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Supplementary Report: RESOURCE RECOVERY FROM MUNICIPAL SOLID WASTES

A report prepared by the
Committee on Mineral Resources and the Environment (COMRATE)
Commission on Natural Resources, National Research Council

NATIONAL ACADEMY OF SCIENCES
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PREFACE

The Committee on Mineral Resources and the Environment (COMRATE) was established by the Governing Board of the National Research Council in September 1971 to provide a long-term review of problems affecting the production and use of minerals. COMRATE was divided into working panels, each of which tackled a separate area of concern. The first COMRATE report, "Mineral Resources and the Environment," published in February 1975, discussed opportunities for materials conservation through technology, the estimation of reserves and resources of the fossil fuels and of copper, the environmental impacts of coal production and use, and present and future demand for minerals and energy. COMRATE's final reports supplement and develop these themes with three separate studies: Uranium Reserves and Resources in the United States; Coal Workers' Pneumoconiosis - Medical Considerations, Some Social Implications; and Resource Recovery from Municipal Solid Wastes (bound here).

The working idea in COMRATE has been to consider topics that Committee members felt needed special attention. COMRATE has not attempted to prepare a report covering all aspects of mineral production, use and misuse. No reports could have been prepared had it not been for the generous contribution of time and effort by many experts, conferees, observers, panel members and of course COMRATE members. To all these dedicated people from the spheres of academia, government and industry, my sincere thanks are extended.

The Committee, and especially its Chairman, wish to express their gratitude for all the aid, concern, guidance and sheer perseverance given by the NRC staff in bringing this report to fruition.

Brian J. Skinner
Chairman
Committee on Mineral Resources
and the Environment

INTRODUCTION

THE MATERIALS CYCLE

It is becoming increasingly recognized and understood that the main flow pattern of materials in our society can be represented by a "global" materials cycle (see Figure 1). This cycle has been described in the COSMAT Report (NAS 1974) and the first COMRATE Report (NAS 1975):

> From the earth and its atmosphere man takes ores, hydrocarbons, wood, oxygen and other substances in crude form and extracts, refines, purifies, and converts them into simple metals, chemicals, and other basic raw materials. He modifies these raw materials to alloys, ceramics, electronic materials, polymers, composites, and other compositions to meet performance requirements; from the modified materials he makes shapes or parts for assembly into products. The product, when its useful life is ended, returns to the earth or atmosphere as waste. Or it may be dismantled to recover basic materials that reenter the cycle.
>
> The materials cycle is a global system whose operation includes strong three-way interactions among materials, the environment, and energy supply and demand. The condition of the environment depends in large degree on how carefully man moves materials through the cycle, at each stage of which impacts occur.

Worldwide, the demand for materials is expected to continue on an upward trend for a considerable time to come on account of the increasing world population and efforts to raise standards of living in many countries. This increased demand threatens to create severe imbalances between the materials supply side of the cycle (the left-hand side) and the materials usage side (the right-hand side). The main purpose of the technology section of the first COMRATE report was to discern broad directions of how technology could alleviate these imbalances both by improving materials supply and by reducing demand through the more efficient use and management of materials. Overall, the report struck the theme that a conservation ethic will have to be practiced increasingly in the future. The principal basis for this conclusion was not that there are basic shortages of materials in the ground (with a few exceptions), but that there are basic

THE TOTAL MATERIALS CYCLE

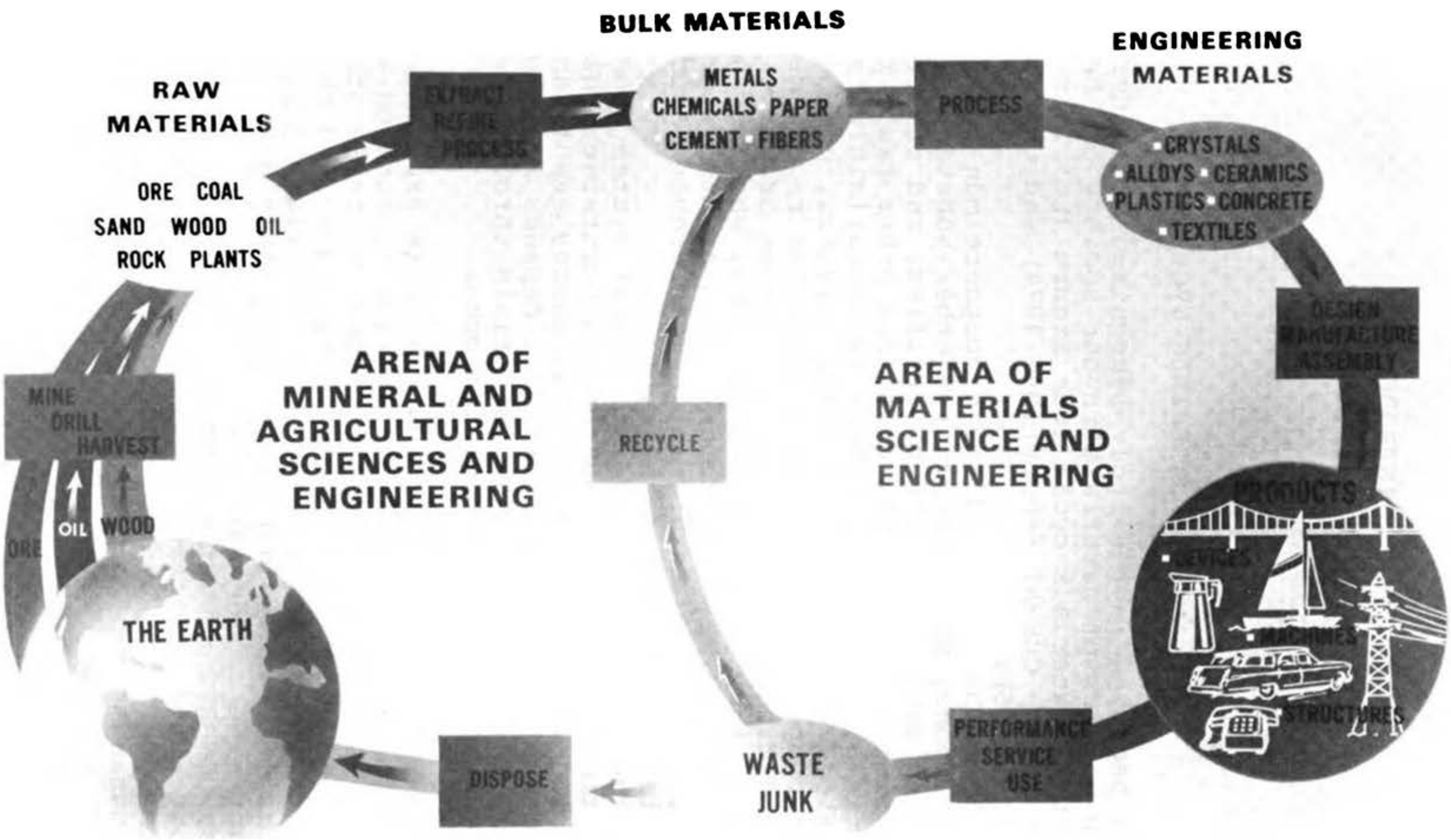

Figure 1

physical constraints, as well as capital, manpower, and other constraints, that will limit the rate at which new materials can be made available. Furthermore, bearing in mind that it generally requires decades for new technology to become fully implemented, we are sufficiently close (in time) to these limiting conditions to warrant giving increased priority to deliberate technological approaches to alleviating strains resulting from materials supply and demand imbalances.

PRINCIPAL CAUSES OF MATERIALS SUPPLY-DEMAND IMBALANCES

The principal causes of these strains are:

a The growing world population. While projections vary as to the absolute number of the world's population in the year 2000 and beyond, they agree that the trend is upwards. Estimates imply a population several times the present population by the middle of the next century. If this population growth is distributed across all income levels, then a more than corresponding growth in the demand for materials can also be expected. Even if, as is more likely, the principal growth occurs in the low-income countries of Southern Asia and Latin America, the increase in resource demands will still be substantial.

b Expected improvement in standard of living. Most of the population growth is expected to occur in the developing countries. At the same time it is expected that most of these will strive to raise their standard of living, as measured in material terms. This will further increase the demand for materials.

c Increasing demands for energy. Associated with the increasing population and rising standard of living will be an increasing demand for energy. In time, technology may be developed that could meet this demand but concern for the effects of large quantities of man-released energy on the environment and ecology, on climate and agriculture, may impose limits on the maximum amount of energy release that can be tolerated. This constraint will affect materials supply, as mining and mineral processing are energy-intensive activities. In fact, the ultimate limit to the rate at which new materials can be taken from the earth may well be set by the tolerable energy release rate and the amount of energy that society can allocate to this function in compliance with all the other needs for energy.

d Increasing environmental constraints. Mineral and materials operations create wastes and pollutants. Increasingly, many of these, particularly the pollutants judged hazardous to health, will have to be contained and/or neutralized. While such treatment is generally technically feasible it adds to the capital costs and diverts technical effort from primary production processes.

e Capital and manpower requirements of materials production. Besides having to compete for energy with other sectors of the economy, the materials sector has to compete for the capital for new facilities and for modernizing old ones, and for manpower to operate the materials industries and provide for their technical development. Such capital and manpower constraints can severely limit the rate at which the materials industries can expand to meet rising demands. These constraints will be further intensified by the trend towards exhaustion of the higher grade and more accessible ore deposits.

f Technological responses take time. Technology can help ease these constraints. Improved technology, while requiring capital for its implementation, can reduce the amount of energy required for producing materials through process innovations, and reduce the needed level of manpower through automation. Nevertheless, the innovation process usually takes more time than the public may realize.

As a consequence of the above factors, the worldwide demand for materials is expected to outstrip the supply in the forseeable future. Accordingly, the process costs of materials will rise more rapidly than the cost-of-living or gross national products of the industrialized countries. Society will need to respond to these changes by developing new life-styles and new technologies.

This will be particularly true for the United States which, despite its immense material resources, is projected as becoming increasingly dependent on important materials. Thus, increasingly, the U.S. will have to face challenges from other nations interested in acquiring for themselves a larger, but arguably more equitable share of the earth's resources.

Taken together, these developments seem likely to compel the world in general and the United States in particular to pay special attention to increasing the care and efficiency with which materials are to be used--in short, to practice a conservation ethic. This view is steadily becoming more widely recognized and adopted.

MAJOR STRATEGIES FOR THE EFFICIENT MANAGEMENT OF MATERIALS

Principal materials management strategies for increasing supply to meet demand include:

a Improvement of prospecting methods. There is a need for considerably more precise information concerning mineral deposits. This points up, in turn, the need to expand geological exploration activities, to find and develop better geophysical and geochemical methods for geological exploration, and to improve the methods for interpreting the data so obtained.

b Improvement of the energy-efficiency of mining and extraction methods. Vast amounts of ore have to be handled, transported, and processed to yield the desired materials, and these activities are usually highly energy-demanding. Anticipated limitations on energy supply and use make it more important for the mineral and material industries to find more energy-efficient methods and processes to maximize the amount of material that can be obtained with the available energy. The need for this increased efficiency can only become more acute as leaner and less accessible ores have to be worked, though it must be recognized that there will be practical upper limits to the efficiency that can be achieved.

c Improve pollution control technology. While improved pollution control usually does not of itself increase the production of materials, it can relieve possible restraints on materials production resulting from environmental legislation. (In certain special situations, however, significant quantities of high value materials may be recovered from effluent.)

On the usage side of the materials cycle some principal strategies for closing the supply/demand gap are:

d Materials conservation in product design. Many opportunities exist for practicing materials conservation in designing devices, machines, and structures. Increasingly important tactics include: design for longer service life and to facilitate repair; design to minimize the dispersal of scarce materials; design to use scarce materials only where their particular properties are required; design to facilitate product dismantlement and material reclamation; design to employ, wherever possible, more abundant materials instead of scarce ones, materials from renewable resources rather than from nonrenewable ones, and less environmentally offensive materials instead of those more so; miniaturization; simplification and standardization; design to allow wider tolerances in material properties; and design to minimize materials wastage in manufacturing. Clearly, not all of these objectives can be achieved simultaneously; engineers have to find an optimal compromise consistent with the performance objectives.

e Materials substitution. Probably the first strategy to come to mind when certain materials become scarce is to seek suitable substitutes made from more abundant ingredients. Some types of application are quite receptive to substitutions; other applications, particularly in the more complex technologies, are much less so. It is important to recognize that direct substitution is not always possible.

f Functional substitutions. An alternative to finding a substitute material to perform a given function is to find a completely different way, product, or device to perform this function. This new approach can have an impact on material resources that is vastly different from that of the old, e.g., transistors instead of vacuum tubes; adhesives instead of nails, rivets, bolts, or fasteners; nuclear reactors instead of oil-fired boilers; video and facsimile transmission instead of mail transport.

g Recycling. Increasingly, recycling in its various forms is regarded as a major approach to the conservation and efficient management of materials. And because of the composition of solid wastes, extraction of secondary materials from them can represent, besides an extension of supply, a considerable energy saving over extraction of primary materials from ores.

In its previous report COMRATE gave some attention to each of these strategies. The present report focuses in more detail on one particular aspect of recycling--the recovery of material and energy values from municipal solid wastes.

An undercurrent to this report and its organization is an image of the degree of recycling that will have to be practiced by the end of this century. This, in turn, requires a strategy of how to reach that objective starting from present circumstances. The first emphasis is on technological directions that might be taken. It is recognized that not all innovations are ready yet for application, but that it is very probable that some will be practiced at various times in the future. But technology alone cannot solve the problems of resource recovery from wastes; society as a whole is involved, raising many social, economic, and political issues that have to be faced.

Thus, both technical and social innovations will be needed as we move towards the desired national posture for recycling. This progress must be deliberate and coordinated--above all, we should avoid taking near-term actions that will obstruct better long-term solutions.

The next section summarizes the principal findings of our study. It is followed by two supportive chapters devoted primarily to the technical and the social issues involved. These chapters, in turn, draw on information contained in the Appendixes which consists of papers contributed by panel members, COMRATE staff, and conferees at a briefing meeting held by this panel on April 3 and 4, 1975.

SUMMARY OF PRINCIPAL FINDINGS

1. Priorities for National, Regional, and Local Policies for Municipal Solid Waste Management

The rising cost and difficulty of waste disposal and strict environmental regulations are, at present, the principal driving forces for more attention to resource recovery. Impending materials shortages, whatever their cause (physical, economic, political, cartels), over the next two or three decades are not, as yet, a primary motive, though the alleviation of shortages will progressively assume greater significance. Through cooperation between local communities and private industry, the corresponding adjustment in priorities, from an emphasis on waste disposal to one on resource recovery, appears to be taking place at a reasonable pace, a pace that is consistent with the need to develop, evaluate, and assess the consequences of new technology. Nevertheless, depending on local factors, we foresee waste disposal via landfilling, if designed and operated properly, continuing to be, though decreasingly, an economically and environmentally acceptable option for years to come. Furthermore, some landfilling will always be necessary since all resource recovery systems leave some residue.

The overall aim for all segments of society should be to maximize the efficiency of materials usage; this is important for aiding materials supply, conserving energy,and preserving the environment. But policies aimed at forcing a rapid and universal switch-over from waste disposal to resource recovery are unwarranted. Instead, it should be the steady policy for all levels of government--federal, state, and local--to facilitate and encourage a smooth shift in priorities from waste disposal to resource recovery, and where necessary, to provide suitable incentives, so that by about the year 2000, most of the nation's population will be served by resource recovery systems embracing refuse collection networks, refuse processing facilities, markets for recovered materials and energy, and appropriate administrative organizations.

2. Emphasis on Establishing Resource Recovery Systems

The principal obstacles to practicing efficient resource recovery are usually more institutional than technical. The most immediate need in the whole area of municipal solid waste management is to facilitate setting up resource recovery systems through the cooperative efforts of federal, state, and local governments and private industry. Wherever possible, primary emphasis should be placed on opening up opportunities for resource recovery; otherwise, these opportunities may be reduced, if indirectly and unintentionally, through changing regulations, laws, taxes, and controls reflecting a piecemeal approach to environmental improvement or control of business in what has to be a combined operation of the public and private sectors. Efforts should be made to eliminate, simplify, or modify regulations, restrictive practices, and financial problems that hinder the formation of resource recovery systems. Coordination is needed among the various federal agencies involved in resource recovery from wastes, including the Bureau of Mines (USBM), the Energy Research and Development Administration (ERDA), and the Environmental Protection Agency (EPA). In particular, *an overall systems approach needs to be taken to resource recovery--the technical elements of which involve product design, the waste collection systems, resource recovery facilities, and market sectors for the recovered energy and material values--in order to optimize the technical operation and the economic and social benefits to the communities it serves.*

As a guiding principle, recovery of all useful materials from wastes is preferable to "cream-skimming."

3. Organization of Resource Recovery Systems

There is no universally best formula for establishing resource recovery systems but usually, outside the large cities, the economies of scale will call for regional systems serving several local communities. *The overall approach to efficient operation will frequently call for vertical integration in place of fragmentation of collection systems, resource recovery plants, and utilities and market sectors for the recovered energy and material values.* A properly integrated system greatly eases functional communication and planning activities between its various components. In a real sense, the existence of markets determines the nature of resource recovery facilities; these, in turn, influence the operation of the waste collection system. All three components have to work symbiotically in an evolutionary manner and in ways which take into account local or regional factors. As far as possible, the approach in planning resource recovery systems should be first, to discern how to optimize the technical and economic aspects of the operation, and then, to devise the most appropriate administrative, regulatory and institutional structure--not the other way round.

The institutional problems faced in operations which are hybrids of the public and private sectors need special and immediate attention. The objectives of providing a public service and of making a profit have to be reconciled; the probable future trend toward regarding resource recovery as a natural monopoly providing a public service more than as a profit-making venture may give it some of the aspects of a regulated utility. The need to establish state solid waste management authorities merits attention. Nevertheless, if private industry is involved, the organizational and financial arrangements have to be sufficiently flexible to allow raising capital for the continual upgrading of the facilities and experimenting with new approaches to resource recovery.

4. Financial Support and the Apportionment of Costs and Benefits

Ultimately, when fully operating, resource recovery systems (collection systems plus resource recovery facilities) must have income sufficient to cover their expenses and profits. Support from the sale of recovered values is unlikely to be more than a fraction of the total costs of operating the system. The balance must come from the general public, paid either directly to the resource recovery system, as with utilities, or indirectly through local taxes. Further financial support may be needed by local governments in the initial phases of establishing resource recovery systems to pay for technical advice from consultant or industrial firms and for demonstration or pilot-plant projects. Federal loans and grants can be particularly important at this stage. Subsequently, capital can be raised by issuing general obligation bonds or, more likely, industrial development bonds. Other financial measures include the rapid amortization of resource recovery facilities.

Unusual problems are posed, however, by the hybrid, public-private institutional nature likely to be characteristic of most resource recovery systems. The contrasting views of the two sectors--service versus profits--have to be reconciled, and agreement has to be reached on equitable ways of sharing the costs, risks, and benefits. It is manifestly unrealistic to expect industry to accept all the risks and allow the public sector to enjoy all the benefits or vice versa. In most cases a framework and mechanism for arbitration may be advisable.

Obstacles to long-term agreements to support resource recovery systems faced by the public sector (particularly local governments) include, for example, restrictive procurement laws, the problems of split bidding and legal requirements to accept lowest bid, and various constraints, such as effects on tax status, generally acting against participation by the public sector in commercial operations. Investment in resource recovery from municipal solid wastes was, until recently, unattractive to the private sector because of uncertainties over markets for the recovered products, reasonably long-term stability and uniform enforcement of government regulations, and public acceptance of the profit motive in this activity as an incentive for providing funds for continuously upgrading the facilities.

Besides the problems facing apportionment of costs and benefits between the public and private sectors, problems arise when the costs and benefits have to be apportioned between several participating communities. Establishment of state or regional authorities for overseeing solid waste management may circumvent at least some of these problems.

In short, it is felt that many of the most pressing problems in implementing resource recovery systems lie at the public-private and community-community institutional interfaces.

5. Policies for Regulations, Standards, and Taxes

Society, acting through its various levels of government, has several mechanisms for communicating its wishes about resource recovery systems. For example, it can apply mandatory regulations, laws, and ordinances; it can establish and enforce conformity to standards; and it can shape operations by imposition or removal of taxes. The merits of the various approaches depend on what is felt to be the best compromise between rigidity and flexibility. We believe that to optimize the benefit to society, without compromising public health and safety, it is better to err on the side of flexibility and adaptability rather than on that of rigidity and constraint; of incentives and rewards rather than of punitive measures; and whenever feasible, of voluntary rather than mandatory actions.

Direct federal controls and regulations over such things as mandatory proportions of resource recovery and landfilling, types of recovery equipment, or product specifications may pose problems and impose hardships as a result of differing local factors.

Environmental pollution resulting from waste disposal and resource recovery operations, and the safe handling and processing of wastes are, however, clearly areas appropriate for federal standards. Costs of meeting these standards have somehow to be internalized in the total resource recovery system. The question also arises whether resource scarcity standards will eventually be considerd; for example, it is conceivable that recovery standards could be set for materials judged to be scarce or strategically vulnerable.

Legislators wishing to influence commercial activities think first of taxes, as preferable to direct controls since they usually allow some freedom for maneuver and the search for the economically-optimum configuration. However, simply to impose taxes on one part of a system without giving corresponding relief from taxes at another part may well be a disincentive for innovation and efficiency. Tax-neutrality should probably be sought--the shape of an economy can be altered by moving taxes around, whereas simply adding taxes tends to depress it.

Whatever course is chosen, whether through controls, standards, or taxes, legislators should, wherever possible, aim at setting the broad, overall boundary conditions and constraints that reflect the public interest in environmental quality, health, safety, and conservation of resources. They should avoid proliferating overly-specific or detailed measures, each aimed at only a small part of the total waste management problem.

