel-making industry, it seems reasonable to expect that this material would find a market at a price equivalent to the number two bundle price which is essentially the lowest priced scrap purchased.

The number two bundle price average is about $20/ton FOB the steel mill. On the Prototype Operating Statement, a revenue of $15.00/ton to the recovery facility is shown. This is believed to be achievable, given a relatively nearby outlet for ferrous scrap. It would not hold over long shipping distances. For example, the costs for transporting secondary ferrous for 100 miles is about $4.50/ton based on an 80,000 lb. minimum shipment (Southern, 1971).

Revenue estimates on the glass fraction are even more difficult to determine, primarily because of uncertainties with respect to the technical ability to produce a clean and relatively well color sorted glass fraction. Experience with post-consumer glass cullet has been limited to hand-separated glass, the product of voluntary recycling. For this, the glass companies have paid roughly $20.00/ton (Owens, 1972). The raw material substitution price, which varies among glass making localities, would no doubt govern if increased volumes of glass cullet, such as would be produced by large sized mechanical separation facilities, materialize. The technical feasibility of the cleaning and color sorting process should be established in the near future, based on the project funded by EPA and the Glass Container Manufacturers Institute at Franklin, Ohio and work being done by the individual glass makers.

The key to the profitable recycling of glass for return to the basic glass making process is the removal of impurities, such as metals, plastics, and organics, and the sorting of the small fragments of glass into clear (flint) and colored fractions (green and amber). Mixed cullet has some utilization, but it is limited in the basic glass making process. It may be included in a glass melt in which color is not very critical, or melted and spun into "wool" for insulation. Malisch et al. (1970) reports that the University of Missouri at Rolla has had successful results in employing the glass waste as aggregate in a bituminous mixture named glasphalt. However, glasphalt and insulation are relatively low value utilizations compared to containers. A number of uses for recovered glass are discussed in Ryder and Abrams (1971).

The overall glass recovery rate (based on proportions of raw refuse) is shown as 5%. National averages would lead one to expect approximately 6 to 8% glass in solid waste in an "as received" condition. However, the effect of the shredding step on the recovery potential is likely to be considerable. It is expected that a relatively large proportion will be ground to such a fine consistency that it will not be possible to efficiently separate it from the organic fraction during the air classification step; that is, it will go up the air classifier with the light material rather than falling with the heavy.

For that portion of so-called "fines" that does drop, it is doubtful that optical scanners will be able to sort that which is less than ⅜ of an inch in size. For this material, a revenue yield of $1/ton can be realized by using it as a gravel and sand substitute. High intensity magnets such as used by the Bureau of Mines in their incinerator residue system could perhaps accomplish a sorting among the more magnetic colored and the less magnetic flint, but the cost/effectiveness of this separation is not clear. For the remainder of the glass fraction—the larger pieces—a net yield of $12/ton (color sorted) is shown.

The basic facility described by the Operating Statement does not envision any mechanical separation of paper. Rather, it is expected that there will be some handpicking of bundled newspapers and of corrugated boxes. The projection is for 20 tons/day, or 4% of the input of mixed raw refuse. According to the estimates shown on the Operating Statement, approximately one-third of the recovered paper will be corrugated boxes with a market value in the range of $10/ton. The remaining paper recovered will be of mixed quality (news and kraft) and for this there is shown a value of $6/ton.

The Prototype Operating Statement shows a ½% aluminum fraction recovered. According to Bourcier et al. (1972) ½% is roughly a national average for aluminum in the waste stream. However, not all aluminum is recoverable. The assumption here is that the facility in question is located in an area where the aluminum percentage is ¾% as a result of higher than average number of aluminum beverage containers and that 2/3 of this, or 1/2%, is recovered. At present, the market for recovered aluminum from the voluntary recycling centers is 10¢/lb. or $200/ton. It is expected that this price would hold if the material recovered from mixed refuse conformed to roughly the same specifications. It appears technically feasible to produce a recovered aluminum of similar specifications, since the bulk of the material recovered will be cans. Most of the remainder will be foil, pie plates, T.V. dinner trays, etc., which do not adversely affect the market value of the can scrap.

The final revenue generating byproduct is a mixed nonferrous residue. One-fourth of 1% is shown as the amount recovered and 15¢/lb. is shown as the revenue generated. The Bureau of Mines estimates that this material will essentially consist of copper-zinc and that it will be worth 19¢/lb. (Sullivan and Stanczyk, 1971). It is not contemplated that further separation of this fraction would take place on site due to the small amount recovered. Rather, it would be sent to a facility specializing in nonferrous separation.