Adaptability of the adopted measures to changing conditions and varying local factors is preferable to rigidity and constraint. The measures must be easily understood and uniformly employed and enforced, and should take into account the time required for technology to respond and develop--often many years. Because of this long lead time--reflecting not only the time it takes to discover, develop, and evaluate new technology but also the time needed to build up the necessary capital investment--a major hazard facing operators of resource recovery systems is sudden, unexpected impositions or changes in regulations and standards. Measures that are arbitrary or capricious, which often reflect sudden yielding to special interests, impair the effectiveness of the overall resource recovery system, and adversely affect employees, employers, and those it serves. Legislators, before taking action, need to be fully informed about the possible consequences of their activities, particularly the risks they are imposing on the private sector and the additional costs that ultimately have to be passed on to the general public.

Overall, we believe that the technological problems of dealing with solid wastes can be solved; but regulations and standards make solutions more difficult, time-consuming, and costly. *Wherever possible, the emphasis should be on finding ways to minimize and simplify the necessary regulations and standards, to aim at broad rather than detailed requirements, and to apply them evenly, steadily, and with adequate forewarning.*

6. Making Information Available Concerning Resource Recovery

Governments at all levels, but particularly the federal government, have a need and responsibility to provide technical and managerial information to system operators and information about the purposes of resource recovery to the general public.

System operators need technical information concerning various resource recovery technologies; systems planning approaches; systems engineering; the time scales involved; the nature of recovered values; and information on such topics as financing and management options, preparation of contracts, the respective roles of local, state, and federal governments, and ways to achieve equitable apportionment of costs and benefits between the public and private sectors and between the various participating communities.

Topics on which more public information and awareness would help enlist the cooperation and support of the public at large include: the value of practicing resource recovery; the pros and cons of source separation; the increasing technical sophistication of resource recovery; the time taken for requisite technology to be developed and evaluated; the emergence of resource recovery as a hybrid public-private enterprise with a mix of the public service and profit-making motives; and the acceptability of products (e.g., "off-color ones") made from recovered materials.

7. Promoting Markets for Recovered Materials and Energy

Resource recovery is of no value if there is no market for the recovered products. Efforts to promote such markets need wide exploration. These efforts include not only direct ones on behalf of the secondaries themselves but also measures aimed at ensuring that primary materials and fuels do not enjoy unfair advantages over secondaries.

Approaches to opening up markets for secondaries are both technical and institutional. They include: establishing a scale of standard, specifications for secondaries widely acceptable to various user industries and reflecting varying degrees of criticality; finding new uses for various grades of secondary materials in manufacturing products; finding an effective way to disseminate the latest information on the availability of recovered materials and engineering data on their characteristics and possible uses; relaxation of material specifications by manufacturers, wherever possible, to accept secondaries; providing various economic incentives to manufacturers who might otherwise prefer primary materials; and removal of regulatory and institutional restrictions, many of them local, reflecting the varying attitudes of local regulatory bodies. Examples of the latter include regulations which inhibit the direct sale of secondary fuels to utilities or incorporation of secondary materials in noncritical applications such as road-building. On the other hand, the sale of refuse-derived electricity to utilities appears to be an interesting approach, not only for technical reasons but for the way in which it circumvents some of the basic regulatory problems as well.

There is some evidence that primary materials enjoy economic advantages over secondary materials because of, for example, economies of scale, depletion tax allowances, foreign tax credits, preferential transportation rates, purchasing specifications and pejorative labelling. On the other hand, secondary materials, as a whole, will increasingly possess the advantage of lower energy costs in their production. We do not see a need or justification for the primary material sector to subsidize the secondary material sector, at least until the limits of technological and marketing ingenuity with secondary materials have been fully explored. Furthermore, any measures for tipping consumption in favor of secondary materials, such as mandatory requirements that certain products contain percentages of secondary materials, need to be viewed not only as to their impact on product performance, but as to their impact on the general economy, the primary material sector, and international trade and technology transfer as well. In general, we believe that a guiding principle for regulations, ordinances, and taxes, aimed at modifying the balance of the primary-secondary usage pattern, should be equitable rather than discriminatory economic treatment.

The secondary material industry also faces the particular problem of wide fluctuations in the price of primary materials.

Together with changes in product specifications by consumer industries, these fluctuations can result in very erratic demand patterns for secondary materials, a major risk which tends to deter investment in resource recovery. A private sector or federal government purchasing and stockpiling program to help smooth these fluctuations, thereby providing a steadier market for the various grades of recovered materials, could have beneficial effects. Wide price fluctuations and supply variation also occur at various stages in the collecting, holding, and processing of recycled materials. The concept of stockpiling should also be examined as a means of price stabilization and supply normalization at strategic points in this flow.

8. Needs for Research and Development

While much can be done with existing technology, given the capital, there is a need for research and development on a wide range of topics, including pilot plants and demonstration projects. In its present formative and fragmented stage the resource recovery sector itself is in no position to support directly a well-balanced, comprehensive R&D program--it has to rely on R&D performed by equipment suppliers on their own initiative or on projects supported by contracts from federal agencies, particularly the EPA, the USBM, and the ERDA. Likewise, communities seeking technical advice must turn to industrial firms, consultant firms, or federal agencies. For the immediate future we therefore see a vital role for the federal agencies in supporting the necessary R&D, demonstration projects, and systems studies. It is also important that federal agencies, such as USBM, EPA, and ERDA, coordinate their activities in this area. Eventually, however, we believe most of such work should be supported primarily by the resource recovery sector itself, regionally and nationwide, and secondarily, by its equipment suppliers. Over the next decade or more we foresee R&D leading to steady improvement of the resource recovery technologies already envisaged. In the longer term there will be exploration of novel and speculative approaches and sophisticated system designs. Consequently, there will be an extended technology learning period which must be taken into account in establishing resource recovery systems.

The R&D topics that need attention are both technical and socioeconomic. They include (not in order of priority):

(a) some investigation of slurry or vacuum pipeline collection systems and their potential utility for urban areas in which there is a high density of solid waste;

(b) mechanical wear and tear of waste handling and pulverizing equipment;

(c) corrosion, erosion, slagging, and fouling of furnaces and other equipment used for processing;

(d) improved and economical automatic sorting techniques, including effective automatic means for monitoring the composition of incoming waste streams and recording their variation;

(e) processes for converting wastes into useful chemicals;

(f) metallurgical processes for separating complex alloys and fused mixtures of metals, with special emphasis on finding processes more economical in their use of energy;

(g) studies of combined combustion and pyrolysis systems;

(h) techniques for controlling pollutant and effluent emissions from resource recovery operations;

(i) approaches and standards for characterization of secondary materials and recovered fuels;

(j) processes and methods for recycling plastics;

(k) the effects of organizational arrangements and the size of resource recovery operations on the net costs to the public;

(l) systems design, engineering, and architecture studies to maximize resource recovery efficiency at costs consistent with financial prudence and responsibility to the public;

(m) the possibility of extending resource recovery systems for treating municipal solid wastes to include also agricultural, forest, animal, and human wastes; and

(n) improved methods for storing and transporting refuse-derived fuels (which tend to be somewhat corrosive compared with conventional fuels).

Many of the above objectives are currently being pursued in a variety of institutions--industrial laboratories, universities, consulting firms, federal agency facilities--with federal agencies providing some support and coordination. As the resource recovery sector grows in importance, it will be necessary either to expand the capabilities of the federal, and perhaps some state agencies, or to establish new national, regional, or decentralized R&D organizations. Prototypes for the latter that could be considered are the central laboratories of the nationwide telephone system; or the institute supported by the electric power utilities for contracting R&D to various laboratories, or a national laboratory somewhat analogous to the United Kingdom's National Engineering Laboratory at Warren Spring. Whatever form is chosen for a solid waste management center serving the whole nation, initially it should be jointly funded by government and industry, with the resource recovery industry taking an increasing share of the support as the industry matures.

It is important to encourage the attention to solid waste management of highly-skilled technical, managerial, and professional people. One way of doing this would be for the center to be suitably coupled to, though administratively separate from, a large university, preferably one well-established in process and materials engineering, and with strengths in the related physical and social sciences. Working with the university, the center might also stimulate courses in solid waste technology and management and generate related educational materials, textbooks, and technical reports. At the same time, the center might work more widely with two-year community colleges to provide education and training for technical personnel. Information, technical advice, and marketing data arising from the R&D, pilot plant, and socioeconomic studies sponsored by the center would be made available to any part of the solid waste management sector, including all levels of government.

9. The Effect of Product Design and Waste Reduction on Resource Recovery

To the extent that certain combinations of materials and product designs make subsequent material reclamation difficult or hazardous, it is desirable to devise ways of keeping such items out of the waste stream. In general, rather than using strict ordinances and legislative measures to prevent entry of certain products (other than known hazards) into the waste stream or even by applying tax disincentives or recycling deposits to products, every effort should first be made to develop guidelines for product designers. This requires functional communication between resource recovery facility operators and product designers on such matters as recovery costs versus product design and material composition and on the prospects for secondary markets. The importance of information exchange between these two activities has been seriously neglected. The role of the federal government should be primarily that of a catalyst and information source for such cooperation.

No one will deny that waste reduction is in itself a worthwhile objective; it relieves the impact on the environment that handling large quantities of material necessarily incurs, and reduces the drain on primary energy and material resources. In principle, waste reduction can be achieved, legislatively, in various ways; by restrictions on primary materials; by detailed control over product designs; and by control over waste disposal. We believe that controls over the amount of material and controls over disposal methods are more feasible and acceptable than control over product designs. Generally accepted controls over sources and sinks can concentrate on the prime objectives of preservation of the environment and natural resources, but can leave maximum scope to the industrial and social sectors to find a range of adjustments within these overall constraints. It would seem that much caution should be exercised before, if at all, applying rigorous product regulations to manufacturers on account of their potential economic, social, and employment consequences; it also needs emphasizing that the more technically sophisticated the product the less amenable it is to design and material content controls. Nevertheless, systematic attention should be given to all elements that affect the nature and extent of the waste stream, its amenability to recycling, the resource recovery process itself, and the economics of recycling and return to use.

As a general principle, care should be taken to ensure, as far as possible, that at every step in the life cycle of a product its internal energy or organizational state is changed as little as possible--the principle of minimizing the rate of entropy increase. This means that, in resource conservation, maintaining products in service through repair is usually to be preferred to destruction of the product in the resource recovery process; that burning paper for energy recovery may be less efficient, overall, than recycling it as long as it is fit for the latter; and so on. While the repair and maintenance of automobiles is served by a variety of commercial activities, there are insufficient facilities for household appliances. The practicality of such services could be much enhanced by much greater resort to modular design and standardization of component parts. (It would not be inappropriate to use any movement towards such standardization as an opportunity for introducing metrication.) Making products more durable is a well-recognized approach to reducing the quantity of waste though again, great caution needs to be exercised if strict controls are contemplated on account of their potential consequences--technical, economic, and social--which may prove overall more costly than the problem they are intended to solve. The concept of product life-cycle costing needs to be explored, but there is also a need for the public to be better informed of the relative pros and cons of life-cycle costs versus first costs.

CHAPTER 1

TECHNICAL ASPECTS OF RESOURCE RECOVERY FROM MUNICIPAL SOLID WASTES

RECYCLING STREAMS

Originally, in the public mind, conceptions of recycling were probably rather simple, focusing on finding better ways of dealing with wastes than simply depositing them in unsightly, ever-growing dumps. The actual opportunities for recycling turn out to be much more complex. Referring to Figure 1, opportunities for recycling occur at every stage in the materials cycle, with residues and wastes being returned to some point upstream by some means. The variety of these pathways is brought out in Figure 2 (Page 1974). The materials flows in Figure 2 are:

A. post-consumer waste to environment (e.g., refuse to dumps, litter along highways);
B. producer waste to environment (e.g., effluents in the air, rivers, and oceans, industrial and commercial waste to dumps);
C. extraction waste to environment (e.g., mine wastes and tailings, effluents);
D. environmentally recycled waste (e.g., carbon and nitrogen cycles, biodegraded wood wastes);
E. consumer residuals recycled to the production sector (resource recovery--the focus of this report);
F. consumer residuals recycled to the consumer sector (e.g., returnable bottles, containers, crates, rebuilt engines);
G. home scrap (e.g., from steel mills) and prompt industrial scrap (e.g., from product manufacturers);
H. primary, raw, or virgin materials to extractive sector (e.g., trees, minerals, sand, and crude oil);
I. primary, raw, or virgin materials to productive sector (e.g., wood, metals, ceramics, glass, petrochemicals, plastics);
J. final goods or finished products to consumer (self-explanatory); and
K. "urban ore" to production sector (resource recovery from existing dumps and landfills).

The dashed line in Figure 2 separates the economic sector from the environmental sector. At H materials flow into the economic sector and waste streams A, B, and C flow back into the

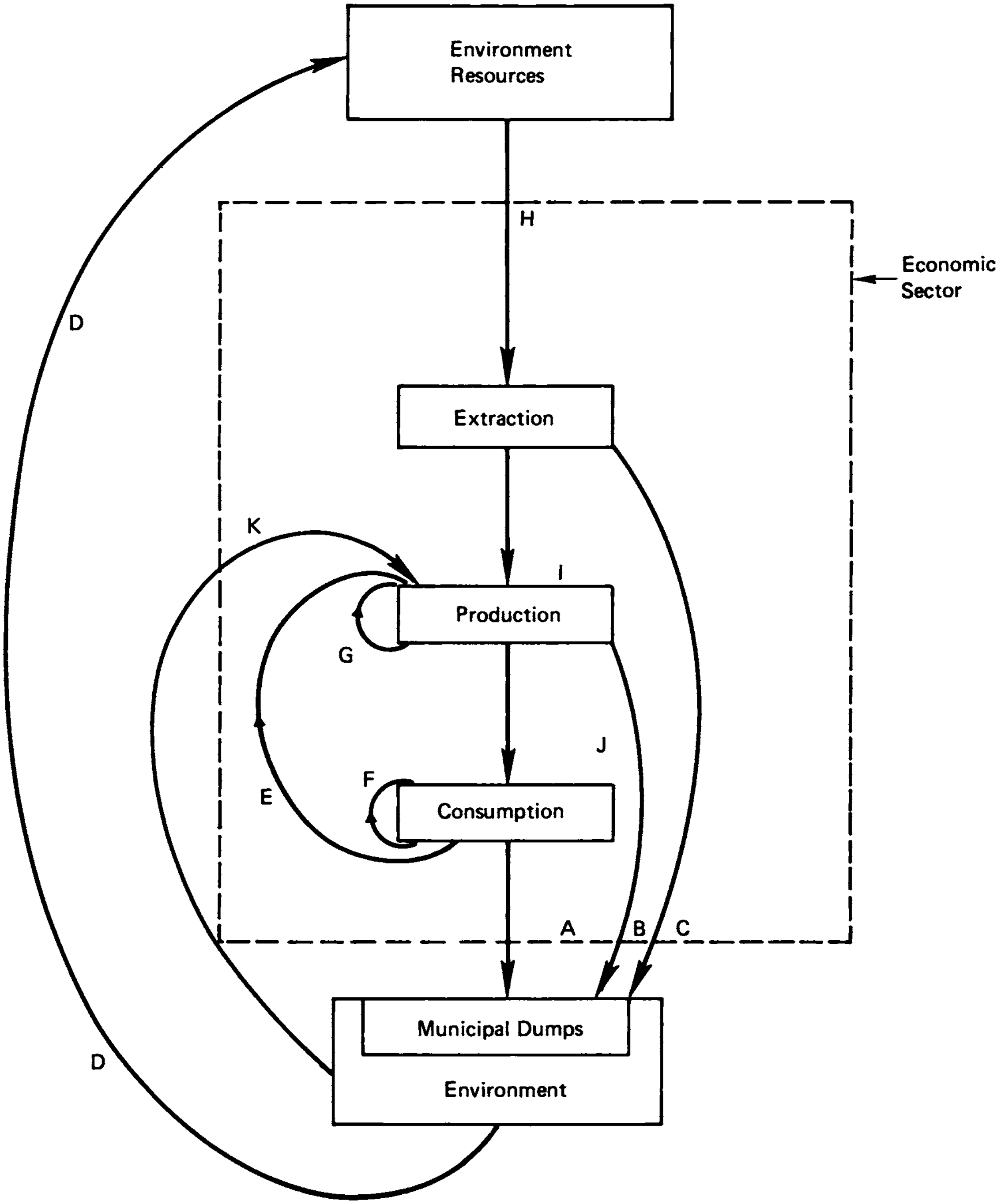

Figure 2 Recycling Paths in the Materials Cycle

Source: Page (1974)

environmental sector at the other end. The growth in quantity of the wastes is moderated to the extent that values can be deliberately recycled back upstream, along paths E, F, and K.

As depicted in Figure 2, the flows A, B, and C go into various types of sinks, including municipal dumps, mine wastes and tailings, the oceans, and others. But the public is most concerned with the flow into municipal dumps (mainly A), even though this may be a relatively small fraction of the total solid waste flow. Moderating this flow into municipal dumps and landfills, through measures enabling more recycling and resource recovery via routes E and F is the subject of the present study. Other recycle routes, totally within the economic sector such as G, are also important but, in general, they are already well handled by the established industries.

DRIVING FORCES FOR RESOURCE RECOVERY FROM MUNICIPAL SOLID WASTES

Various forces acting in concert favor wide-scale implementation of resource recovery (RR) programs from municipal solid wastes (MSW). These pressures include:

a Aesthetic pressures. Refuse dumps and, to some extent, landfills, have long been regarded as unhealthy, unsightly, and unpleasant to be near, and as the dumps grow in size, public opposition to their presence increases.

b Shortage of landfill sites. Refuse, most prevalent in urban areas, has often been regarded as serving a useful purpose for reclaiming land that would otherwise not be suitable for building on. But such landfill opportunities become fewer all the time, thus raising the costs of suitable sites and public interest in reducing the volume of waste.

c Not-so-sanitary landfill. While use of refuse for landfilling has been quite widely practiced in the past, there is growing concern over the long-term effects of decomposition of products from such deposits, even though supposedly "sanitized" by appropriate earth packing procedures. There is concern, for example, over the possible contamination of surface and ground water supplies by leachate and runoff.

d Alleviation of materials shortages. Because of growing difficulties in assuring future supplies of raw materials, particularly imported ones, there is a growing public conviction that the materials contents of discarded products should be recovered as fully and efficiently as possible; that the materials should not be just thrown away.

e Energy savings from recycled materials. The energy required to recover materials from MSW is usually less, often considerably so, than the energy required to produce equivalent quantities of virgin materials. The rising cost of energy makes materials recovery from MSW increasingly economically favorable.

f Conservation ethic. There is also a significant and probably growing segment of public opinion that believes it is morally wrong to live in a wasteful style in a world in which there is so much poverty.

In the face of these various pressures, public interest in recovering materials and energy from MSW is mounting. This trend is reflected in the number of bills proposed in the 93rd and 94th Congresses with the aim of enhancing the national posture in recycling. Proposed pieces of legislation aim at: (a) funding and promoting R&D, (b) promoting the planning and incorporation of recycling into total municipal waste management, and (c) regulation, for instance, by prohibitions and incentives. Our study reveals, however, that recycling, and particularly RR from MSW, is a far more complex issue than perhaps many realize and that any legislation aimed at improving recycling will have to be carefully constructed in full knowledge of the workings of the materials cycle and the three-way interactions in the materials-energy-environment system. Piecemeal legislation, focused too narrowly on segments of the materials cycle or on particular recycling loops, can have unexpectedly adverse rather than beneficial effects, because of all the interconnections in the system.

MAGNITUDE AND COMPOSITION OF MUNICIPAL SOLID WASTES

The United States Bureau of Mines (USBM) and the Environmental Protection Agency (EPA) have made estimates of the scope and composition of MSW. More recently, the Energy Research and Development Administration (ERDA) has been studying the potential for energy recovery from MSW. In 1973 the USBM estimated the annual rate of generation of urban and suburban refuse as about 300 million tons. Of this (see Figure 3), 160 million tons going to dumps or to incinerators is of a type they regard as suitable for processing plants.

The composition of MSW is subject to seasonal and regional variations. However, according to one study, the average composition of the 160 million ton refuse flow shown in Figure 3 is as given in Table 1 (results from a number of other studies will be found in Appendix A. II).

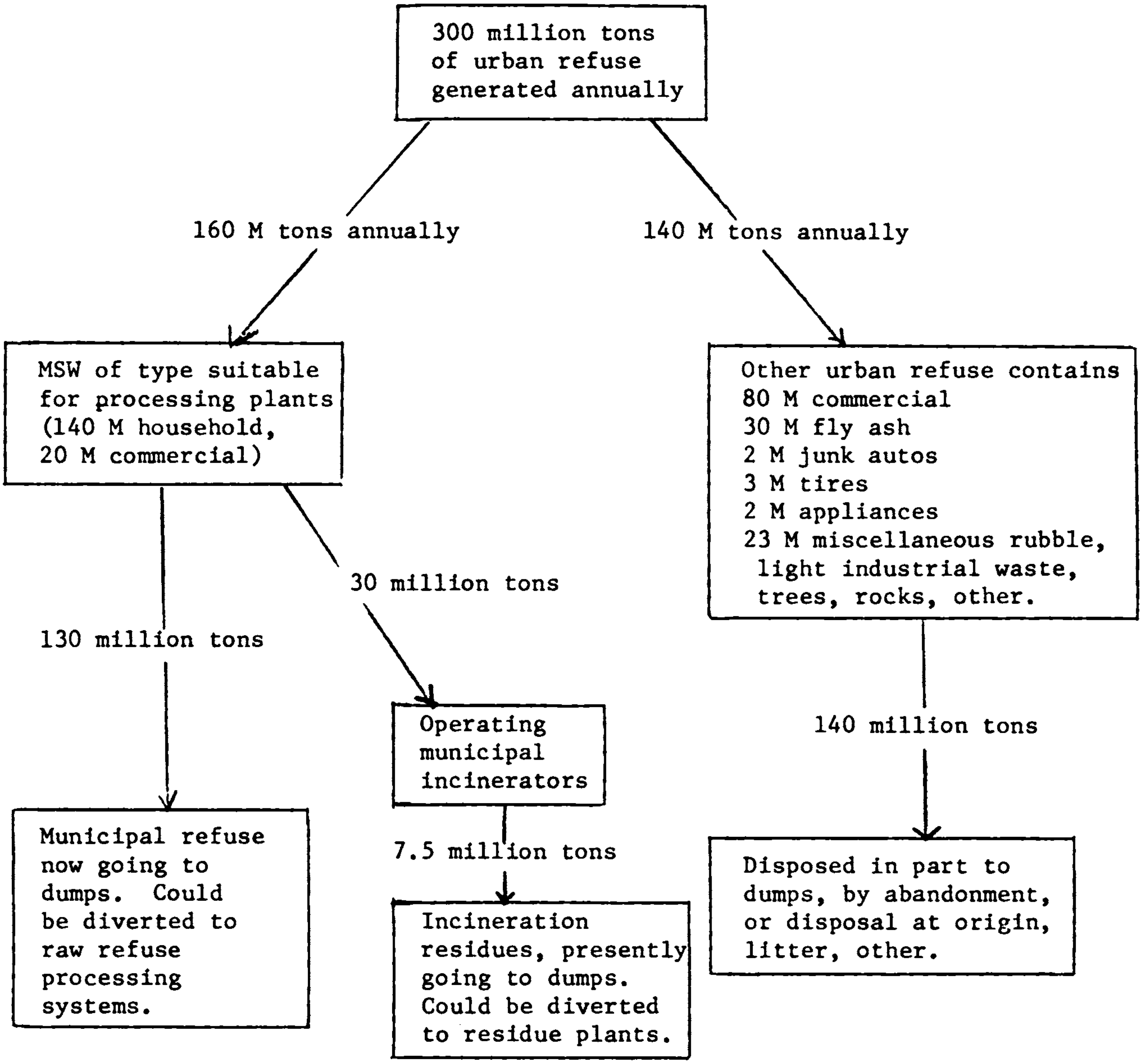

Figure 3 Urban Refuse Disposal in the United States in 1973.

Source: Data supplied to COMRATE by USBM.

TABLE 1

AVERAGE COMPOSITION OF MUNICIPAL SOLID WASTE

Material	Wt./ Percent as Received, Dry
Glass	8.4
Metal	8.2
Paper	35.8
Food waste	18.7
Yard waste	20.4
Plastics	1.3
Leather, rubber	1.4
Wood	2.3
Textiles	1.9
Dirt	1.6
	100.0

Source: Niessen and Chansky (1970).

The average composition of the 7.5 million ton incinerator residue flow in Figure 3 is given in Table 2.

TABLE 2

AVERAGE COMPOSITION OF INCINERATOR RESIDUE
(Such figures are susceptible to some regional and seasonal variation.)

Material	Wt./Percent
Glass	34.0
Ferrous metal	30.8
Nonferrous metal	2.8
Ash and slag	32.4

Source: Data supplied by USBM.

These figures provide a rough quantitative indication of the extent to which materials recovered from MSW could offset needs for prime or virgin raw materials. The answer is, except for glass and paper, only a modest amount.

Table 3 converts the percentages in the 160 million ton refuse flow into actual tonnages and compares them with annual consumptions within the U.S.

TABLE 3

ANNUAL TONNAGES OF VARIOUS COMPONENTS OF MSW AND U.S. CONSUMPTION

Material	Tonnage in Processible MSW Based on USBM estimates (1973)	From EPA 2nd Report (1971)	Annual Consumption (1971)
	(million tons)		
Glass	13.4	12.3	13
Ferrous Metal	12.0	10.6	84
Nonferrous Metal	1.1	1.2	10
Paper	57.3	43	59
Plastics	2.1	4.5	12
Wood	3.7	4.6	40

Allowing for the unavoidable imprecision of these figures it is clear that <u>in principle,</u> the processible MSW could provide large proportions of the nation's needs in glass and paper, but in the categories of metals, plastics, and wood, the amounts ending up in this general waste stream are only a fraction of the annual needs of the country. (The rate of growth of the plastics industry may cause a steady increase in the proportion of plastics in MSW). A large proportion of the nation's metals production does not reach the general MSW stream; it either gets efficiently recycled within the economic sector of Figure 2; or it gets used in long-life applications, such as in building and highway construction; or it ends up in special collection systems (such as autos); or it gets scattered too widely to make retrieval practicable.

While this finding does not reduce the importance of recovering resources, including metals, from MSW, it does bolster the argument that the prime motivation for recycling MSW is to alleviate pressures on waste disposal programs, and that the recovery of resources is a secondary motivation.

The above figures are concerned with estimates of what is <u>theoretically</u> possible. What is possible <u>in practice</u> is much less because of the losses that occur in the collection operation and the technological limits to recovery processes. What is currently being done is even less than this. Of the 300 million tons of urban refuse generated annually, only 220 million tons are regularly collected by public agencies and private firms. The remainder (80 million tons or about 25 percent) is abandoned, dumped at the point of origin, or hauled to uncontrolled disposal sites. It is only recently that any attention has been given to resource recovery; of the 220 million tons collected annually, the resources recovered at present represent an extremely small fraction. Recently, the Environmental Protection Agency (1974) has estimated that, taking into account the various unavoidable inefficiencies in the waste management system, the overall potential recovery expressed as a percentage of U.S. consumption is: iron - 6.7 percent; aluminum - 8.4 percent; copper - 4.7 percent; lead - 2.8 percent; tin - 18.9 percent; and paper and paperboard - 14.0 percent.

As everyone knows, growing dumps of MSW pose ever greater problems to local authorities, particularly in large urban areas where the quantities are greatest and the availability of suitable disposal sites is often least. Coupled with the other negative aspects of disposal sites, these forces are causing local authorities to seek alternative means for dealing with MSW. Under these conditions, opportunities for recovering at least some of their expenses by recovering and marketing the energy and material values in MSW grow steadily more attractive. At the same time so do procedures for reducing the volume of materials that enter the MSW category.

A large fraction of MSW is organic and combustible. As indicated by Table 1, this fraction is 60 percent or more. Instead of consuming this material by burning and, at the same time, adding to air pollution, there has been much interest of late in recovering its energy content in some way. The heating value of MSW, as received dry, ranges from 2000 to 6000 BTU/pound (see Table 4). However, the energy theoretically recoverable from the combustible portion of refuse is equivalent to about only 2 percent of the nation's total energy consumption (or 7 to 9 percent of the total energy supplied to utilities for electricity generation): even if it were recovered, this is only a modest contribution to energy independence. Again, as with material recovery, energy recovery should be regarded as a welcome bonus from improved methods of dealing with the waste disposal problem. Furthermore, most of this energy recovery will occur in large urban areas where the demand for it is greatest.

FUTURE NATIONAL POSTURE IN MSW MANAGEMENT

The rising world demands for materials and the rising costs of satisfying these demands from raw or virgin materials will inevitably force more attention to achieving, to the extent practicable, a closed cycle of materials flow, at least cost of physical and human effort and with least adverse impact on the environment. The ratio of new to recycled material is large now but this is partly because of the rate of increase in per capita consumption of these materials. As the rate of increase begins to flatten, as it must sooner or later, the above-ground accumulation will thereafter be an increasing percentage of total material in the cycle.

In terms of Figure 2 the overall goal of closed cycling implies:

a restricting material flows, as much as possible, to <u>within</u> the economic sector; and

TABLE 4

TYPICAL ENERGY CONTENT OF MSW COMPONENTS

Constituent	Btu/lb Constituent (MAF)
Food Waste	
Garbage	6,484
Fats	16,700
Rubbish	
Paper	7,572
Leaves	7,096
Grass	7,693
Street Sweepings	6,000
Wood	8,613
Brush	7,900
Greens	7,077
Dirt	3,790
Oils, Paints	13,400
Plastics	14,368
Rubber	11,330
Rags	7,652
Leather	8,850
Unclassified	3,000
Noncombustibles	
Ashes	
Metals	
Glas & Ceramics	

Source: From MITRE Corporation, Energy Conservation Waste Utilization Research and Development Plan, Report MTR-3063, July 1975. This table is, in turn, extracted from Bechtel Corporation, Fuels from Municipal Refuse for Utilities Technology Assessment, Electric Power Research Institute, EPRI (261-1), March 1975.

b minimizing the sum of all the material flows so as to minimize the total material flow (adverse effects on resources and the environment generally increase with the quantity of material flowing).

The handling of MSW must be seen against this broader perspective. It requires that, whenever practicable, any material flows that escape from the economic sector into the environmental sector, including into municipal disposal sites, should be returned to the economic sector. At present, the main motivation for returning as much as possible of MSW to the economic sector is to reduce the strain on the environment rather than to ease the demands on sources of raw materials, but as time progresses we anticipate that this second motivation will grow in importance. We foresee a steady evolution towards a coordinated approach to the management of MSW, eventually extending across the nation. Shortages of materials are not so imminent as to demand a crash program, however. Rather, programs should be carefully worked out and deliberately embarked upon, bearing in mind that it may take up to 25 years to get technology in place, starting at the research stage. Further, the behavior as a system of the total materials cycle and all its associated recycling loops should always be taken into account.

The degree to which improved MSW management schemes are necessary varies greatly with location. Large cities already feel strong pressure to find alternatives to dumping and landfilling because of the decreasing availability of suitable sites and their high costs. Small cities and rural areas may still have available to them adequate, economic disposal sites. However, the advantages of resource recovery are expected to increase relative to those of disposal as the costs of raw materials and energy increase. Thus, we foresee a gradually-spreading network for resource recovery, spreading out from the big cities into surrounding, moderately heavily-populated areas, and perhaps, eventually, into significant fractions of the rural areas until a large proportion of the whole country is involved through coordinated regional schemes, both intra-state and inter-state. A key feature of any system for handling MSW will be its ability to evolve and adapt to changing needs and opportunities and to changing characteristics of MSW. Especially important will be the ability to encompass other waste handling problems in regional systems, particularly those arising from agricultural, and human forest wastes.

Elements of an overall program to optimize the handling of MSW include:

a reducing the quantity of the flow from the economic sector into MSW, for instance, by retaining materials (and products) longer within the economic sector through reuse and repair, through improving the durability of products, by legislation controlling in some way the types and quantities of materials and products that can be fed into MSW; and b developing improved means for recovering material and energy values from MSW, and for disposing of those wastes from which no such value can be recovered.

This report is written primarily from the viewpoint of enhancing recovery of resources from MSW in the U.S. It is felt there is a need for efficient means for recovering values and disposing of unavoidable residues from whatever qualities and quantities of refuse are fed into municipal solid waste systems, though the merits of finding acceptable ways of reducing these flows are also recognized.

There are no fundamental scientific or engineering reasons why suitable technology cannot be deployed or developed to accomplish the principal goals of resource recovery. Nevertheless, resource recovery presents a range of technological challenges and issues which will require determined efforts before the technology reaches a satisfactory state of development.

Before discussing these problems and issues, it is useful to review the hierarchy of schemes for dealing with waste disposal and resource recovery.

HIERARCHY OF MSW MANAGEMENT SCHEMES

A feature common to all MSW management schemes is a collection system. The schemes differ according to what is done with the MSW after collection.

In the simplest and most traditional approach (see Figure 4A) the MSW is simply dumped openly or used as landfill, "sanitary" or otherwise. These approaches have the advantages of simplicity and cheapness, provided suitable dumping or landfill sites are available. On the other hand, particularly in large urban areas, such sites are getting harder to find and more expensive. There are also other possible drawbacks such as the pollution of water supplies, the generation of undesirable gases, the formation of pathogens, and the provision of breeding places for vermin. Also, the MSWs in the open dumps often spontaneously catch fire or are deliberately burnt, with resultant problems of air pollution and fire danger. In consequence, dumping is increasingly outlawed while landfills, though not outlawed, are increasingly regulated. Landfills can be made more sanitary; but it can be an expensive undertaking, and furthermore, it calls for a higher level of managerial responsibility than is usually associated with landfilling operations.

The most common first step in the evolution of a MSW handling system, especially in Europe, is to pass the collected MSW through an incinerator (Figure 4B) where the combustibles are burnt off, leaving a residue of ashes and slag. This residue, representing a much reduced volume (by up to 90 percent) compared with that of the original MSW, makes correspondingly smaller demands on dumping and landfill space and usually, though not always, it has been

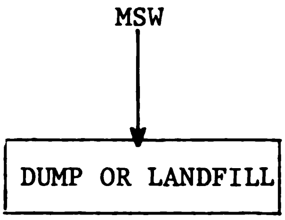

Figure 4a

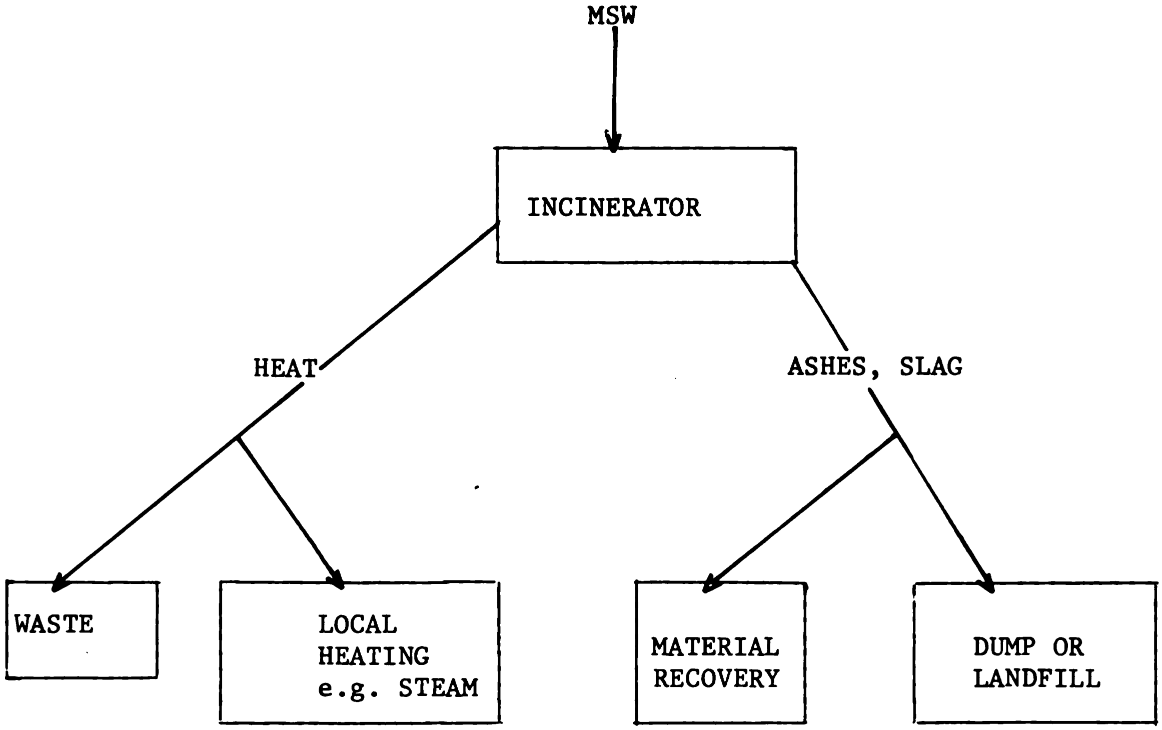

Figure 4b

"sanitized" by incineration. However, the problem of air pollution from the incinerators can be severe and there is the growing feeling that it is wasteful simply to burn many resources away. Consequently, some incinerator installations have been designed to provide heat to local heating systems, either by hot water or steam. There are some heating systems of this sort in operation for small towns, but the installation of an underground insulated pipe distribution system tends to be costly, the useful radius for such a system is limited, and the seasonal variations in demand for heating can present difficulties. As for the incinerator residue, more attention is now being paid to recovering material values from it.

Another scheme for taking advantage of the energy content in MSW is shown in Figure 4C. The MSW is first passed through a sorting process in which most of the combustible organic materials are separated from the noncombustibles. The latter can then go on to disposal or to material recovery stages. The combustibles, perhaps after some shredding to homogenize them, are fed along with traditional fuels, such as powdered coal, into the furnaces of a heating or electricity-generating utility.

If waste represents a small percentage (less than 10 percent) of the total fuel intake of the furnaces and if the particle size of the waste is similar to that of the main fuel, the need for furnace redesign is reduced. But modest redesign can increase the tolerance for MSW up to 25 to 30 percent of the total fuel intake. Above this level, significant redesign is needed because of the lower energy density of MSW. There are sometimes problems, however, with corrosion and abrasion damage, and the greater need for removing slag, which result in a somewhat greater downtime for the furnaces compared with use of conventional fuels alone. Furthermore, such a system is possible only when coordination can be arranged between the MSW handling organization and the energy utility.

A scheme that appears to be gaining favor is indicated in Figure 4D. The MSW is put into a pyrolyzer in which, essentially, the waste is decomposed by high temperature instead of being burnt. According to the actual details of the pyrolysis process this can result in fuels, either liquid or gaseous, which can then be marketed. The residues from the pyrolyzer can go to dumps, landfill, or material recovery, as in previous schemes. One of the residues, char (carbon plus ash), may find growing use as an absorbant for waste-water treatment. Compared with the schemes in Figures 4B and 4C for retrieving the energy content of the MSW, pyrolysis has the advantage that the energy comes out "packaged" in a liquid or gaseous form which is more convenient for storage and transportation. However, developing suitable markets for these fuels can pose some problems; one way around these, which appears particularly attractive, is to use the fuel within the waste handling system to generate electricity, which can then be sold to a utility.

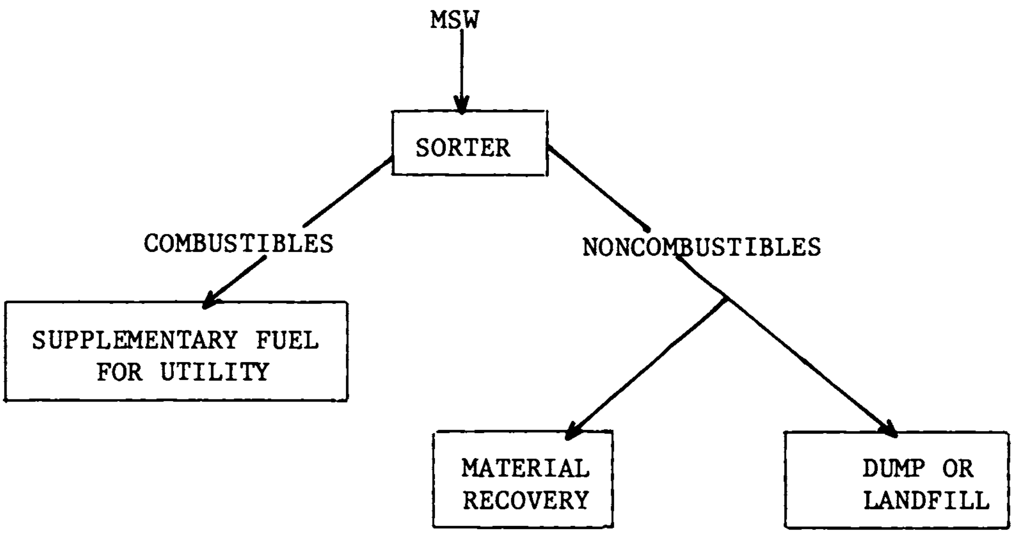

Figure 4c

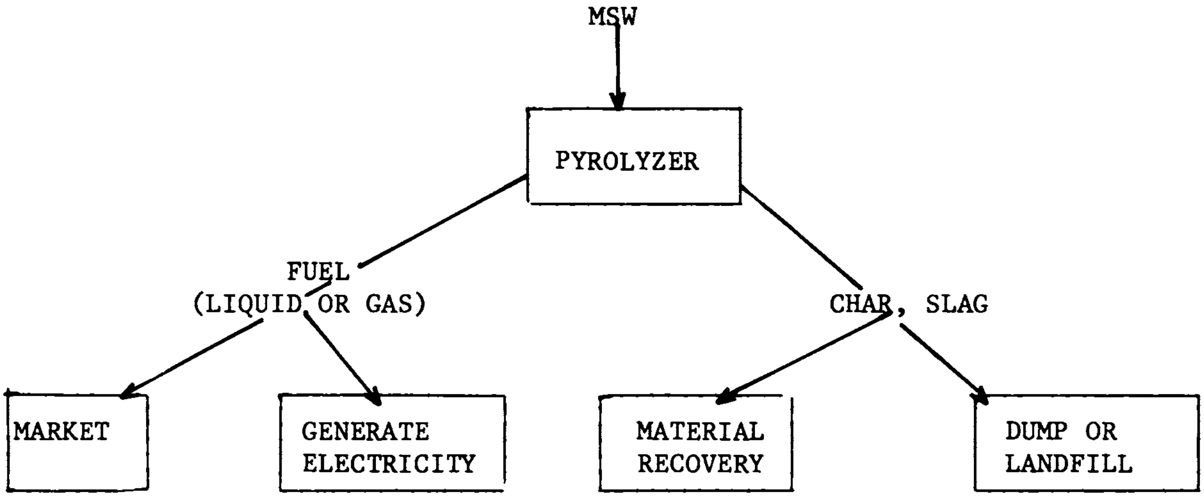

Figure 4d

It will be recognized that several options exist for utilizing the organic, combustible wastes. Instead of being used directly as fuel (Figure 4C), either for local heating or for a utility, or being pyrolyzed to make liquid or gaseous fuels (Figure 4D), some of them can be processed (Figure 4E) into composts, or chemically or bacteriologically converted into useful chemicals, fertilizers, and nutritional materials, while in some cases, material recovery can be practiced; for example, mixed papers may be recycled to low, but useful, grades of paper and cellulose fiber products. Which of these alternatives is best will vary among regions, depending on a variety of factors, including the local composition of the MSW and the potential markets for the recovered products. Not all organic ingredients in MSW lend themselves to each of these processes; the chemical and bacteriological processes, especially, will benefit from some presorting of the organic waste stream, particularly to remove the synthetic polymers.

TECHNICAL PROBLEMS AND ISSUES

Separation at Source

The pros and cons of keeping certain components of MSW separate from the main stream, right from the source, are often debated.

Pro:

- Source separation is useful for dealing with those items destined for direct reuse, e.g., bottles, or where valuable secondary materials are relatively concentrated, e.g., appliances and containers.
- It can be useful for those materials that would become unsuitable for direct recycling through contamination in the main waste stream, e.g., keeping newspapers out of the main stream allows them to be recycled to newsprint; and aluminum cans are an attractive form of remeltable scrap.
- Subsequent separation procedures may be helped somewhat if there is some separation at source, e.g., separation of organic or combustible wastes (such as food wastes, paper, textiles, plastics) from the inorganic, incombustible ones (such as metals, glass, and dirt), though such separation processes are usually not very difficult.
- The practice of separation at source has a useful educational value, alerting citizens to the needs for resource recovery.