The sum total of byproduct revenues in this particular example amounts to $443,000. The total recovered fraction represents 15.75% of the raw refuse by weight. Given annual costs of $338,000 for operation and maintenance, $198,000 for depreciation and $60,000 for interest expenses ($800,000 at 8% with quarterly repayment of principle, paid out of Net Income) the annual costs ex-

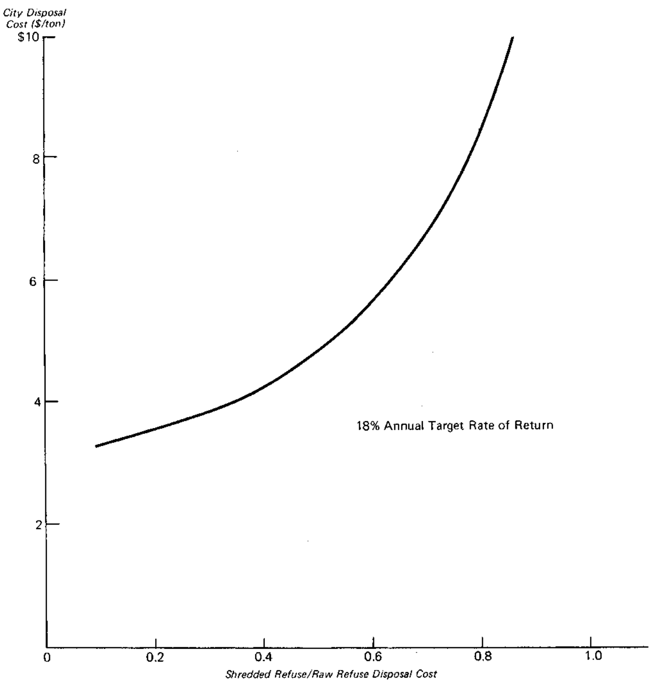

Fig. 8. Disposal cost versus the ratio of shredded refuse/raw refuse disposal cost.

clusive of the cost of disposing of the nonrecovered organic fraction is $596,000.

Under an assumption that the facility is private and must compete in the private capital market for funds, the next step is to determine the dumping fee which must be charged if this facility is to achieve a reasonable return on investment. If direct private investment is not involved—that is, if public sector funds are available for the facility—the target rate of return could be scaled down to reflect public borrowings at lower interest rates.

The dumping fee is only one of the two unknowns left on the operating statement. The other is the fee that must be paid by the facility to dispose of the nonrecovered organic fraction. This assumes that the facility is operated as a recovery oriented cost center and is not in the disposal business. Rather, it must have another outlet for disposing of its residue (presumably the city).

To achieve the target rate of return, one is left with a single equation with two unknowns. It is useful to hypothesize some relationship among these unknowns. There is reason to believe that in certain circumstances the cost of disposing of shredded refuse is less than the cost of disposing of a like amount of raw unprocessed refuse. If, for example, in a community it costs $6/ton to dispose of raw refuse by incineration, $4.90 for burning, and $1.10 incinerator residue disposal, then with the inerts removed before incineration, the weight of the incinerator residue should be reduced by about 80% with a potential savings of 88¢/ton. In addition, it is possible that the burning of shredded refuse in certain incinerators will increase the through-put of the incinerator, provided the incinerator is not B.t.u.-limited while lowering its maintenance expenditures because there are no inerts in the material to cause the grates to wear.

On the Prototype Operating Statement, a relationship of $Y = 0.75X$ is assumed although it should be understood that the actual relationship can probably only be established by testing. In this case "Y" equals the real cost of disposing of the shredded refuse and "X" equals the real cost of disposing of raw refuse. Given this assumption, one can complete the Operating Statement. The target rate of return (18%) is reached when $X =$ $7.71/ton and $Y =$ $5.78/ton. Figure 8 shows the sensitivity of the "X" value to the relationship assumed to exist between "X" and "Y." For example, the same 18% target rate of return with a 0.5 rather than 0.75 relationship would be obtained in an environment where the real cost of disposal of raw refuse is $5/ton and the real cost of disposal of shredded refuse, following the 0.5 relationship, is $2.50/ton.

One should note that this is an indifference analysis. It assumes that at the prices quoted the ongoing disposal operation is indifferent to whether or not there is an adjunct resource recovery activity. Given the figures in the basic Prototype Operating Statement, it costs the municipality $1,002,000 (130,000 tons × $7.71/ton) to dispose of the raw refuse with no recovery. The city's cost is the same with the recovery facility. First, there is a net sum of $369,000 paid to the facility. This is 130,000 tons × $7.71 minus 109.525 tons × $5.78. To this is added the $633,000 representing the assumed real cost of disposing of the residue shredded refuse.

Hence it is at its indifference point. There are no savings generated by the resource recovery, but there are no costs either. Minimum conditions for a resource recovery facility are satisfied. Savings would be generated for those cities where the cost of disposing of the assumed 130,000 tons/year of raw refuse is greater than the $1,002,000 shown here, the value to the disposal process of shredded cleaned up refuse warrants more than a 25% discount, or when the recovery percentage goes up. Table 7 illustrates the latter case. The other variables are held constant. The prime indicator of saving is the fact that the dumping fee drops to $4.06/ton.

Materials Recovery Plus Energy Recovery

For the purpose of this illustration, assume that the Union Electric experiment previously discussed is successful. Further, assume that the price negotiated for supplying shredded solid waste as fuel to the utility, taking into account additional power company expenses for ash handling, corrosion (if any), extra air pollution control equipment (if any), plus a return on the capital invested by the company, results in a price/ton paid by the utility to the city which just exactly offsets the cost of the city transporting it to the power company. Suppose further that 75% of the organic fraction is disposed of in this manner, thus alleviating the need to incinerate or landfill this refuse at the $5.78/ton real disposal cost shown on the operating statement. As a result, waste product disposal costs fall to $158,000, leaving room for either a rather large increase in earnings for the recovery facility or a reduction in the dumping fee. If all were accrued by the municipality as a reduction in the dumping fee, the fee would fall to the $4.06/input ton previously mentioned. This fee is sufficient to maintain the 18% return on investment. The city's cost is then a net payment of $369,000 to the facility plus $158,000 to dispose of the unburned remainder. This is a saving of $3.65/ton or 47% below the original cost of disposing of 130,000 tons of refuse at the $7.71/ton real cost of raw refuse disposal assumed to exist prior to the utilization of the recovery option.

In terms of the spread of resource recovery, the availability of options such as burning in an available utility

TABLE 7. RESOURCE RECOVERY FACILITY WITH ORGANIC FRACTION UTILIZED PROTOTYPICAL OPERATING STATEMENT ($ MILLION/ANNUAL RATES)

Dumping revenues		$0.527	
$4.06 tons, 500 tons/day, 260 days yr., 130,000 tons/yr.			
Byproduct revenues			
Ferrous fraction			
6%, 7,800 tons/yr., $15.00 ton (net)	$0.117		
Aluminum fraction			
½%, 650 tons/yr., $200.00 ton (net)	$0.130		
Glass fraction			
5%, 6,500 tons/yr., $9.25 avg. (net), 4,875 ton/yr. cullet at $12.00 ton (net) and 1,625 tons/yr. fines at $1.00 ton (net)	$0.060		
Fiber fraction			
4%, 1/3 corrugated at $10.00 ton (net) and 2/3 mixed at $6.00 ton (net)	$0.038		
Systems residue (other nonferrous)			
¼%, 325 tons/yr., $300.00 ton (net)	$0.098		
Gross byproduct revenues		$0.443	
Total gross operating revenues			$0.970
Waste product costs		$0.158	
$5.78 ton, 79% reduction, 106 tons/day, 27,380 tons/yr.			
Operating and maintenance costs		$0.338	
Depreciation		$0.198	
Interest Expenses		$0.060	
Total operating expenses			$0.754
Net operating income			$0.216
Equity: $1.200 mil.	Return on investment: 18%		

boiler means that cities cross the indifference line and enter the savings region for resource recovery when the real costs of disposing of raw refuse are in the $3.00 to $4.00/ton range.

CONCLUSION

What should be clear from the above is that given reasonable assumptions about the prices that might be obtained for recovered materials (subject to meeting reasonable specifications with respect to purity), resource recovery based on materials separation alone is economically feasible only in high disposal cost municipalities. Progress in effecting a widespread application of resource recovery techniques as substitutes for traditional disposal methods lies in the area of useful conversion of the organic material such that it can be marketed at a price—if not positive—at least less negative than current disposal cost. The example above is based on utilizing its energy value. Other ways to effect an economic utilization have already been mentioned. These include conversion to a storable fuel (oil or gas), fiber reclaim through mechanical rather than hand separation, and fiberboard utilization. The challenge to the engineer and the potential of substituting recovery for disposal lies in accomplishing this at capital and operating costs that do not exceed the savings likely to be generated.

Clearly, resource recovery is at a stage that causes one to look forward with cautious optimism. Systems have been designed and many have already proven to be technically and operationally successful; however, new markets for products must be developed in order to increase the potential applicability of these systems to a larger number of cities. With greater interest in the area generated by greater knowledge of the likely benefits of resource recovery, technicians and entrepreneurs alike will undoubtedly continue to make strides toward the ideal of an economically feasible near total resource recovery system.

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