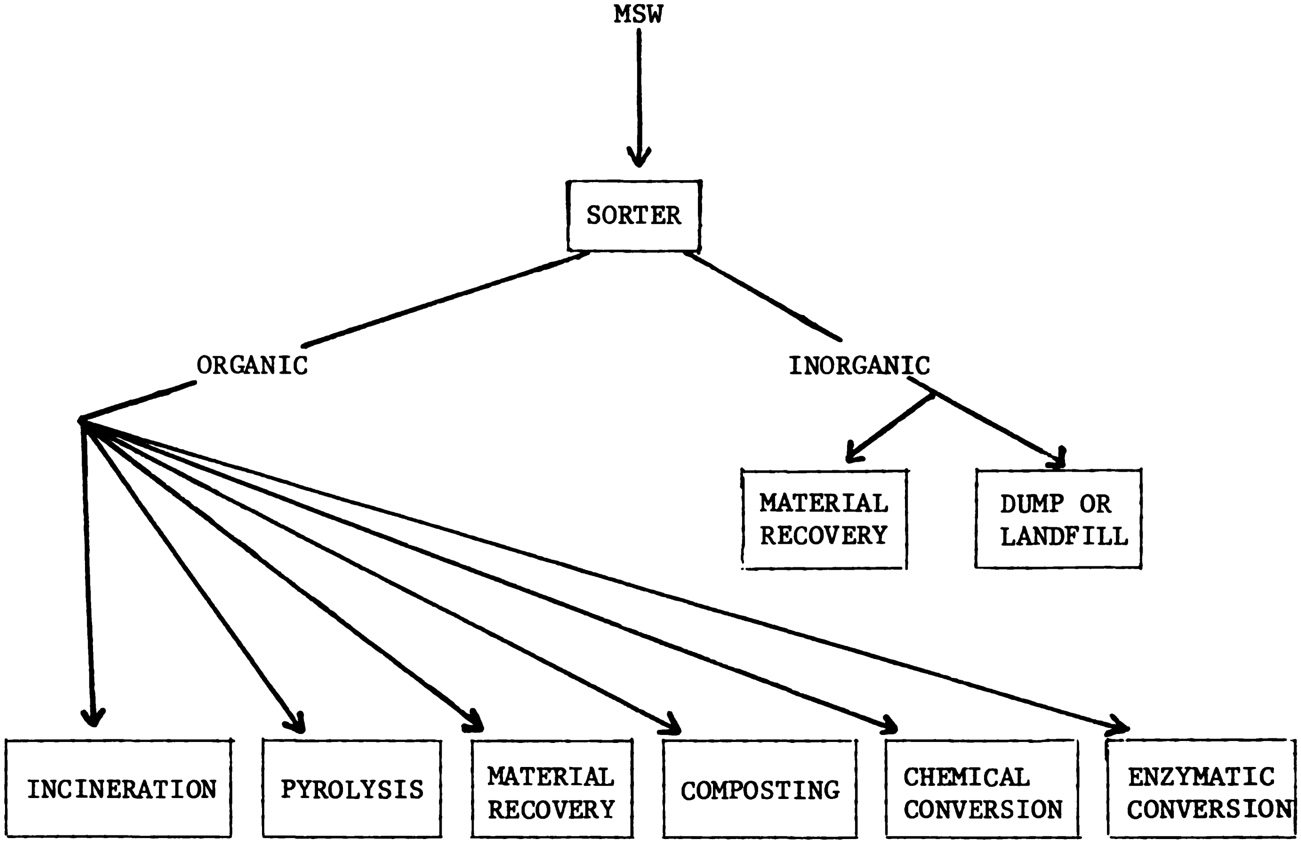
MSW
SORTER
ORGANIC
INORGANIC
MATERIAL RECOVERY
DUMP OR LANDFILL
INCINERATION
PYROLYSIS
MATERIAL RECOVERY
COMPOSTING
CHEMICAL CONVERSION
ENZYMATIC CONVERSION

Figure 4e

Con:

- It requires separate collection systems or redesigned refuse trucks and separate treatment paths which may be uneconomic.
- It can never be 100 percent efficient because many products are complicated mixtures of materials and because 100 percent citizen cooperation cannot be achieved, so that main stream processing plants still have to be designed to handle the complete range of ingredients of MSW, even if the proportions are quite changed.
- Changing the proportions of the ingredients in the MSW main stream may make it more (or less) difficult or economical to practice further resource recovery "down the line" (e.g., removing paper may alter the combustion properties of the waste sufficiently to prevent its subsequent use as a supplementary furnace fuel).

Conclusion:

There is no clear-cut universal case for or against separation at source though, depending on local circumstances, it may well have a place in the overall design of a MSW management system. The principal difficulty is to justify source separation economically.

Compaction of MSW at or near Source

Compaction has been practiced for several decades with automobiles and appliances to make more manageable "packages" for transporting and handling by the secondary metals industry. Refuse trucks are generally fitted with a compacting device and stationary compactors have been developed for use in transfer stations. Recently, small domestic compactors, which produce a particularly dense compact, have come on the market for dealing with mixed household refuse. Compaction and baling of MSW produces a package which is convenient for dumping or landfilling, and is frequently practiced. Pros and cons of compacting MSW before processing are:

Pro:

- The reduced volume of MSW reduces the burden on the collection and transportation system, resulting in, for example, reduced haulage truck flow into and out of the processing center, reduced haulage costs, and increased payload.
- Compacting MSW reduces the demands on space when it is to be dumped or used as landfill.

- Compacted or briquetted refuse possesses a higher energy density than uncompacted refuse, which may be an advantage in certain uses (though before it can be used in incineration it generally has to be cut up again).

Con:

- Compacted refuse can pose weight problems--bundles that are difficult for workers to lift and handle and that overload refuse trucks.
- Compacted refuse generally needs to be broken up again before it can be effectively sorted into its component ingredients.
- Wear and tear on compactors causes a service problem.
- Material recovery from some items (e.g., metal cans) may be made more difficult if they are first passed through a compaction stage.
- The mechanical stability of baled refuse is not always adequate for handling and storage, especially if its moisture content is high and as it decomposes.
- As with unbaled refuse, baled refuse can present a flammability hazard. Though the process occurs more slowly than in unbaled refuse, it too can pose a pollution hazard as it decomposes and a leachate problem in landfills.

Conclusion:

Compacting and baling are attractive for reducing the demands on transportation systems, but this advantage may be offset, somewhat, by the need for shredders and different sorting equipment as with unbaled refuse and by environmental problems.

Collection Systems

Collection systems are common to all MSW management systems. In nearly all systems, refuse is collected from residences, commercial buildings, business premises, and many of the smaller industrial plants by refuse trucks which take it to a dump, landfill site, or processing center. A small amount of household refuse is transported through the sewer system to the sewage plant after having passed through a domestic grinder. Collection systems tend to be labor-intensive and with low productivity as measured by the man-hours required per ton of MSW collected.

In large urban areas, refuse trucks may take the refuse to transfer stations, instead of directly to processing centers, where the refuse is transferred to container trucks or, in some cases, trains or barges. Compaction of the refuse and, sometimes, containerization is practiced to reduce the amount of transportation equipment necessary.

Another method that is being experimented with in Japan and Sweden (and also at Roosevelt, New York) is a vacuum transportation system involving use of pipelines. The system involves vacuum collection of wastes by pipes, compressing them by presses into packed form, and transporting them to a processing plant. The advantages claimed for this system are: (1) avoidance of traffic congestion, (2) no unpleasant odors or noise, (3) immediate and rapid transport to the processing center, and (4) considerable reduction in labor costs. A variation on this approach is to transport the wastes through the pipelines as slurries. The household refuse disposal unit in which refuse is ground and washed by a water stream into the sewage system is a small-scale example of a slurry system.

Some pros and cons concerning collection systems:

Pro:

- Truck systems are simple and can adapt relatively easily to changing MSW patterns in the area served.
- Rail systems are useful when large amounts of MSW have to be transported over relatively long distances, such as when a large region is served by a central processing plant, or when the MSW has to be transported to distant processing, landfill, or dumping sites away from the urban area.
- Fitting selected urban areas with vacuum (or slurry pipeline) waste handling utilities may have many attractive operational and environmental features.

Con:

- The heavy traffic near large processing centers or disposal sites is a major drawback of truck collection systems.
- Rail collection systems are generally confined to existing railroad network patterns, which may not be compatible with the needs of the MSW management system.
- Large vacuum or slurry pipe networks for handling MSW are, at present, a virtually untried, untested technology. Slurry systems pose problems of interfacing with water supplies and effluent treatment. Furthermore, retrofitting would be expensive, disruptive, and time-consuming.

Conclusion:

- The MSW collection network problem has not received sophisticated technological attention in the past. But with the growing need for efficient handling of MSW, including achieving the economies of scale that can be offered by large processing centers, more attention needs to be paid to collection technology. The optional planning of collection routes and schedules can significantly reduce overall labor and collection costs; more operational analysis in this area appears warranted. The concept of a pipeline network serving urban areas as a utility similar to other utilities (water, gas, electricity, telephone) is particularly intriguing and deserves effort to determine whether it is technically and economically feasible.

Homogenizing MSW Through Size Reduction

Homogenizing MSW by shredding, tearing, pulverizing, hammermilling, grinding, and so on plays an important role in many MSW handling schemes. Whether the MSW is destined for disposal sites or recovery centers, homogenization or comminution of it into a "standard" size or a smaller range of piece sizes, is often helpful. It can aid in overall compacting, thus reducing transportation and landfill costs, and it can aid in tailoring a feed-flow to the handling capabilities of recovery equipment. It is claimed to lead to a more sanitary landfill and it transforms MSW into a form more suitable for combustion in incinerators or for pyrolysis. On the other hand, it is not always obvious which, if any, is the best place in the flow scheme for homogenization to be carried out, i.e., at the "front-end," handling all the incoming waste, or after some presorting. Not all items are readily homogenized; rubber tires, for instance. For such items some novel processes may be helpful, such as first freezing with liquid nitrogen so that they can be more easily pulverized into granular form, but these processes are expensive.

Some pros and cons of homogenization techniques for size reduction:

Pro:

- Homogenization helps avoid unnecessary proliferation of types of waste handling machinery. It is also the first step in nearly all material and energy recovery schemes.

Con:

- Homogenizing equipment tends to be very costly and also requires considerable maintenance. In hammermills, for example, the impact edges of the hammers have to be frequently retipped by hard-faced welding or cobalt plasma spraying. When hard and tough materials are involved this may have to be done after every 12 hours or so of operation.

- Certain items in refuse are particularly difficult to deal with, for example, rugs, sheet plastic, explosives, and "tramp" metal--anvils, crankshafts, steel cable, and so on. Such items can damage, cause excessive wear, or clog the homogenizer and special precautions or mechanisms have to be designed so that they can be diverted.

Conclusion:

- Homogenization by size reduction is an essential step in almost all resource recovery schemes, but some of the technical problems, particularly erosion, wear and tear, and methods for dealing with recalcitrant items, as well as the general design of equipment, require much more attention before the process can be regarded as technically and economically satisfactory.

Open Dumping

Practiced since time immemorial, but now outlawed in several states, open dumping is still resorted to in rural areas (and also along highways, railroad right-of-ways, and stream beds). Usually the combustible refuse is openly burned.

Some pros and cons:

Pro:

- Cheapness and simplicity.

Con:

- The rising cost of dump-sites and of transporting MSW to them.
- Fire hazards.
- Air and water pollution hazards associated with raw refuse.
- Public health dangers.
- Aesthetic offense.

Conclusion:

- The use of open dumping is likely to be increasingly prohibited in the future, reinforcing its continuing decline.

Sanitary Landfill

A commonly practiced waste disposal method in urban and suburban areas, sanitary landfilling is an important and, if practiced properly, a moderately satisfactory technique. In this technique, the waste is spread in a layer, compacted by rolling, and covered daily with a layer of soil. However, suitable sites for landfilling are getting harder to find, and consequently more expensive. Nevertheless, the technique is likely to be the most important alternative to resource recovery systems for some time to come.

Some pros and cons:

Pro:

- As with open dumping, sanitary landfilling is relatively simple and usually not expensive, especially in rural areas.
- It can have a beneficial effect in reclaiming land that would otherwise be unsuitable for commercial, residential, or social purposes.

Con:

- The rising cost of suitable landfill sites and of transporting MSW to them as more remote ones have to be used.
- Some landfills are not as sanitary as they should be; decomposing refuse can give rise to pathogens, noxious gases, and methane (though schemes are underway to tap the latter as a useful fuel gas) and leachates are a big problem and difficult to control, leading to contamination of ground water.

Conclusion:

- Some work is needed to find ways of making landfills more sanitary but the principal need where environmental problems arise is to establish better operating and management practices. The potential for recovering material values from old landfills also needs to be carefully evaluated.

Composting

Efforts have often been made to prepare composts for soil conditioning out of the organic components of MSW through natural bacterial activity. Though technical feasibility has been demonstrated and there are one or two operating plants, such schemes have generally not been commercially successful.

Pro:

- Composting is one of the simplest ways of making use of some of the resource value of MSW.
- Economic feasibility of composting might improve, especially in rural areas, as rising cost of energy forces up the price of synthetic soil conditioners.

Con:

- Composting requires the existence of nearby suitable markets.
- Contaminants, such as plastics and, particularly, heavy metals, such as cadmium, lead, and mercury, can make the compost unsuitable for food growing though it may be usable for forests and parks.

Conclusion:

- Perhaps because of the lack at present of an accepted methodology for determining costs versus benefits, composting does not appear a very promising approach for widespread adoption as a resource recovery through waste disposal scheme. However, in view of the possible attractiveness of composting in the long term, more attention to the economics of composting is warranted.

Pre-Treatment Sorting and Separating

A possible first step to resource recovery is to sort the incoming raw refuse as far as possible and to separate out major components ("front-end" sorting). In the past this has been done by hand--"pickers" would take out the various components (cans, cardboard, metal products, bottles, and so on) of the refuse as it passed before them on a conveyor belt. In plants now being developed the handpicking fuction is being replaced by a series of separation stages through which the waste passes. Major objects, particularly heavy metal items, are usually picked out first, after which the refuse may be shredded. Air blower stages are often used to separate light components (paper, plastics, textiles) from heavy ones (bottles, metals, stones); the light and heavy streams then being dealt with separately. Magnetic separation is used for ferrous metal items and strong magnetic fields are being investigated for separating out nonferrous metals as well through the inducing of eddy currents. Water elutriation of the wastes can also be used for separating out organics and the lighter components from the heavier ones, but such approaches, in which everything gets wet, may reduce the subsequent energy return and may lead, for instance, to lower quality of recovered paper.

Electrostatic separators are being studied for separating metals and wet paper (conductors) from organics and plastics (nonconductors). Figure 5 illustrates a comprehensive system being investigated by the United States Bureau of Mines.

Beneficiation-type processes such as the above operate by the use of two opposing forces (usually gravity or inertia) to which at least one of the component particles reacts differently by virtue of its physical or chemical properties. The sensing and picking steps are performed, in essence, simultaneously, by the force field acting on the whole array of waste particles.

Robotic systems to perform refuse sorting, particle by particle, have been experimented with and may increase in capability as the technique of automatic sensing of the shapes of articles and their material compositions becomes more refined and as the associated minicomputer and servo-mechanism systems are developed.

In principle, sensing followed by switching of objects or particles into appropriate hoppers can be achieved in two ways. One is by making successive binary choices until the sorted products of several branches will be sufficiently pure to meet secondary material requirements. The other is the multiple-choice system in which the identified item is switched at one point into one of several hoppers. In both cases the sensing act relies on some basic characteristics or "code" of the object or material being detected. The principal physical characteristics are: magnetic, electrical conductivity, color, optical reflectance at various wavelengths, X-ray absorption, and those conventionally used such as density, drag in an air stream, surface properties (as in ore-beneficiation processes by froth flotation), bounce (hard pieces bounce more than soft ones), and pulping followed by density or other separation. Other physical properties also have been or could be considered for sensing, such as ultra-violet produced fluorescence, X-ray fluorescence generated by high energy electron beams, microwave transmission, spectral analysis of vapor puffs from the refuse particles produced by laser pulses, and mechanical impact transient analysis. More than one sensing effect could be used simultaneously to identify an item more precisely. However, the technical and economic feasibility of these more sophisticated approaches to refuse sorting has yet to be convincingly demonstrated.

In many respects the aim in sorting equipment is to devise a robotic system capable of performing the routine operations that are gone through in hand-picking--the human operator visually senses an object by its shape, size, texture, color, and structure and in his mind instructs his hands to "switch" the object out of the refuse stream into the appropriate hopper. Replacement of human operators by robots for such tasks is an intriguing direction for further automation research. It is an area which requires the combined skills of scientists and engineers from both

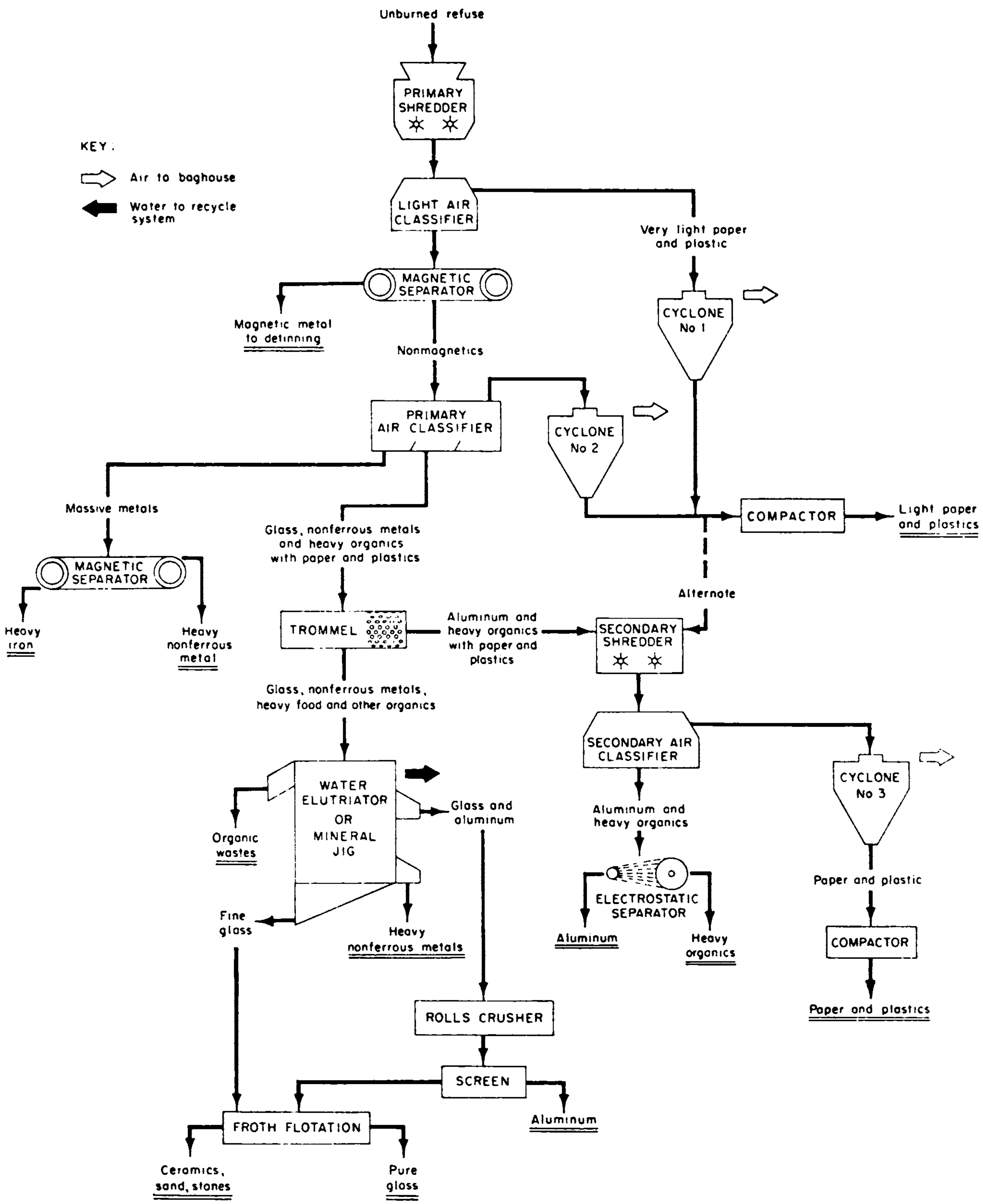

Figure 5 Raw Refuse Separation Flowsheet

Source: U.S.B.M. (1973)

materials and computer disciplines but, repeating the above caution, early payoff cannot be expected.

Sorting and separating increases in value the greater its accuracy and completeness. However, several circumstances pose difficulties at present, even to sophisticated systems. For instance, sorting metal objects made up of both ferrous and nonferrous metals (e.g., beer cans made of tinned steel bodies and aluminum caps); composite materials (often composites of many different materials, "pernicious contraries," as some have termed them); the myriad kinds of alloys and polymeric substances; and sorting colored from uncolored glass.

Some pros and cons concerning sorting systems:

Pro:

- Some degree of sorting is required in all resource recovery systems. The higher the accuracy and completeness of the sorting, the better the market prospects for the recovered materials.
- Sorting is usually a nonpolluting process, though unless care is taken, wet separation systems can lead to water pollution.

Con:

- The more sophisticated the sorting system the more expensive it is likely to be, and hence the greater the need for an assured market for the recovered materials, a factor that will vary with time and with local circumstances.
- Some materials in a refuse stream are very difficult for robots to identify so that sorting cannot be 100 percent efficient. This can result in residual contaminations which can seriously detract from the value of the recovered materials.

Conclusion:

- The relative simplicity and ruggedness of beneficiation-type processes in which the waste particles essentially "sort themselves" by virtue of gravity or intertia, or electro-magnetic field effects, makes robotic approaches seem a remote possibility at best. Nevertheless, some R&D is needed to explore and develop more efficient forms of automatic sorting equipment. Particular attention needs to be paid to some of the more subtle material differentiations, especially among colored glasses, alloys, or polymer varieties, or organic versus light inorganic materials. Composites can provide particularly difficult problems, not only of sorting, but also of liberating their components (e.g., insulation from wire; reinforcing bars from concrete; wire and fiber from rubber tires; fiberglass from plastics; aluminum tops from steel beer cans; plastic and cardboard from laminates).

Incineration and Co-firing

With a higher premium on sites for dumping and landfilling, incineration as a means of reducing the volume of MSW has been widely practiced in Europe for some time. It was a natural step to develop ways of making use of the heat generated rather than allowing it to escape up the chimney, and many incinerators became boilers for producing steam. Commonly, in Europe, the steam is used seasonally in local heating systems, being distributed in insulated pipes in subways up to a few miles. Another, and potentially more important, way of using the steam is to drive turbines which, in turn, drive electricity generators. In this way, for example, Amsterdam supplies 6 percent of its electricity needs.

In the U.S., such schemes for direct burning of combustible components of refuse to release heat and create steam are beginning to make their appearance. The refuse, preferably after removal of the noncombustibles, is used as a supplementary fuel (co-firing) in a conventional fossil-fuel boiler, providing up to 10 percent (more if the furnace is modified) of the total heat input. Usually the refuse has to be homogenized to some extent, for example by shredding, before being fed into the furnace. The feed method can be a moving grate or the shredded refuse can be blown in as an "air suspension." At an average heat content of around 6000 BTU/lb (dry basis) and allowing for an overall generation efficiency of 35 percent, it can be estimated that the combustible portions of MSW in the U.S. could supply as much as 8 percent of the country's electricity needs.

While providing a modest but useful source of energy, the contribution of incineration to reduction in waste volume is major, as shown in Table 5 (which includes other methods of waste disposal for comparison).

There are some problems with refuse incinerators, however. The MSW feed tends to be variable in composition, varying from minute to minute, day to day, seasonally, and from position to position in the furnace; its moisture content can also exhibit wide seasonal variations. All this variability affects the combustion behavior and, in some cases, can cause sufficient reduction in efficiency to more than outweigh the higher price of conventional fuels. Thus, furnaces generally need to be specially designed if MSW is to be any part of the fuel intake, thereby incurring additional capital costs.

Unless special equipment is added, incinerators cause air pollution and/or water pollution if water scrubbing systems are used to cut down the emission of pollutants from the stack. Air and water pollution codes can be effective, depending how diligently they are enforced, in regulating the qualities of these effluents.

At conventional temperatures the noncombustible residues collect mainly as ashes and some slag and metals. High temperature incinerators create rather more slag--oxidized and

TABLE 5

WEIGHT REDUCTION AND DENSITY OF SOLID WASTE

Process	Shredding	Baling	Conventional Incineration	High-Temperature Incineration	High-Temperature Pyrolysis	Sanitary Landfill with Compactor	Sanitary Landfill with Track Dozer
Weight Reduction %	0	0	75	75	75	0	0
Density of Processed Waste (lb/yd^3) in final disposal site	1000	1000	1200	2750	2750	1200	750
Volume of process waste percentage of volume of landfill by track dozer	75	75	16	7	7	63	100

Source: Fife (1973) (Copyright by the American Chemical Society) fused materials. The ashes and slag have to be removed by some means from the incinerator, again occasioning redesigns. In some designs the slag tends to accumulate and reduce efficiency, thereby requiring shut down for cleaning. Refuse incinerators generally require more shut-down time for servicing than do conventional boilers, adding to the capital and operating expenses. The slag produced by high temperature incinerators can be poured out in the molten state and high temperature quenched in a water bath where it breaks up into a sandlike material known as frit. This frit, generally alloyed metal surrounded by a ceramic-like glass, is extremely inert, unlike usual incinerator residues. For the latter no codes yet exist as to the extent of unburned organic or biologically active material that can be left.

Finally, a major technical problem is corrosion. Unlike conventional fuels, which introduce a known and relatively limited chemical variety, that from MSW varies considerably and unpredictably. In addition to the direct corrosive effects of wastes, many wastes and combinations of wastes can react in the combustion chamber to produce further corrosive products which can attack the inside walls and flues of the furnace. One of the most commonly used methods to minimize this corrosion is to coat the exposed surfaces with refractory materials. Another important problem is abrasion.

Summarizing some of the pros and cons of incineration:

Pro:

- Municipal incineration is a long established process (in Europe) with fairly well-known cost and reliability characteristics.
- Incineration considerably reduces the demands for landfill sites.
- Incineration with heat-recovery can make a modest contribution to reducing needs for conventional fossil fuels in utility boilers.

Con:

- Incinerators tend to have a poor public image largely on account of the levels of air pollution that they gave rise to in the past.
- Because of necessary design changes if boilers are to accept MSW as a fuel component and because of the variability of the fuel and the corrosive effects it can produce, incinerators for MSW can present higher capital and operating costs than conventional utility boilers. These costs will be offset, to varying extents, by the cost of the conventional fuel saved or energy recovered, income received from sale of recovered materials, and the saving of a portion of landfill costs.

- The energy recovered by burning materials may be significantly less than the energy that would be saved by recycling the materials as much as practicable.
- The major technical problems appear to be slag build-up, corrosion, and the generation of noxious gases.

Conclusion:

- Incineration in its various forms (incineration alone, incineration with heat recovery, or incineration by using MSW as a co-fuel in a utility boiler) is an important option for reducing the volume of wastes that have to be disposed of and for facilitating the recovery of energy content and materials. R&D needs to be done in the area of corrosion to find structural materials that can withstand attack from the complex array of chemicals present in the incinerator at high temperature, or to evolve concepts to keep structures from contact with these corrosive materials. It is important to note that it is easier to maintain material quality (particularly metals and glass) in recovery from raw refuse than from incinerator residues.

Briquetting for Solid Fuel Recovery

An alternative to using the combustible components directly as fuel in an incinerator is to recover and store the convertible energy content of the MSW by briquetting or pelletizing. After separating out the noncombustibles, the combustibles, usually shredded, are dried and compacted into briquets or pellets. In this form the energy content can be in the range of 6,000 to 7,000 BTU/lb; this solid fuel is clean and can be stored for considerable periods. In rural areas it may also be an attractive option to include in the briquetting process wastes from agricultural, forest, human, and animal sources. On a weight comparison these fuels can be as efficient in steam boilers as pulverized coal and produce, at most, comparable amounts of fly-ash.

Some pros and cons of briquetting:

Pro:

- A relatively clean, conveniently stored solid fuel.

Con:

- Needs an available secondary market; otherwise, it would appear to be an unnecessary step if they are going to be burned in the incinerator or MSW processing plant.

Conclusion:

- Briquetting and pelletizing the combustible fractions of MSW may be attractive alternatives to incineration or pyrolysis provided suitable markets are available. This approach may be particularly appealing in rural areas where operation of large incinerators or pyrolyzers for energy recovery may not be economic.

Pyrolysis

When organic materials are heated in the total or partial absence of oxygen they break down into combinations of gases, liquids, tars, and solids (ashes and char). The relative proportions of these constituents change as the temperature is varied between 500 F and 1500 F, with gas production increasing and liquid production decreasing as the temperature increases. Usually the MSW has to be pulverized or shredded before feeding into the reaction chamber, though at least one process has been shown to work on as-received refuse.

Pyrolysis has been used for years by industry--for example, production of charcoal and methanol from wood and coal gasification. It has the large advantage that, in comparison with incineration, there need be virtually no discharge of pollutants to the environment (though, unless care is taken, waste water may be high in biological oxygen demand). The solids which remain after pyrolysis are inert and can be used for landfill or material recovery, though, as with incineration, recovery of the inert materials is probably accomplished more satisfactorily ahead of the pyrolysis stage.

The liquid fuel produced from pyrolysis has an average heating value of about 12,000 BTU/pound; the low sulphur char has a heating value of about 9,000 BTU/pound. A heating gas, 600 BTU/cubic foot, can also be produced. Some of these fuel products can be used on-site to provide the heat for the pyrolyzer.

A high temperature enclosed pyrolysis process to produce oil and fuel gas has been developed by Union Carbide (see Appendix B. VI) in which raw refuse is fed into the top of the chamber and oxygen at the bottom. Figures are given in Tables 6 and 7 for the product streams from the furnace.

TABLE 6

PRODUCTS FROM UNION CARBIDE PYROLYSIS PROCESS

Product	Wt %
Molten residue (metal and glass, mainly)	15-20
Dry gas	40-45
Water vapor and water-soluble organics	35-40
Oil	5

The molten inorganic residue flows out of the bottom of the furnace and is quenched to form a frit or slag. The major components of this slag are given in Table 7.

TABLE 7

COMPONENTS OF SLAG PRODUCED BY UNION CARBIDE PYROLYSIS PROCESS

Component	Wt/%
Oxides of iron	9.7
Manganese oxide	0.6
Glass	53.0
Calcium oxide	11.5
Aluminum oxide	7.7
Titanium oxide	0.1

The total energy recovered from the process is about four times that required to run it.

Some pros and cons of pyrolysis:

Pro:

- Pyrolysis can be environmentally clean, especially when compared with incineration.
- It accepts a wide variety of input materials.
- It can provide a quite high efficiency of recovery of both energy and material values.
- It can produce clean-burning fuel gases and liquids (a form convenient for shipping and marketing) and sterile, compact residues.
- The frit from high temperature slagging pyrolyzers, as with slagging incinerators, might find some markets in construction and building materials.
- Processes are being developed for handling raw as well as shredded or pulverized wastes. Also, pyrolysis is a continuous rather than a batch process.
- Pyrolysis, like incineration and some other processes, offers economies of scale and is compatible with the concept of

industrial symbiosis between the resource recovery operation and local markets for the recovered values.

- The potential public acceptability of pyrolysis plants appears generally much higher than for incinerators.

Con:

- Low temperature pyrolysis plants produce residues which may not be completely sterile and also produce some pollutant emission, though these problems can be dealt with.
- Although pyrolysis systems offer a greater range of potentially marketable by-products than do incinerator systems, the true value of these products will vary with their location and distance from the market.
- Corrosion problems inside the pyrolysis chamber are severe.
- Pyrolytic fuels tend to be unstable against long-term storage.
- Recovery of material values from quenched slags is especially difficult and costly.

Conclusion:

- Pyrolysis, particularly <u>after</u> separation of the metals and glass, appears to be an important option for maximizing resource recovery and minimizing the amount of residue that must be disposed of. Its economic value, however, depends on the local availability of markets for its fuel products and for the slag or the material components. Technical feasibility appears promising though more information will need to be gathered on operating costs and reliability. As with incinerators, there is need for particular attention to corrosion and abrasion problems and possible hazardous products of chemical reactions involving unexpected, unusual components in the waste stream.

Material Recovery from Incinerator and Pyrolyzer Residues

As noted above, incinerators and pyrolysis plants separate out the noncombustible metals and glass in the form of residue with high ash content, or slags. The USBM has been addressing the problem of how to reclaim the metal and mineral values contained in non-slagging incinerator residues. By adapting various standard mineral beneficiation techniques, separations have been achieved for the ferrous metal fractions, aluminum and copper-zinc scrap, a glass cullet, and a magnetic ash fraction. The recovery of metals from slags does not appear to have received much attention yet, though it is likely to be unattractive because of the compositional complexity and impurity content of slags. An alternative that has received and perhaps deserves more attention is to find ways of incorporating slags in construction materials (e.g., cinder blocks).

Some pros and cons:

Pro:

- If furnace residue separation can be practiced, the metal and glass value can be recovered and the volume of residue ultimately destined for landfill further reduced.

Con:

- Mixed metals recovered from the molten residues of high temperature incinerators and pyrolysis are of very little value.
- Incinerated (or pyrolyzed) ferrous residue has no value to detinners (while it has less value than unburned scrap, it can be used by steel markets).

Conclusion:

- Both efficient materials recovery techniques for incinerator residues and available markets for the recovered metals and glass are essential if materials recovery from MSW is to be practiced. Otherwise, disposing of the immediate residues in landfill is the necessary procedure in most cases. Whenever possible, inorganic material recovery should be done ahead of the combustion stage.

Chemical Conversion

Another alternative for handling the organic and carbonaceous fractions of MSW is to convert as much of them as possible directly into useful products by chemical means. Various processes have been proposed or are under study for converting these organic wastes to sugars, ethanol, methane, and so forth. For example, cellulosic solids (paper and wood wastes) can be converted to carbon monoxide and hydrogen by partial combustion with oxygen and steam. This gas can be used as a medium heat-content fuel gas or it can be converted to methanol using available technology.

Another process that has been proposed is to hydrolyze the organic wastes to produce fermentable sugars and, subsequently, ethanol. In this process the organic fraction is pulped in water and reacted with sulfuric acid at a temperature of about 230 C. A high degree of conversion to fermentable sugar is estimated to take only a few minutes. Subsequently, after cooling, neutralization with calcium carbonate, further fermention, and finally distillation, ethanol results. Alternatively, sugars can be used as a feedstock in other processes leading to other products, such as yeast.

Some pros and cons:

Pro:

- In principle, chemical conversion offers opportunities of synthesizing a number of useful fuels and chemicals out of organic wastes.
- It is amenable to treating not only MSW but also agricultural, animal, forest, and human wastes.

Con:

- The complete technical feasibility of most of these processes has not yet been demonstrated.

Conclusion:

- The options that chemical conversion can potentially offer make such processes well worth investigating. Research on, and pilot plant testing of, various chemical conversion processes for organic wastes should be supported with the aim of determining the range of products that can be so produced from MSW, and the costs of applying these processes to large volumes of waste.

Enzymatic Conversion

Organic wastes can be converted into useful basic chemicals by enzymatic processes. Work at U.S. Army laboratories (Natick, Massachusetts) has shown that cellulose (e.g., paper) can be converted to glucose in a process that operates at 50 C and atmospheric pressure (see Appendix B. VI). The key is the efficient development of high quality, cellulose-specific enzymes. The glucose product can subsequently be converted to other chemical raw materials, single-cell proteins, fuels, solvents, and chemical antibodies. Apparently, while specific to cellulose, the enzymes are not affected by the kind of cellulose processed, for example, straw, peanuts, newspapers, or mixed paper wastes. In the case of newspapers, about 70 percent of the bulk is available cellulose and bulk reduction to glucose of more than 50 percent has been reported. However, the efficiency of the enzymatic process can be hampered by certain impurities.

In a different process (bacterial), the carbonaceous fractions of MSW are blended with sewage sludge into an aqueous slurry which then undergoes anaerobic digestion in a stirred reaction vessel at 60 C. At that temperature complete digestion requires about five days. The gas products are 50 to 60 percent methane and 40 to 50 percent carbon dioxide. The spent sludges, after removal and dewatering, could be used for soil conditioner. However, the resulting volume remains relatively high, about 50 percent of original volume, making disposal a problem if there is no agricultural market.

Some pros and cons:

Pro:

- Enzymatic conversion of carbonaceous and cellulosic wastes to fuel gases or glucose and other materials appears an attractive option for resource recovery.
- Microbes work around-the-clock and are self-generating.
- Beyond treating MSW, enzymatic conversion may prove attractive for dealing directly with wood wastes, or even to use wood as a primary feedstock for important chemicals.

Con:

- The process is still relatively untried beyond the demonstration of technical feasibility in the laboratory.
- The process may be slow, requiring large facilities.

Conclusion:

- Enzymatic conversion processes, both in the laboratory and in pilot-plant versions, warrant intensive investigation as a potentially important means for recovering energy and material values from organic wastes. It is too early at present to assess accurately the economics of such processes, but they would appear to have the potential of low cost, requiring no heat or energy inputs or corrosion-resistant containers.

PROBLEMS CONCERNING PARTICULAR CLASSES OF MATERIALS

Reclamation of Paper

By weight or volume, paper is the major constituent of MSW. If kept sufficiently clean and free from contaminants it is technically possible to recycle it so that it may be used as an extender in its original use. For example, telephone directories, if kept separate from the general waste stream, can yield a pulp which is largely suitable for reuse in directories; newspapers can be recycled to newsprint provided "de-inkable" inks are used. More often, though, a wide variety of papers enter the general MSW stream where it is then impossible to separate out and sort the various grades. Instead, these mixed papers may be separated as a group. This segregated, shredded mixed paper can be dried and marketed as a dry fiber extender, used in the manufacture of roofing felt, or pulped and marketed as a secondary pulp as an extender for primary pulps in the manufacture of various grades of cardboard and building paper.

Of course, if the paper content of the general waste stream is removed for recycling to some form or grade of paper, it is no longer available for use in combustion, pyrolysis, or chemical conversion processes. Thus, for example, recycling paper may reduce demands for virgin forest materials but the paper cannot then contribute directly to lessening the demand for primary fuels. Also, removing the paper from the waste stream may leave the residual waste unsuitable for incineration, for example, and might then increase the need for landfill sites over what it would have been if the paper had been left in. Such trade-offs point up the need for the determination and widespread understanding of national priorities concerning energy and raw materials and also the need for the overall systems approach to resource recovery so as to optimize the whole process. However, analysis of the comparative energy balance of recycling versus incineration suggests a decision in favor of the former, if net energy expenditure is the dominant consideration.

Some of the more important factors to be considered in recycling paper are: collection arrangements; sources of contamination; the logistics of transporting secondary versus primary supplies to paper mills; and the markets for recovered paper. A successful experiment in recycling paper from commercial sources is described in Appendix B. VIII.

Recycling paper to its original use, or a closely related one, clearly calls for keeping the paper out of the general waste stream by maintaining separate collection systems and separate processing lines. An increasing number of communities are doing just this by arranging for separation at source by householders and commercial generators of waste paper. The incentives for citizen participation are usually moral, though these can be reinforced by cost penalties on unsegregated refuse and other measures; it may not be necessary to go to the extreme found in Sweden (see Appendix A. V) where the paper is regarded somewhat as national property and not to segregate it is a civil offense. (Even in Japan, where no such penalties exist, the recycling rate is two to three times that in the United States.) It is difficult to keep all unwanted materials <u>completely</u> out of the segregated paper; small amounts of paper clips, staples, rubber bands, polyethylene wrappers, nonsoluble adhesives, and so on, can interfere with successful recycling of acceptable qualities of paper.

While the above contaminants can be minimal in the segregated waste they are often serious problems in the mixed waste stream. They can include wire, paper-plastic laminates, some coatings used for paper, pressure and heat sensitive adhesives, nonsoluble inks, and various polymeric materials. Such contaminants, together with the effects of various chemicals and dirt, usually seriously degrade the quality of recycled paper, limiting its suitability to building and construction papers only. However, it is worth noting that in the Netherlands, lacking natural resources for paper, the recycling of paper from mixed wastes is receiving close attention.

Provided it is not too contaminated, mixed paper (as well as segregated paper) can be made into secondary pulp that can be used to extend primary pulp. There are some problems, however: usually more machinery is needed to handle secondary pulp, than virgin pulp, and furthermore, paper pulp mills are usually located near forest sources of virgin materials rather than near cities where the waste is generated. This involves added machinery and transport costs.

Mixed papers, or pulps derived therefrom, generally have poor markets. Some of this stems from the variability of the input waste and consequent variability of the properties of the recycled paper. Another marketing uncertainty is the price of materials from virgin sources; these tend to reflect marketing practices in Canada and are therefore outside the control of the domestic paper industries.

Some pros and cons of paper recycling:

Pro:

- Provided that source and treatment stream separation is practiced, many grades of paper can be successfully recycled to their original use.
- Recycling is an optimal practice insofar as energy balance is concerned.
- Recycling eases the burden on prime sources of raw materials for paper and reduces pollution and energy consumption.
- Mixed papers can be recycled to lower grades of paper for which suitable uses can often be found.

Con:

- Maintaining separate waste streams can be costly or impractical.
- Removing the paper for recycling may leave the waste stream unsuitable for certain energy and resource recovery processes.
- Contamination of the paper, in use, during collection, and during processing, is a major problem hindering restoration to grades approaching the original ones.
- Difficult separation problems are posed by certain composites and combinations of paper with other materials.
- Information is somewhat lacking on the properties and grades of recovered papers, thereby hindering marketing.

- The market for recycled paper is vulnerable to price variations of virgin materials.

Conclusion:

- When waste paper is kept separate from the main waste stream, recycling is often economical, particularly for newsprint. Prospects for mixed paper wastes are much less certain, reflecting quality variations and a wide variety of marketing factors. In many cases it may be more economical to use it for incineration, pyrolysis, or chemical conversion. The main technical problem in paper recycling is to avoid or eliminate contamination; others include finding ways to reduce segregation and collection costs and developing applications for recovered, degraded paper, particularly in building and construction materials--roofing, insulation, acoustic tile, particle board, and others.

Recycling of Metals

Metals have long been a prime object in recycling schemes, reflecting their relatively high value per unit weight and volume and physical characteristics that make them comparatively easy to separate from the other components of the waste stream. Large metal objects are often identified and manually taken out of the waste stream. The remaining metals can usually be separated readily into their magnetic and nonmagnetic fractions. A major problem with magnetic separation is contamination of the magnetic, ferrous, fraction by nonmagnetic pieces attached or clinging to the ferrous metals. The separated ferrous fraction is usually acceptable for use in the copper industry in chemical exchange processes and for use by the steel industry. Detinning makes the ferrous materials a prime charge for steelmaking. However, detinning and other decontamination and purification processes become much more difficult and costly, if not impossible, if the waste metal has been subjected to heat in an incinerator or pyrolyzer.

Contamination of scrap metal is by far the biggest technical problem, since relatively small amounts of alloying elements can drastically alter the properties of the major metal. Most product manufacturers rigidly specify the metal quality to be used in the product, and meeting these specifications with recovered metals is often not possible or economical. There is much scope for improved physical and chemical methods for purifying and refining recovered metals, e.g., removing lead and bismuth (originating in solders) from tin; removing zinc, tin, and copper from iron; and removing zinc, tin, and copper from aluminum.

As has been foreseen by the American Society for Testing and Materials, for example, there is a general need to develop better standards and specifications for metals recovered from MSW; for both foundrymen and manufacturers, use-oriented specifications, such as for detinning operations, iron foundries, steelmaking, nonferrous metal fabricators, and for concrete reinforcement, would be particularly helpful. In the absence of these, secondary metal processors are likely to play it safe by insisting on the higher grades of scrap quality. Labelling and tagging schemes for recycled metals, indicating their contamination content, have been considered but it would seem that a generally practical scheme of this sort has not yet been found. An additional complication in specifying scrap quality may be expected to occur increasingly in the future when metal has already been recycled several times, picking up more contaminating alloying elements each time.

A solution frequently sought for marketing recycled metals is a cascade of uses of successively decreasing sensitivity to metal composition, especially impurity content. One end-use frequently suggested, and practiced, is as reinforcing bars in concrete, but even here there are instances where a plant making such bars across the street from a metals recovery plant would not accept the recovered metals at any price.

Material recovery is never worthwhile unless there are markets for the recovered materials. Whether such markets are available will depend very much on local factors. It is necessary to be assured in some way of a suitable market in planning a metal recovery system. But even if such a market exists it may fluctuate in its capacity to absorb the recovered metals just as the supply of the latter can fluctuate reflecting seasonal and other variations. This suggests an opportunity and need for greater stockpiling of recovered metals, to smooth out the short-term fluctuating imbalances between the supply of recovered metals and the demand for them as well as for helping to provide a national strategic reserve. Stockpiling has generally been thought of in connection with the more valuable strategic and exotic metals, of which only relatively small amounts appear in MSW; the stockpiling envisioned here would have somewhat different though equally vital objectives.

Some pros and cons of metal recycling from MSW:

Pro:

- Metals (along with energy) are the most valuable component in MSW, the recovery of which can ease slightly the burden on primary sources.
- Considering the metallurgical processing alone and not including transport, the energy required to recycle metals is always less than that required to produce primary metals; likewise, the environmental impact is usually much reduced. These energy differentials are particularly notable with aluminum.
- Markets can usually be found for secondary metals.

Con:

- The composition specifications of metals recovered from MSW can be difficult to maintain at an acceptable level owing to the variability of the input stream; this adversely affects the marketability of the recovered metals.

Conclusion:

- Metal recovery is a major objective in any waste handling scheme but better ways need to be found to monitor, specify, separate, upgrade, and purify the composition of recovered metals so that they can be matched to an array of suitable markets of varying degrees of criticality. At the same time, product manufacturers should seek opportunities to specify their needs for materials in terms of performance rather than composition. The design of metal recovery systems should not be undertaken without due regard to markets, usually local ones, and where appropriate, stockpiling initiatives, by either the private sector or the federal government, should be considered.

Recycling of Glass

As with newspaper, the public has long been interested in the recycling possibilities for glass, a major component by weight or volume of MSW. The separate collection of glass bottles for reuse was a traditional practice until recent times when retailers turned towards nonreturnable bottles because of their convenience and economic attractions. A major problem in bottle reuse is the variety of manufacturer-specific bottles necessitating many separate return paths. Bottle standardization could help enormously--this is being pursued, for example, in Denmark. The rising cost of virgin glass, reflecting in part the rising costs of energy used for making the glass, may swing future emphasis more in favor of reusing and recycling glass.

Basically there are three types of recovered glass: (1) glass artifacts, mainly bottles, for cleaning and reuse; (2) broken glass for use as cullet, for reuse in bottlemaking; and (3) crushed glass which may be used as aggregate in construction materials.

Whether collecting glass bottles for reuse is economically practical will depend on local factors, but when practiced, obviously, the glass does not enter the general waste stream. This can affect the average composition and value of the remaining glass that does do so, i.e., the quality of the cullet derived from the waste stream can be affected, and adversely, by separating out the bottles in the first place. Again, this is where an overall systems evaluation is needed to determine the optimum waste handling scheme.

Glass that enters the general waste stream must be thoroughly separated from the rest of the waste stream for it to be useful as cullet. Separation is never perfect; but the more the glass is free from contamination, the greater is its value. After segregation of the glass, usually broken in prior shredding or hammermilling processes, there is usually the need to color-sort the pieces--this mainly reflects manufacturer reluctance to produce, and consumer reluctance to accept, glass of varying colors, even if other physical requirements of the glass products are met. Color-sorting is often practiced at source, calling for separate handling streams thereafter, but it is much more difficult to do in the general waste stream. Research and development work is going on aimed at achieving practical, economic color-sorting machines, but while the problem looks technically solvable, the solutions have so far generally proved too expensive in relation to the low value of recovered glass. Particular problems concern the variation in size and shape of the glass pieces, as well as a practical method of interrogating the glass based on its optical or related physical properties. Dirt and contamination can also interfere with the sorting process by generating spurious signals. Automatic sorters usually channel the identified pieces into various paths using air pressure--this again sets upper and lower limits on the range of particle sizes that can be accepted by the machine. Methods of crushing or pulverizing glass that result in greater uniformity of particle size are obviously to be preferred over those which result in a range from powdery dust to jagged shards.

An alternative to sorting by individual color is to interrogate the glass stream with the aim of recording and specifying its color content. If suitable grading systems for mixed colored glass can be developed, such a procedure could be much cheaper than actual sorting, but there is uncertainty over whether an adequate market will exist for this glass.

Contamination of the glass intended for use as cullet is perhaps the biggest technical problem. The broken glass should be washed clean and kept dirt-free during the separation procedures. Organic contaminants such as paper, rubber, and plastics must be removed; so must metals such as iron, aluminum, and chromium; and likewise, ceramic materials such as stones, earthenware, and so on. Besides affecting the color, failure to keep undesirable materials down to the extremely low permissible maximum levels can introduce air bubbles, separate phases and precipitates (termed "stones") which seriously degrade the quality and performance of the glass subsequently prepared from remelting.

Key to the success of glass recovery schemes, as with other materials, is having suitable markets. Hitherto the acceptance standards for cullet set by bottle manufacturers, reflecting traditions with cullet from virgin sources (as home scrap), have tended to be too difficult to meet for secondary cullet; finding acceptable ways of lowering these standards and of mixing secondary with primary cullets is clearly desirable and the industry, together with the American Society for Testing and Materials (ASTM), is moving in that direction. However, for recovered cullet which does not meet current or new standards because of its composition or size distribution, effort to find secondary uses is necessary. One alternative would appear to be for the manufacture of glass bricks and fiber insulation. Also, after further crushing, if necessary, use as aggregate in building and paving materials is often considered. However, in such applications the material must compete with low cost aggregates such as sand. Whether it can compete economically will depend on local circumstances.

Summarizing, some pros and cons:

Pro:

- Glass recovery will become increasingly attractive as the cost of the energy required to produce virgin glass increases.
- Certain glass items, particularly bottles, are relatively easy to separate at source.
- Some markets can be developed for mixed as well as uniform cullet.

Con:

- Recovery processes have to be exceedingly economical for recovered glass to compete with virgin sources.
- There are severe technical problems facing the development of economical color sorters and keeping contamination levels sufficiently low.

Conclusion:

- Continued efforts to increase the recycling of glass are needed, focusing mainly on improving the sorting and decontaminating efficiencies of broken glass in MSW and, at the same time, on developing suitable uses for glass made from mixed cullet. Industry standards need to be modified, where possible, to accept secondary cullet, and public education is needed regarding the acceptability of, and need for, recycled glass materials.

Recycling of Plastics

Plastics are a small but growing component of MSW. The major types of plastic found in MSW are polyolefins, styrenes, and polyvinylchlorides. There is also a wide variety of small amounts of specialty plastics. In contrast to the recovery of metals, paper, and glass, the recovery of plastics is still in its infancy and there are many severe technical problems that need to be addressed. Once in the general waste stream, many varieties of plastics become mixed together and they are also vulnerable to contamination. Some of the major classes of plastics can be separated because of their density differences, but efficient sorting can be made difficult by the subtly diverse differences between various plastics. To date there has been negligible recovery of plastics from MSW for recycling and reuse and, in contrast to metals, there is no secondary plastics industry. Instead, the plastics industry has so far been heavily oriented towards virgin materials. On the other hand, industrial in-house recycling of plastics is increasingly practical and can be efficient--an important factor is the control that can be exercised over plastic composition in-house.

Plastics come in a wide variety of forms (structures, containers, sheets, and films) and compositions, making efficient separation all the more difficult to achieve. Proposals have been made for "tagging" polymeric molecules so that sensors can recognize them through a particular physical property (optical, magnetic, electrical conductivity, among others) so imparted, but no really satisfactory way of doing this has yet been achieved, nor is it clear that it can be.

The principal decision with regard to plastics in MSW is whether to recover them, to use them in incinerators as fuels, to pyrolyze them, or to chemical convert them. So far the latter paths have been followed. The heat content of plastics is high, making them relatively attractive as supplementary fuels. They also are amenable to the production of gaseous and liquid fuels by pyrolysis, and to other chemical conversion processes, such as hydrolysis to monomers and other basic chemicals. As with paper, removal of plastics from the waste stream for recycling and reuse may make the residual waste stream less suitable for incineration or pyrolysis--again, the trade-offs have to be considered.

Plastics, especially PVC, have a reputation of releasing corrosive acids such as hydrochloric acid and other chemical substances during incineration, though there is evidence that with proper furnace design and with careful monitoring of the composition of the waste stream many of these corrosive products can be neutralized and held in the incinerator or pyrolyzer residue. A further problem is the release of toxic substances, such as those used as flame retardants and stabilizers.

As with other recovered materials, mixed plastics have difficulty finding markets because of uncertainty over their composition and properties (as well as uncertainty over steadiness of supply). Again, industrially-acceptable standards for mixed recovered plastics are needed. New applications need to be explored for secondary plastics--often they might be suitable as fillers or for use in noncritical applications.

Summarizing the principal pros and cons:

Pro:

- Recycling, incinerating, pyrolyzing, or chemically converting plastics can have a growing beneficial, though slight, effect on needs for petroleum.

Con:

- There is as yet little market for recycled plastics.
- The release of corrosive and toxic substances during incineration or pyrolysis can be a serious problem.
- The technical and economic feasibility of recycling processes for various kinds of plastics has yet to be demonstrated.

Conclusion:

- For the short- to medium-term at least, incineration, pyrolysis, or chemical conversion appear more practical than recycling plastics for reuse. For reuse to become viable, better separation and recovery processes are needed, new market applications must be developed, and standards arrived at for recovered materials. There is an opportunity for the plastics industry to undertake an investigation, perhaps in collaboration with ASTM and similar organizations, of which plastics should or should not be permitted to enter the waste stream in the first place because of their adverse chemical or toxic effects in waste management processes.

RECURRING THEMES

In the above sections, many themes have tended to recur, implicitly or explicitly. These include:

the control of quantity and composition of MSW for RR
hazards and environmental problems associated with RR
research and development needs associated with RR
standards for secondary materials
markets and uses for secondary materials.

Further comments on these topics follow. A sixth topic:

resource recovery systems optimization

will be dealt with at more length in the next chapter.

The Control of Quantity and Composition of MSW for RR

Much attention is being paid to measures that might effect a reduction in the volume and throughput of MSW in order to reduce demands for landfill sites and reduce demands on the environment, energy, and virgin materials. Measures are also being contemplated that would regulate the composition of MSW with the principal aim of facilitating energy and material recovery.

The intent behind these efforts is laudable, but much care will have to be exercised to ensure that regulatory measures are not so restrictive, or so ill-conceived that they end up doing, overall, more harm than good. It is relevant and necessary, for example, for standards to be set (as they are being) and adhered to governing dumping and landfilling operations; overall air, water, and aesthetic pollution; and control of toxic or hazardous substances. But existing standards, focused primarily on the environmental sector, provide little incentive to return waste products and materials to the economic sector. Such standards, if wisely and shrewdly designed, can provide encouragement and incentives to the economic sector to exercise ingenuity and imagination to provide society with the desired standard of living while minimizing the accumulation of waste. But much care has to be exercised in designing these standards or guidelines when dealing with such matters as product durability, material composition of products, size of packaging, and so on. Otherwise, the objective of resource conservation may be served only at unacceptable economic and social cost. Maximum scope and flexibility must be left to the economic sector to adapt internally to changing boundary conditions and constraints such as overall pollution standards, the terms of international trade, the availability of energy, and the general state of the economy. For example, if there is concern over depletion of the forests by the wood and paper industries, it might be more satisfactory to seek conservation standards for the forests rather than, as might be proposed, detailed regulations concerning the quality and quantity of wood used in a vast variety of products and structures. If there is concern over the environmental impact of mine wastes, standards might be set for dealing with these wastes rather than regulate the related material content of products. If there is concern over the growth of landfill sites, consideration might be given to setting appropriate standards and conditions that have to be met if such a waste disposal course is followed. In every case the costs of meeting these resource and environmental boundary conditions will be passed on to producers and consumers, as is necessary, but in ways which are relatively equitable and which still leave maximum scope for maneuvering and choice by the economic sector--both product manufacturers and individual citizen-consumers.

Increasing costs provide natural feedback mechanisms. Supply shortages cause prices of virgin materials to rise. This encourages both economy in the use of the material on the part of product manufacturers and recovery of the material from various secondary sources. But the manufacturer is still left free to use the material where, using the best of engineering and economic judgment, there is no satisfactory alternative. Regulation which would deny this freedom could cause serious harm to an industrial sector vital to society.

But while over-regulation must be resisted there is nevertheless need for the development of guidelines for product manufacturers reflecting environmental and resource recovery pressures. These guidelines, which various industrial associations are already pursuing, need to be developed cooperatively between industry and government. There is a need for mutual agreement, for example, on which materials are likely to be most critical in the future and on tactics to head off supply-demand strains. Regarding the handling of MSW, such guidelines might pertain to certain materials which are difficult or costly (e.g., in energy) to recover, combinations of materials that are inherently difficult to separate, product designs that hamper material recovery, and materials that would prove dangerously toxic in RR processes. Ultimately, however, we foresee that as the resource recovery sector grows and matures it will be able to communicate more directly with manufacturing industry with the aim of symbiotically coordinating and optimizing product manufacture and resource recovery.

Hazards and Environmental Problems Associated with RR

Practicing RR from MSW diminishes the air, water, and aesthetic pollution consequences of dumping, open burning, or not quite sanitary landfilling. On the other hand, some of the processes used in RR can themselves produce pollution. Sorters can create dust problems; incinerators produce air pollutants unless these are removed from the flue-stack, for example, by water-scrubbers. But the latter only transfer the pollutant to the water which then has to be treated to meet effluent standards. As a result, the original pollutant often ends up as a sludge which, when dried, has to be disposed of. No matter how effective the RR process, there will always be some residue that has to be dumped or used as landfill; regulations concerning dumping and landfilling, while protecting against health hazards and other dangers, must not be so restrictive as to vitiate the RR process.

A topic that needs considerably more attention than it has so far received is the generation of pathogens--biologically active and harmful substances. Opportunities for the generation of these pathogens abound whenever refuse is concentrated and/or allowed to accumulate, particularly where large quantities of organic and food wastes are involved. Refuse workers are most immediately exposed to these dangers, which can result in disease, and their problems merit special attention. Steps also need to be taken to ensure that harmful quantities of these pathogens are not released to the general environment. The pathogen which causes foot and mouth disease is a case in point, where the need for stringent measures to avoid dispersal is generally recognized.

Safety and health standards are necessary regarding toxic or dangerous substances that might be produced as by-products of RR processes. Besides hydrochloric and sulfuric acids, chlorine gas and fluorine compounds which can result from incineration and pyrolysis, it is not inconceivable that other noxious substances, cyanides and certain heavy metals for example, might be produced depending on the operating conditions and the nature of the input waste stream (more analytical work is needed in this area). Where such eventualities can be foreseen it is appropriate to consider control over the MSW input, preferably through presorting and separating technology whenever possible, but by regulation if not.

The introduction of certain hazardous substances and products into the resource recovery operation has to be guarded against. Such items include ammunition, explosives, some poisons, insecticides, and corrosives. If separate treatment and disposal cannot be provided for these items, it may even be necessary, in extreme situations, to prohibit some products or substances from manufacture.

Large MSW handling plants, with conveyor belts, shredders, hoppers, chutes, cyclone separators, and so on, tend to be noisy; noise suppression in the design and operation of machinery needs attention. While not peculiar to the transport of MSW, the noise associated with heavy truck traffic is an ever-present problem.

Research and Development Needs Associated with RR

In previous sections, several R&D needs have been identified but there are some that are sufficiently critical, or general in their importance, to warrant further emphasis. These include: (1) mechanical erosion, wear and tear, (2) corrosion, (3) efficient sorting by physical means, and (4) new and improved chemical separation processes.

Machinery for transporting, conveying, shredding, pulverizing, and other such operations with MSW is subject to heavy stresses, particularly when "indigestible" objects get into the waste stream. Equipment maintenance and durability is a major factor that can affect the efficient operation of a plant. Down-time has to be kept to a minimum. Stopping the flow in one place can jeopardize the proper functioning of RR processes further down the line, e.g., at pyrolyzers or furnaces. R&D aimed at reducing erosion, wear and tear problems in all parts of MSW handling plants is of high importance. Improvements gained in this area would also be relevant to many other industrial and materials handling operations.

Chemical damage due to corrosion, like physical damage, also requires determined R&D effort. Corrosion is particularly troublesome in incinerators and pyrolyzers because of the high temperatures and the variety of corrosive substances that can be liberated from mixed waste.

Efficient sorting of MSW is often crucial to the economic success of an RR operation. While there is already substantial effort in this area, there is scope for improvement. It is particularly important to find simple, efficient ways to improve the automation of these operations with an acceptable upper limit to the frequency of errors. In view of the wide range of characteristics, and combinations of characteristics, physical and chemical, of objects and materials in the waste stream that might be considered for identification and action purposes, there is felt to be much scope yet for improving sorting technology. Collaboration of materials scientists and engineers with computer scientists and engineers can be expected to be particularly fruitful in this area. Work should also be pursued on finding simple aids to sorting by "tagging" materials or product compositions.

Chemical separation processes are likely to become increasingly important. Besides direct chemical conversion of wastes to useful products (fuels and basic chemicals), improved ways need to be found for separating alloys and mixed metals into their constituent elemental materials.

Plastics pose particularly subtle and diverse problems calling for exploration of various chemical approaches for converting and separating them. Effort should also be addressed to evolving plastic compositions which are amenable to recycling and resource recovery. More efficient methods of depolymerizing polymers bear study, as do the biodegradability and photodegradability of plastics. The development of processes to deal with plastics is often hampered by proprietary rights withholding data and information on plastic compositions. Composites of various plastics, or plastics with other materials, often pose severe challenges for materials recovery. Another example of the complexities introduced by plastics is the parallel push to find ways of making plastics less flammable--can nonflammable plastics be compatible with resource recovery processes? In sum, there is more scope and need for technological developments for dealing with plastics than for any other classes of material.

Standards for Secondary Materials

A universally-felt need is for industrially acceptable standards describing the composition, quality, and properties of reclaimed materials whether they be paper, pulp, metals, alloys, glass, cullet, plastics, fuels, chemicals, or biological materials. Among these materials there is considerable variation in the degree to which standards have been developed. While the value of reclaimed materials increases with purity and homogeneity, the key to the usefulness of these materials is often the ability to guarantee a reproducible quality. And standards for metals, for example, will become all the more important as recovery volume increases and becomes a bigger percentage of foundry intakes. This emphasizes the need for improved material quality monitoring and control techniques and equipment. This equipment will generally have to be relatively sophisticated because the performance of materials in devices and structures is almost invariably sensitive to minute amounts of additives or impurities. It is mainly because of uncertainty over impurity content that most materials consumers shy away from using secondary materials, at least partly, and sometimes wholly, especially in applications that are at all critical.

Markets and Uses for Secondary Materials

Resource recovery systems are of no use unless there are markets for the recovered materials. In general, secondary materials experience a buyer's market, and indeed, the market may saturate as the amount of material recovery increases. In the face of competition from the traditionally used virgin materials it is necessary to make strenuous efforts to establish markets and uses for secondary materials. Tactics for accomplishing this include: (1) establishing effective specifications for, and providing technical information about, various grades of secondary materials and recovered fuels; (2) seeking new applications for secondary materials and disseminating information about these applications; (3) establishing stockpiled reserves in cooperative relations with municipalities and consuming industries; and (4) programs aimed at gaining public acceptance of secondary materials.

Various industrial associations and professional societies, such as ASTM, can and do play an important role in developing standards, specifications, and technical information. Such work should be extended to embrace all materials, including energy materials, recovered from MSW.

Considering ways in which secondary materials might be incorporated in product designs, or the possibilities for modifying product specifications to accept secondary materials, is still an unfamiliar habit for most product designers. Wider dissemination of information about new ways of using secondary materials is desirable. Particular attention is needed for novel ways of using mixed metals, multi-colored glasses, and multi-polymers for less demanding applications. Again, industrial associations and professional societies could take the lead in this activity.

The same points are true for education of the general public toward greater acceptance of secondary materials, for example, papers and off-color glass and bottles. The public needs to be better informed of the merits of making use of secondary materials in many applications where hitherto they have been accustomed to using products based on virgin materials.

An important factor for industrial users of secondary materials is the steadiness of supply of secondary materials of given grade. Supplies that show strong seasonal variations in quantity, or wide composition variations due to fluctuating compositions of the waste stream, may prove much less attractive to the industrial user or consumer than virgin materials, even when the latter are more expensive. In this connection, conflicts can arise even within individual firms between policies to accept more secondary materials and policies to maintain product quality.

Nevertheless, widely fluctuating prices of virgin materials pose perhaps the severest problem to marketing secondary materials--when the price of virgin material drops sufficiently, especially below the cost of recovering materials, the market for the latter is wiped out. A system in which stockpiling of various grades of secondary materials is practiced might serve to smooth out both types of fluctuations. Stockpiling of secondary materials may also help build up strategic reserves of economic materials as a hedge against interruption of foreign supplies of raw materials. In this case the federal government could act as the purchaser of the recovered materials. Again it should be noted, however, that typical MSW is relatively poor in the strategically important or valuable materials.

Secondary materials enjoy market advantages most frequently when the customer is geographically close to the resource recovery plant, thereby avoiding large transportation and distribution costs. For this reason, local contractual arrangements between RR plants and consumers should be encouraged whenever possible. Often it may be most beneficial if the resource recovery operation is closely coordinated, or even integrated, with secondary industries that absorb the recovered materials--for instance, if mixed paper is fed directly to plants using it for making roofing paper and other construction materials; or if ferrous scrap is fed directly into a plant making concrete reinforcing bars; and so on. In time we may well have some such integrated systems depending upon recovered materials for their primary input and using virgin materials as a secondary supply to smooth out fluctuations.

At present the economic system tends to provide virgin materials with a number of advantages, such as their reputation for reliability and adequacy of supply and reproducibility of composition and quality. Other advantages are more economic and institutional, such as the lower freight rates that go with the greater quantity of virgin materials, procurement specifications that exclude secondary materials, tax advantages from depletion allowances, the relatively lower tax overheads of sources of virgin materials compared with those that have to be carried by RR plants in built-up areas, and so on. Recognition of these advantages has led to many proposals for tilting the economic system to some degree so as to provide better market prospects for secondary materials. There are many ways in which such tilting might be accomplished, with a combination of incentives and disincentives, but none should be adopted without first carefully considering as fully as possible the potential effects on the economic and social structure of society and informing the public about them. Furthermore, if such measures are decided upon, they should generally be introduced gradually, at a pace that enables the socio-technical system to adjust without suffering costly disruptions.

The fear is sometimes expressed that an increasingly widespread and efficient practice of material reclamation will seriously and adversely affect the primary material producers. We believe this fear is overdrawn. There is little risk of a sudden destabilizing of the market for primary materials. While the needs for primary materials will be somewhat less than they would be in the absence of recovery, the continued overall growth in demand for materials, the relatively small quantities of most materials that end up in MSW, and the gradual rate at which efficient recovery practices will become established will combine to require only a relatively modest and gradual adjustment, if any, in the long-range plans of most primary material producers. Nevertheless, this situation will bear constant monitoring, and remedial actions may be necessary in special cases. The material industry most likely to be affected by efficient recovery is perhaps the paper industry.

We wish to emphasize that, in our view, there are already many unavoidable forces at work which will strengthen the trend toward resource recovery and utilization and that even without any legislative and regulatory innovations these forces will eventually result in a higher level of resource recovery and utilization. Proposals for new taxes, regulations, prohibitions, penalties, and so on, apart from those measures necessary to create and preserve a healthful environment, should be approached with caution, if at all. On the other hand, measures that would remove legislative, administrative, and fiscal barriers could speed and simplify the establishment of efficient resource recovery and utilization systems by local communities and regional authorities in cooperation with private industry.

CHAPTER 2

SYSTEMS APPROACH TO RESOURCE RECOVERY AND REGIONAL PLANNING

From Chapter 1 it will be apparent that there is no single best solution for the design of a resource recovery facility to serve all communities with their various local conditions. Instead, an overall systems approach should be adopted for each situation. In such an approach the many alternatives are considered, tradeoffs are evaluated, and choices made, both technical and economic and social.

In the initial planning for the system design, a number of questions must be addressed. Thus: What should the system aim to do? Dispose of wastes? Recapture all economic values? Recapture all values, on the assumption that external costs of residual waste disposal thus minimized will justify any economic loss experienced and be a legitimate tax charge?

How large a region should the system aim to serve? The smallest economic base for manageability? The largest economic base for flexibly combining waste streams and practicing large-scale recovery? A pre-selected balance of urban, suburban, and rural wastes for stability of flow? A large system that takes into account subregional seasonal variation in quantities of waste generated?

What lifetime of capital equipment should be considered? A long one, for low amortization costs, or a short one to exploit rapidly advancing technology? Or some preplanned combination?

And so on.

DISPOSAL VERSUS RECOVERY

Should the policy be to continue with traditional dumping or landfilling, or to practice resource recovery? In general, the rising costs of landfilling sites versus the appeal of earning some revenue that will, it is hoped, more than pay for the resource recovery operation, will increasingly favor the latter course. Nevertheless, there are many factors that have to be taken into consideration. Some of these are illustrated in the matrix of Table 8 (after Goldman and Logan 1973). The symbols in the matrix are + for a favorable impact, - for an unfavorable one, and 0 for neutral impact. For example:

TABLE 8

AN ILLUSTRATIVE ASSESSMENT OF THE IMPACT OF VARIOUS DISPOSAL METHODS FOR SOLID WASTES

	PRESENT DISPOSAL METHODS					NEW METHODS AIMED AT DISPOSAL			NEW METHODS AIMED AT UTILIZATION OF WASTE			
From point of view of:	Open Dump Burning	Sanitary Landfills	Incineration	Composting	Ocean Dumping	Package Vol. Reduction	Self Destruct Vol.	Grind to Sewers	Pyrolysis	Incin. with Power Prod.	Recycling	Reuse
Neighbors	-	-	-	0	+	+	+	+	+	+	+	+
Gen. Public												
Economical	+	+	0	-	-	?	?	-	?	+	(±)	+
Convenient	0	0	0	0	0	0	+	+	0	0	0	-
Air Poll.	-	+	-	+	+	+	+	+	+	+	+	+
Water Poll.	-	(±)	+	+	-	-	+	-	+	+	+	+
Wasted Resources	-	(±)	-	+	-	+	-	+	+	+	+	+
Local Govt.	-	+	$\bar{0}$	0	-	+	+	-	+	+	+	+
Equip. Mfgr.	-	+	+	+	-	-	-	-	+	+	+	0
Disposal Svcs.	-	0	0	0	0	0	-	-	0	0	0	+
Sci. Comm.												
Tech. Avail.	+	+	+	+	+	-	-	+	+	+	+	+
Econ. Process	+	+	+	-	-	-	-	-	-	-	(±)	(±)

Source: After Goldman and Logan (1973)

Neighbors of waste disposal projects are felt to be unfavorable to open dump burning, landfilling, and incineration, but mainly unaffected by composting and in favor of ocean dumping. However, neither composting nor ocean dumping are regarded as economical.

In terms of air pollution, both open dump burning and incineration are regarded as unfavorable with all other disposal methods satisfactory. With respect to water pollution, open dump burning and ocean dumping are both unfavorable, and the other disposal methods mostly favorable. Sanitary landfills listed as both favorable and unfavorable would be favorable with really sanitary methods used to prevent water pollution. Focusing on the last two lines, note that technology is available for all the present disposal methods.

Turning to newer methods of disposal, technology is not fully available at present for package volume reduction and self-destruct packaging though it is for grinding for sewers. A surveying of all the <u>disposal</u> methods indicates that there are most plus signs for sanitary landfilling and incineration. Furthermore, most and perhaps all of the negative signs in these two categories are susceptible to being changed into positive impacts by suitable technical and educational programs.

Looking at the newer methods of utilization--pyrolysis incineration with power production, recycling and reuse--we see on the whole even more plus signs. The principal need is to demonstrate convincingly and widely the economic advantages of these methods.

While any particular evaluation in the matrix might be questioned, especially reflecting variations in local factors, the overall conclusion is that there are many plus signs for sanitary landfilling and for resource recovery. We foresee sanitary landfilling as continuing to be an important method of handling waste, but improvements in the technology, its economic advantages, and the increasing scarcity of landfill sites, will make resource recovery the preferred choice for a steadily-increasing number of localities.

MAIN COMPONENTS OF A RESOURCE RECOVERY SYSTEM

There are three main components in a resource recovery system:

(1) The Collection System--the system by which the waste is collected from every source: residential, commercial, business, and industrial, and transported to the resource recovery facility.

(2) The Resource Recovery Facility (RRF)--where the MSW is sorted and processed to recover its material and energy values.

(3) Markets and uses for Recovered Resources--usually local, where the energy can be used for heating or power generation and

the recovered materials can be reprocessed into industrial materials and basic products. (There must also be a facility, usually a landfill site, for disposing of the irreducible and worthless residue).

Clearly, the RRF is central to the system. Without it there would be no products to market. The collection system exists no matter whether the MSW is transported to a central RRF or to a central landfilling site. All three components are, nevertheless, highly interdependent and must operate compatibly. We begin with a closer look at the RRF.

Resource Recovery Facility

The general plan for a Resoure Recovery Facility that seems to be emerging is depicted in Figure 6. MSW, as received at the RRF, may be unsorted, or may have been presorted at the source to some degree. If presorting is adequate, e.g., for newspapers and, perhaps, bottles, the separated items may be sent directly to a recycling plant where the newspapers are recycled to newsprint, bottles are cleaned for reuse, and so on.

But usually, further sorting of the MSW is undertaken. The major sorting step is to separate organics and combustibles from the noncombustible metals and refractories. Shredding of the waste may be done before (usually) or after the sorting, or not at all, depending upon the nature of the subsequent processing steps and uses for the recovered values.

Obviously, metals and glass are recovered as such, either before (perfectly) or after combustion, but there are several options over what to do with the organic materials. They can be burned on the spot; used as supplementary fuels in utility or industrial furnaces; converted to storable fuels, solid, liquid, or gaseous; or converted to chemicals, fertilizers, and other materials. Or combinations of these options can be arranged. Plastics can be directed either way; with the combustible or chemically processible materials, or to be recovered as plastics. The actual paths chosen will depend critically on what types of markets for the recovered values are available. However, in most cases it is likely that the RRF will produce a combination of energy and materials.

It is convenient to recover the energy in a storable and transportable form, especially if remote markets are to be sought. Alternatively, the energy wastes can be used directly in furnaces, usually as a shredded supplementary air-blown fuel, to create steam or hot water. These can, in turn, be used for local heating, or in the case of steam (or recovered fuel gas), for generating electricity.

Thus, a very large variety of RRFs is possible, and which is the best one will depend almost entirely on local factors--geography, markets, financing arrangements, and so on.

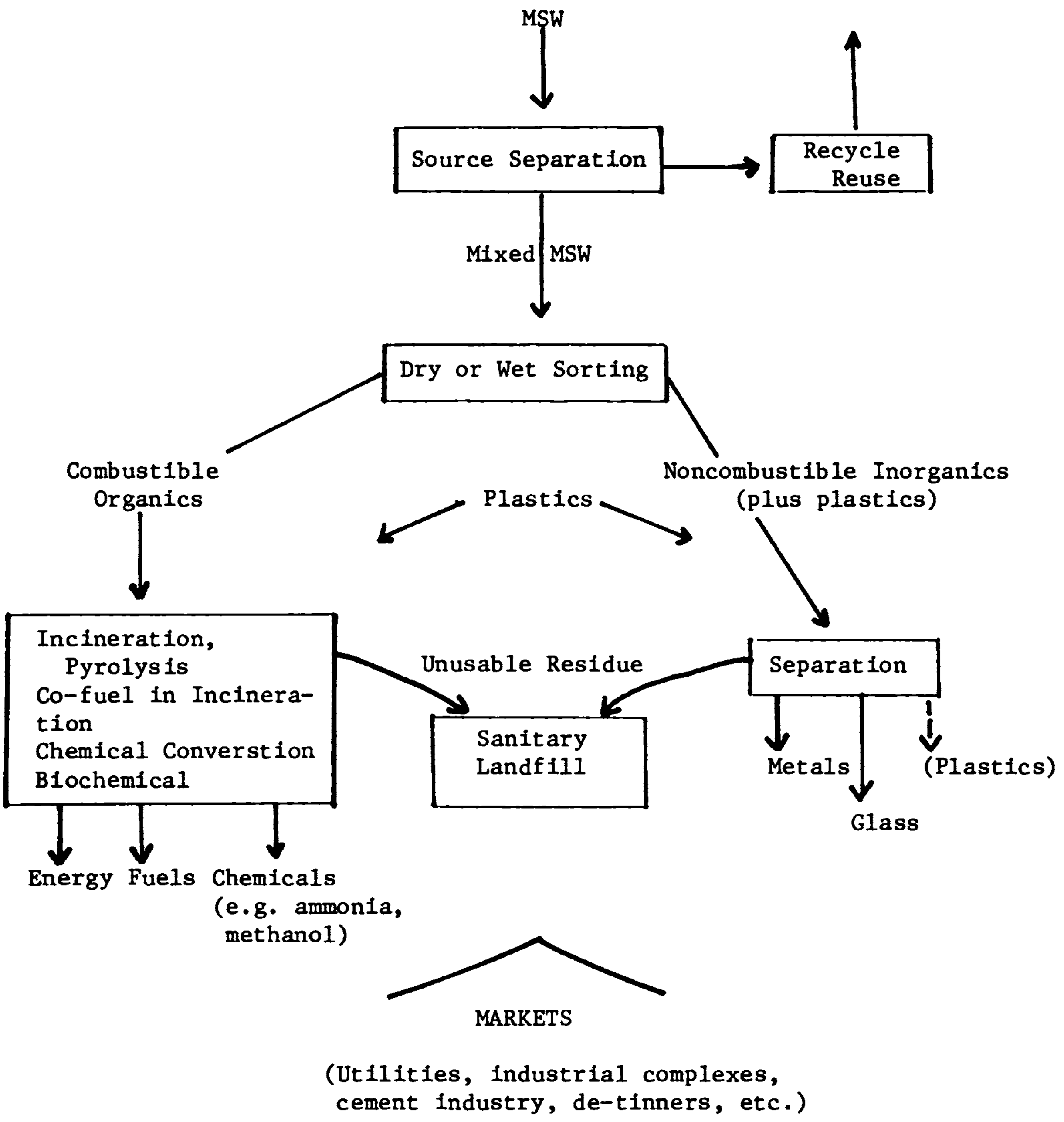

Figure 6 General Pattern of a Resource Recovery Facility

There is probably no single best solution suitable for all locations.

The EPA (1974) is or has been involved in a number of different demonstration projects to evaluate some of the principal options:

Shredded Waste as a Coal Substitute--St. Louis, Missouri (this is in operation);

Shredded Waste as a Fuel Subsititute or Compost--Wilmington, Delaware (does not appear to be a success at present--may convert to providing supplementary fuel for oil-fired boilers);

Wet Pulping for Materials Recovery--Franklin, Ohio (in operation, though the high moisture content of the waste tends to reduce the efficiency of associated energy recovery);

Pyrolysis to Produce Fuel Oil--San Diego County, California (substantial cost overruns are expected);

Pyrolysis for Steam Generation--Baltimore, Maryland (starting up: some air pollution problems still); and

Incinerator Residue Separation--Lowell, Massachusetts (may be cancelled).

Engineering data are, or will be, forthcoming from these and many other studies being undertaken by private industries, other government agencies, and local communities. It will be important to ensure that this information, which will be so relevant to making systems decisions, is made readily accessible.

Coordination of Resource Recovery with Local Markets

Given the necessity of having a market for recovered energy and materials, the potential market will usually have a strong influence on the design of the RRF. It makes little sense to convert the organic material to soil conditioner when the most available customer is a power utility. It is of little value to produce ferrous scrap suitable only for low-grade uses, such as making reinforcing bars, if there is no such potential consumer nearby. And so on. On the other hand, once a steady, reliable source of recovered materials gets established it may attract secondary satellite industries. It cannot be emphasized too strongly that insufficient attention to the development of markets for recovered products may result in little or no income to offset the costs of operating resource recovery facilities.

Clearly, there must be room for some pushing and pulling between the RRF and the secondary material consumer sectors. The two may be expected to develop together, symbiotically, given an environment that is conducive to such coordination and cooperation. The needs for such close working together increase as the whole operation becomes more sophisticated and as progress becomes measured in small, ingeniously worked out, incremental improvements in efficiency rather than dramatic leaps forward. In many cases, the arrangement that will bring optimal benefit to the general community might be called vertical integration, in which the whole operation is optimized for lowest cost and/or most benefit to the community. (By vertical integration in the context of waste management we mean the total system under one management, comprising the collection network, the resource recovery facilities, and possibly some users of recovered values as well; the latter might include some utilities and some manufacturing operations based mainly on the recovered materials). It is very often possible that an optimal system for the RRF results in a less than optimal situation for the secondary material consumer; consequently, the sum or total operation can be less than optimal. For example, left to itself, an RRF might find it cheapest to produce a shredded waste fuel; but a local utility might find it more expensive to adapt to shredded waste than to burn liquid fuel directly. Under these conditions, who should adapt or compromise? Such issues, of which there is an almost endless variety, become much easier to resolve within an organization that has unified, total technical and managerial responsibility.

Coordination of Resource Recovery with Collection Systems

Just as there usually needs to be close coordination between an RRF and local markets, so also must the facility have close coordination with the collection system. Source separation, with its separate transport requirements, is of no value if the RRF is not designed to handle separated wastes as input. (Conversely, an RRF designed to handle separated wastes will operate inefficiently if the MSW is not separated at the source.) Also, the quantity of MSW collected and the rate at which it is delivered to the RRF has to match the throughput capability of the latter. However, these organization coordination problems, apart from those to do with getting several muncipalities to pool their wastes, are not so subtle or difficult to resolve as those at the interface with the market. Furthermore, collection systems already exist and can be included in the planning, though they will generally have to be redeployed to optimize the matching to the RRF rather than to landfilling. The principal technical responsibility of the collection system is to maintain a steady delivery of waste to the RRF, particularly where the RRF is under contract to provide a steady supply of steam, electricity, or any other product to a customer.

FURTHER NEEDS FOR THE SYSTEMS APPROACH

Above we have advanced several reasons why a systems approach is needed for resource recovery (the need for it in the past for waste disposal has been less critical). There are some others.

An integrated resource recovery system, involving the collection system, the RRF, and at least some of the markets, is in a better position than a fragmented, laissez-faire arrangement to respond quickly and efficiently to changing situations. Some of the external factors that can force changes on a resource recovery operation include: wide fluctuations in the market price and demand for secondary materials; seasonal changes in the nature of the waste stream; new technological developments that need to be incorporated; and the often unexpected consequences of new federal and local regulations (especially environmental ones) and taxes. A total system is better able to make a systematic adjustment, when needed, than a fragmented system in which each relatively independent organizational component has to do the best it can while inadequately informed about what the other components are doing. By the same token, an integrated system is also more flexible and able to adapt to demographic changes in the region it serves.

Some representative resource recovery systems under current development or in the planning stage are described in the appendices. Typifying principal approaches to combining resource recovery with power generation are the following examples.

St. Louis, Missouri

A system is being planned by private enterprise (in fact, the only utility-sponsored project, to date) to serve St. Louis (see Appendix B. X). It is based on a current, smaller-scale demonstration project which was supported by the EPA. Refuse haulers (a separate company) will deliver the MSW to transfer stations where it will be compacted, containerized, and transferred to trains for transport to two processing centers. After pulverizing and separating out the ferrous and nonferrous metals, glass, rock, and other materials, the residual combustible material will be blown into power plant boilers as a supplement to the normal pulverized coal fuel. The whole operation will be planned to run at a profit based on income from the fees charged the refuse haulers and earnings from the sale of the burnable refuse and recovered materials. No government money is involved.

Saugus, Massachusetts

In this plant, under construction, the energy content of the MSW will be used to generate steam in a waterwall furnace incinerator for sale to a nearly industrial plant, while metals and other materials will be recovered as in other schemes (see Appendix B. XI).

Refuse-Generated Electricity within the RRF

In some schemes that have been proposed or are under consideration, material recovery will be practiced as in St.

Louis, but whereas in St. Louis the combustible refuse is burned in boilers owned by the utility company, the resource recovery center generates electricity on its own premises and sells it, instead of fuel, to the utility company at mutually advantageous rates (see Appendix B. XII). It is worth noting that converting the energy content of MSW immediately into electricity avoids the storage and transportation costs associated with bulk fuels and at the same time offers considerable operational flexibility. Assuming that refuse-generated electricity is likely to be only a relatively small fraction of the base-load of the utility, it relaxes the siting problem; it does not shut down the utility if the refuse stream is interrupted; and it does not have to match the fuel or steam requirements of the utility.

Westchester County, New York

An environmental industrial park has been proposed to serve the county (see Appendix C. V). The MSW would be received and processed by a size-reduction and materials recovery (front-end) facility. The recovered materials as well as refuse-derived fuel would be consumed by industrial facilities in the park. The fuel would be supplied to tenants either as supplementary fuel or converted into process steam at a central plant to serve the needs of the park, including heating and air conditioning. Some incentives to industrial tenants are expected to result from proximity to materials and fuel supplies, and certain governmental policy decisions which make capital available at reduced cost for pollution control and economic development, both of which apply to solid waste disposal and resource recovery. Prospective tenants for the park include the resource recovery facility, an energy conversion facility, a recycled newspaper mill, a recycled corrugated mill, a detinning mill, a mini-steel mill (mini-mills), and a cement plant. Other candidates are a glass wool insulation plant and a brick plant, both utilizing the recovered glass. However, certain conflicts arising from past zoning practices may first have to be overcome--industrial parks have generally been associated with light industries, yet a large-scale RRF ranks more as a heavy industry.

COLLECTION SYSTEMS

Visitors from any European countries are astonished at the litter and filth they see in American cities. What they see is clear testimony to the inadequacy of refuse collection activities. The responsibility for this inadequacy must be shared by those who create the refuse as well as those who are supposed to collect it, but there is clearly a breakdown in the system at this interface. And so far, technology has not done much about this problem.

Utilities such as electricity, gas, telephone, and water bring their services right into the client's premises. With refuse, on the other hand, the householder, building owner, or operator has to make his own arrangements to get his refuse to some outside location for it to be picked up by the city collection service. Human frailties often make this linkage inefficient, and technology seems to have passed this problem by, though with some minor exceptions: garbage disposal units in sinks enable putting food wastes directly into the sewer system; some modern, large apartment blocks are equipped with refuse chutes leading, where they are not illegal, to a basement incinerator which, in turn, may be used to help provide heating and hot water for the building. More commonly, the chutes lead to basement compactors, but in either case, chutes present the problem of dirt sticking to their walls.

Two on-premise areas in particular deserve attention from technology: (1) storage and handling of refuse and (2) usage of refuse and volume reduction. The first is almost always left to amateur initiatives, using grocery bags, plastic bags, and assorted primary containers. These, in turn, are placed in assorted barrels, bins, and hoppers to await collection. The sanitary aspects are often unsatisfactory. Refuse gets spilled, or is carelessly left around in the first place, presenting an environmental defect and health hazard. The refuse that is in reasonably conventional containers in recognized locations gets collected at intervals; the rest is often left lying around indefinitely. Standardized, well-sealed containers in well-designed pick-up spots would generally lead to improvement, especially if source-separation is to be practiced, but it would seem that there is a big need and opportunity to devise and incorporate into building designs in the future refuse disposal systems that would deliver the refuse directly to sealed containers to await collection. (Note, examples of vacuum collection systems are those in Disney World and on Roosevelt Island, N.Y.). This would greatly reduce the chance of refuse escaping into the general surroundings.

Probably much more could be done to achieve the on-premises usage of refuse and volume reduction. Making use of the combustible fraction in local incinerators has already been mentioned but whether this is, overall, more efficient or cost-effective, or sufficiently less polluting, than collection and conversion to power at some central facility needs to be assessed. Household-size garbage compactors have made their appearance in recent years but are mainly a convenience item at present; they can be a nuisance when RR through biological conversion is practiced. However, incineration, with its consequent smaller residue to be collected, as well as compactors, reduce the demands on trucking and other transportation, though at some cost in increased air pollution.

Technology cannot provide all the solutions, however, to the problems of the source-collection system interface. Somehow, the willing cooperation of all individuals has to be achieved. The factors that instill a sense of responsibility, of civic pride, of desire for cleanliness, and a feeling that an individual's efforts are important, may be difficult to pin-point and work on, but there may be some lessons to be learned from sociological studies of communities in other countries at equivalent income levels, as from social science research into motivations for socially functional behavior, generally.

Beyond the technological and sociological aspects there are the questions of ordinances, regulations, or standards, and their enforcement. Environmental standards for refuse handling and containing could well merit attention though it is recognized that defining cleanliness standards for cities and their units, and who is responsible, is likely to be a thicket of problems. Nevertheless, attempts to tackle this problem have been made in some instances. Notices along highways, for example, remind people of penalties if caught littering the roadside, though unfortunately, if they are not enforced (or enforceable) or sufficiently severe they can result in litter laws being regarded generally as unimportant.

Turning to the refuse collection services provided directly by the city, or through private contractors, major problems concern lack of performance standards, inflexibility of the service, and lack of management information tools. Beyond specifying frequency of collection and location of containers there is relatively little effort to specify the thoroughness of collection that should be achieved, or how to measure it. Most collection systems are unable to adapt readily to the varying needs for collection, from location to location and from time to time. And there are few aids to the managers of the system to indicate the current state of refuse collection, where most collection effort needs to be deployed on a day-by-day basis. (In a 1974 survey by city administrators, waste management problems were ranked first out of thirty-nine problems faced by cities.) In short, unlike electricity and telephone utilities, or police forces for that matter, ways for centrally monitoring the collection operation have generally not been developed.

Following schools and roads, solid waste management represents the largest municipal expenditures on a nationwide basis. Refuse collection is very labor-intensive, with many impediments to efficient operation written into service contracts. For example, a significant fraction of time is lost in the whole crew travelling to and from the disposal or resource recovery site. Also, refuse collection is often only a part-day activity though a full day is charged. Attention to ways of obviating or minimizing the use of truck collection systems should receive high priority. Slurry or vacuum pipeline collection systems in dense urban areas would call for large capital outlays but might result, if reliable and sufficiently free from blockage troubles, in much lower running costs than truck systems, as well as being much more congenial, environmentally.

The whole layout of a collection system for a community deserves, and is receiving, attention. Direct transport of the refuse to the RRF may be suitable in a dense urban area of limited geographical sprawl, but more generally, for serving larger areas a network needs to be set up in which packer trucks transport the MSW to intermediate or satellite centers from where it is transported in bulk in large transfer trailers to the main RRF. Just such a network is being set up in the St. Louis program. As it takes shape it begins to take on some of the characteristics of other utility networks, particularly the electrical and, to some extent, the telephone networks. The need is for the operation of the network as a whole to be optimized with respect to cost to the public. Such optimizing, reflecting varying local circumstances, can call for a variety of transport technologies and schedules and, in large areas, perhaps a hierarchy of transfer and intermediate processing centers. For example, it could be more economic to do partial sorting and incineration at several satellite centers while transporting the remaining separated materials to a central resource recovery facility for further processing and refining.

REGIONAL PLANNING

Resource recovery plants, especially as they become more sophisticated, call for capital outlays and operating expenses previously largely unknown in the waste handling industry. In turn, to be economically viable, such plants have to handle a relatively large volume of MSW so as to realize economies of scale. Typically, contemporary plans call for throughputs of hundreds to thousands of tons of MSW per day. This throughput, in turn, implies that the RRF will serve a total population of from several hundred thousand to over a million. This feature has some important implications.

Clearly, large cities can sustain RRFs within their own boundaries but in less densely populated areas, the aggregate "basin" served by an RRF should embrace, perhaps, several communities. That changes in the nature of the transport network will be required is obvious. The larger the region the greater the cost of transportation. A network to serve a large, relatively thinly-populated region is not simply a geographically-expanded version of the network that is most suitable for serving an urban area; the net daily flows in each link of the network will be much different, calling for different scales, and often different types, of facilities.

As the geographical area handled by a single system is enlarged and more variety of waste is involved, the need for subsystems to reduce mass and volume is increased, and the opportunity for maximizing the recovery of high-value components, such as tin and copper, is improved. It seems appropriate to envisage, therefore, a regional system in which these higher-value, but often more-difficult-to-separate, items are collected for processing by a regional center oriented towards these higher technology problems while the generally bulkier, lower-value items, such as glass, paper, iron, and organic materials are handled by local centers.

Thus, overall system design for best serving the total population of a region becomes a far more complex matter than is the simple collection and disposal of refuse within each local community's boundaries. Furthermore, it requires the cooperation and political consensus of several communities, perhaps the main stumbling-block for progress towards resource recovery at the present time.

Currently, a number of organizations are analytically seeking optimum system designs for various geographical regions (see Appendix C. III, IV, V, VI, VII, for examples). The general approach is to postulate a cellular, zone, or district system in which the cell boundaries need not coincide with local municipal boundaries. These cells are served by transfer stations and/or local processing units which, in turn, are linked to more central RRFs and disposal sites. Computer modelling of these systems enables seeking optimal configurations under the overall requirements of handling all the MSW and acceptable environmental impact. Parameters that go into these models include cell sizes, site selections for transfer stations, RRFs and disposal, the sizes of these facilities, the type of processing technology, and the transportation links and flow rates along these links. The optimal configuration is regarded as that which presents the lowest net cost to the public.

However, the lowest cost solution may not be the most politically acceptable. Some of the possible system configurations may be thrown out for this reason, but the analytical models can then indicate the increment in price that the public has to pay in order to satisfy politics--community rivalries, selfishness, union demands, corruption, and so on. If a system appears expensive it may well be that the biggest savings could be made in this social area rather than in the technology sector--technology is usually much more cost-effective than sociology.

System studies reveal a number of issues discussed below that have to be resolved in each case.

Evolution of Regional Schemes

Large densely-populated areas are obviously the nucleating sites for resource recovery systems. But how do these systems evolve and grow to embrace the more outlying areas? Local communities which, for instance, happen to have an adequacy of cheap landfill sites for many years to come may feel little pressure to switch to resource recovery, but what is the likelihood of federal or other restrictions being placed on landfilling as resource recovery receives increasingly higher priority? We believe that regional resource recovery systems covering all but the most densely and the most sparsely-populated areas of the country are inevitable; the issue for local communities not already involved in such schemes is not whether, but when and how best to become involved. From the standpoint of the most orderly development of a regional system, the sooner all affected, or potentially affected, communities work together, the better.

Problems of Rural Regions

There are large areas of the country in which the population is distributed in relatively widely scattered, small- to medium-sized towns. These towns cannot offer the economies of scale available to the large metropolitan areas, and the transportation costs for a regional system covering a very large area of overall low population density might be prohibitively high. While rising costs of energy will tend to increase the attractiveness of local recovery and utilization of energy from the refuse, it is just these regions that are most likely to have low-cost landfill sites available for many years to come. The different circumstances of the more rural and remote communities, compared with metropolitan regions, need to be kept in mind in any regional or national regulation of landfilling.

Also, in many rural regions, the predominance of agricultural wastes may give a different character to the waste handling operation, creating both problems to be considered and opportunities to be explored in the design of rural regional systems. It would seem useful to examine the material recovery potential of landfills. If landfills continue to be created, can they be designed and retained to be available as sources of "raw" materials if at some later date resource recovery from them becomes economically attractive?

Availability of Technology

Much resource recovery can already be done with existing technology, but is better technology going to be available soon? Communities contemplating RRFs may be tempted to adopt a wait-and-see stance, nervous about making a decision now which may prove to be the wrong one within a relatively short time. This posture is understandable. Five years ago little technological attention was being given in this country to resource recovery. Now there are many exploratory and demonstration programs under way and some in the actual construction stage. Within a year or so more engineering information will be forthcoming on the relative merits of some of the various approaches. Nevertheless, it would seem that the main types of approach have now been identified, as reviewed in Chapter 1, even though one can expect steady improvement in the efficiency of resource recovery technology as the industry proceeds along the "learning curve." There seems little reason, technically, to defer entry into resource recovery; the important point is to establish management and financing practices which reflect likely rates of depreciation of the equipment (reflecting, among other things, the learning curve), and to design the system (and financing) so as to facilitate subsequent retrofitting and upgrading as improved technology comes along.

Availability of Sites

The siting of landfills and dumps tends to excite much discussion and argument between communities considering taking part in a regional plan. Depending upon the region, various possibilities can be envisioned: (1) no community has a suitable site; (2) one or more communities do have suitable sites but wish to keep them for themselves rather than make them available to the region; (3) one or more communities have suitable sites and are willing to make them available to the region in return for some other benefit; and (4) increasingly rarely, a community may actively seek landfill to further a land reclamation scheme. Most commonly, though, most communities do not want to be the landfill or dump sites for a whole region.

The situation is apparently quite different with RRFs. Whereas the public image of dumps is very negative, that of the RRF tends to be quite positive. Communities may actively compete with each other to provide the site for the RRF, no doubt reflecting hopes that it will be a prestigious, revenue-earning activity for the community and a magnet for satellite light industries. The RRF is all the more acceptable if sited in a zone already allocated to industry. The RRF should be designed so as to be architecturally or operationally inoffensive (e.g., the problems of aesthetically displeasing stacks and noise). On the other hand, the heavy truck traffic associated with large RRFs is reported to be a serious negative aspect as far as the local community is concerned; attention to routing is needed to minimize this disadvantage.

Another important factor in choosing a site for an RRF is proximity to a market for the recovered energy and materials. The more distant the market the greater the transportation costs, especially for steam and the bulk fuels and materials recovered. On the other hand, electricity generated from the refuse at the RRF can be delivered directly to a utility simply by connecting the RRF generator into the electricity grid, which may prove much less costly than fuel storage and transportation costs (see Appendix B. XII). There is a well-established industrial sector for handling recovered metals, making it possible to explore tie-in arrangements. Markets for recovered glass, and to some extent, paper, vary greatly with locality and time. The steady availability of markets for these materials probably cannot be counted on for some time though, in due course, the lower energy costs generally enjoyed by reclaimed compared with virgin materials should help to generate more markets (especially for aluminum which represents energy savings of up to 95 percent over virgin material).

We conclude that, as part of the regional planning, parameters that have to be entered into the systems analysis include the "prices" (positive or negative) the various communities would charge for siting a landfill or resource recovery facility within their boundaries, reflecting, among other factors, the availability of markets. Only after failure to reach agreement on this basis, through negotiation, bargaining, or auctioning, should more mandatory measures from the state or federal government be considered.

Responsibility for Planning

Responsibility for planning involves all levels of government, from local city councils to the federal government, though there is frequently a lack of funds for carrying it out. For a sufficiently large city the council can assume the responsibility, but for metropolitan or multi-county areas which embrace several communities involvement of the state will frequently be necessary. Clearly, the state is involved in regional planning but beyond that there can be a federal role, especially in coordinating several regional or interstate plans.

Such coordination between communities in an area where they are unfamiliar with the technology is a particularly difficult, institutional issue. Experience indicates that communities that have historically been poor cooperators in other areas are unlikely to be cooperative in RR, or will charge a high price for their cooperation. Getting cooperation is often a matter of timing--different communities will seldom accord the same priority to resource recovery simultaneously. More likely they will all have to weigh commitments to resource recovery against many other pressures for their attention, and the likelihood that all communities can commit themselves simultaneously to the regional resource recovery system could be small. The situation is helped if they all see a financial advantage to the system, and again, the rising costs of landfilling will tend to bring this about. But a community that happens to have a cheap landfill site available might well ask why it should forego this and join in a regional resource recovery system. It is the time taken to resolve vested interest and jurisdictional issues like these that can dictate the pace of implementation of regional resource recovery systems. The planners of the regional scheme can prod patiently, aided if necessary by legislated and tax incentives, but again, communities distrust state enforcement machinery.

The planning tends to be cautious, also, because the newness of the technology leads to communities wanting to find out how others have fared with new processes before investing their own funds. In practice, it is probably those communities which at present find themselves forced to switch from the older landfilling and dumping practices, which take the plunge first, though the rate of switch-over can be expected to accelerate as more experience is gained and information made available and, especially, if resource recovery proves to be less of a financial burden than waste disposal, or even a net source of revenue.

Sources of Technical Input--An R&D Institute

Whereas in the past most local governments felt able to judge and manage landfilling or dumping operations, they are understandably hesitant about making technical decisions about an increasingly sophisticated technology. Instead, they usually turn to private industry for technical advice, pilot plant operations, and often the subsequent operation of the RRF. However, industry is not always eager to get involved in such an uncertain area as resource recovery. In Connecticut, for example, all utility companies were initially canvassed to determine if they would take on RR for the state; they all declined. There are several firms (engineering consultants, energy firms, conglomerates, among others) exploring different approaches, but it should again be emphasized that there is no one best solution suitable for all locations or regional plans. Changing the parameters in a regional plan may alter the optimum mix of pyrolysis versus incinerator plants, or change the total numbers required. Also, too great faith should not yet be placed in econometric models. They are useful rough guides but the parameters that go into them, especially those for incorporating externalities such as pollution and esthetics, have not yet been widely accepted or standardized. (Interest by the EPA in this problem might lead to repairing this deficiency.) It should also be noted that there are as yet few individual firms with adequately broad experience in RR technology to plan and provide integrated systems--most tend to specialize in one or a few aspects of the problem.

As private sector experience with resource recovery increases, this experience should be made available, in some suitable form, to the planners of resource recovery systems so that informed decisions may be made. The federal government could play a role in making such information available while protecting, to the extent possible, the proprietary rights of the firms involved.

Through the U.S. Bureau of Mines (performing in-house studies), the U.S. Environmental Protection Agency (through fostering private-sector work), and the Energy Research and Development Agency (energy recovery studies), for example, the federal government is already supporting some studies of resource recovery technology. There is scope for more R&D leading to technical knowledge in resource recovery. Even though many of the firms already actively pursuing resource recovery technology may seem quite large, individually they are often unable to afford a significant R&D capability to attack resource recovery on a broad front. Furthermore, processing equipment is often not patentable, thereby affording little protection to innovative firms, or incentive for R&D. Even where equipment or systems are patentable, the return from the patents may seem inadequate in relation to the cost of the R&D. This is a familar institutional hindrance to innovation that occurs particularly when the industrial sector is fragmented. Further, collaboration is usually regarded as prohibited by anti-trust regulations. The situation could be alleviated appreciably by setting up an R&D institute for resource recovery technology. At first, it could perhaps be jointly supported by the federal government and the operators (usually private industry) of resource recovery systems. As it gets better established it should become self-supporting. Such an institute could possibly be analogous to the recently formed Electric Power Research Institute, which serves electrical utilities, or to Bell Telephone Laboratories, which serves the Bell System, both completely supported by the industry they serve. Besides performing R&D on resource recovery, the institute could take on the responsibility for disseminating information to industry and the general public about RR systems, planning, financing and management options, and preparation of contract proposals. The preparation of instructional materials and textbooks would also be an important part of its function. Another area of its activities could also be economic studies and assessment of the socioeconomic impact of resource recovery and related matters. (Some of the activities envisaged for the R&D institute are currently undertaken by the National Center for Resource Recovery. The possibility that the role of the NCRR might be expanded should be considered.)

The R&D institute should be of adequate size and, preferably, conveniently sited for involving faculty from a university with established strengths in materials and process engineering and related physical and social sciences.

Ownership and Operational Responsibility

The technology of resource recovery has had a major effect on the decisions regarding government or private industry ownership and operation. For many years municipalities have felt competent both to own and to operate landfills and incinerators. At present, local governments appear to recognize that the technological complexities of materials separation and energy recovery, involving in some cases new and complex chemical processes, may require skills and flexibility of management and operation not readily available to them. Thus, many of these governments are deciding in favor of private ownership and private operation under what may be termed a franchise agreement. Acquiring this franchise agreement under some government procedures for competitive procurement is a new challenge; usually, by its very nature, an MSW collection system, together with its resource recovery facility and some of its associated markets, works most efficiently and at lowest cost to the public as a vertically-integrated monopoly. In fact, it appears very likely that resource recovery systems will more and more come to be regarded as essential utilities operating best as natural monopolies within the purview of state utility commissions.

At present, however, many combinations of government and private ownership, and government and private operation can be found. In perhaps most cases, federal government money has been used to help initiate projects but in others, such as at St. Louis, the sponsorship as well as the ownership and operation are now entirely in private hands (see Appendix B. X). (It is noteworthy that at St. Louis the private company felt it could operate without showing a loss only if it took responsibility for the whole, vertically-integrated system, from collection at transfer stations to marketing of recovered values. Also, the Tennessee Valley Authority is currently studying a similar plan for the entire region it serves).

Economics

As noted several times, we believe the underlying trend is for RR to become economically more attractive than waste disposal and increasingly more competitive with the production of primary materials. At present, however, the uncertainties over actual operating costs, revenues from markets, and the imposition of standards and regulations make communities and private industry alike nervous about investing in RR.

While estimates of operating costs for RRFs abound, they vary considerably and are not yet based on much real experience. Consequently, no great reliance can be placed on them at present.

Revenues from the marketing of recovered values can fluctuate wildly. While there are some instances of long-term contracts (e.g., 25 years) being agreed between RRFs and utilities, more often than not the market for recovered fuels and materials is highly locality-specific and can be virtually switched on or off by moderate movements in the price of primary materials. This can make RR operations that depend critically on revenues from sale of products for their economic viability very risky ventures.

A major cause for concern is the uncertainty over the kinds of standards and regulations applied to waste management by the various levels of government, their steadiness with time, and the diligence with which they will be enforced. Recent costly experiences with vacillating environmental actions, such as those having to do with automobile emissions (see for example, The Sciences, July 1975, page 6 et seq. for a recent review), have made the private sector distrustful of federal policies and wary of entering a new area where it may again be dangerously vulnerable. It is of the utmost importance that, except in cases of real emergency, standards and regulations should be thoroughly worked out, understood and agreed to beforehand, introduced gradually at a pace that enables industry and commerce to make the necessary adjustments, and then enforced uniformly and effectively. Effective enforcement is very important; without it, most firms will try to avoid incurring the costs and penalties associated with the regulations if they believe that laxity in enforcement is enabling their competitors to obtain cost advantages. At the same time, this emphasizes that legislation and regulations should not be introduced if their enforcement cannot be afforded.

In spite of all these uncertainties, the growing conviction that RR is the "right way to go" will result in increasing participation by local communities and private industry. The challenge is to find the most economical, equitable, and effective approaches.

Communities have traditionally covered the costs of MSW collection and dumping or landfilling out of municipal revenues. In practicing RR, the collection costs will be much the same, the dumping and landfilling costs much reduced, but there is the additional cost of operating the RRF. The net cost of RR, not counting on revenues from the sale of the recovered values, may be greater or smaller than dumping or landfilling depending on local circumstances. Revenue from the sale of recovered values can be applied against the operating costs of the RRF, or given directly to the community to offset collection costs, or divided between the two in some way. The actual arrangement chosen will depend on whether the system is wholly owned and operated by the community, by the private sector, or by the two in partnership. It is important that the private component be allowed a reasonable rate of return on its investment in order to attract further financing and also, to provide an incentive for seeking and creating markets for the recovered energy and materials. It is worth noting that in the St. Louis program the Union Electric Company expects to operate the whole system from the refuse transfer station through the RRFs to fuel usage and material marketing at a profit, covering its operating costs and profits from income derived from dumping charges to the refuse haulers and from sale of recovered values. This is indicative that RR may become more generally a financially attractive activity.

Financing

While the auguries are good, the economics of most RR schemes are still to be proved. This lack of experience and potentially uncertain return on investment hinders raising the necessary capital, particularly in a capital-scarce market. Bond issues are most frequently resorted to for obtaining capital. They are of two types: (1) general obligation bonds issued by the municipality and retired out of general tax revenues (e.g., Chicago), though income from sale of recovered materials and energy may also be applied against the debt and (2) revenue bonds which are intended to be repaid entirely by income from the resource recovery operation. The prospectus for the issuance of revenue bonds requires detailed engineering and marketing information about the intended RR operation so that intending investors can assess its soundness; but they are generally regarded by municipalities as more appropriate sources of financing than general obligation bonds, especially where the RR operation is essentially a monopoly service.

Municipalities often face a number of barriers to formulating a financing plan for what, in effect, amounts to an industrial operation. These barriers, which have sound, practical reasons for their existence, include: restrictive procurement laws; laws against entering into long-term contracts; the problems posed by split bidding; the common requirement that the lowest bidder must win; and the uncertainty over which technology to choose. Removal of these barriers, in many cases, requires modification of statutes--obviously a dauntingly protracted, exhausting, and uncertain task. It is not surprising, therefore, that municipalities turn most commonly, where possible, to private industry, usually to share in the planning, operation, and ownership of the RR system, and sometimes to handle it completely. The private sector enjoys a number of advantages: it is freer to enter into long-term contracts (with utilities, for example); it is better placed to embark on planning and designing the system for optimum total lifetime cost; it usually has greater incentives for efficiency than government operations; private industry is usually more able and willing to spend on maintenance costs; and it is more familiar with marketing methods. However, there still remains the need for the community to find some way to enter into a long-term contract with the private sector.

If private industry is made responsible for the whole waste handling operation, it shoulders most of the risks, as it is used to doing, but it is also entitled to benefits, though the latter have to be monitored by the municipality if the operation is a monopoly. More commonly, the municipalities are interested in sharing the benefits, but should then expect to share equitably in the risks. How best to allocate the risks and benefits between the public and private sectors in these unusual hybrid ventures is a problem to be resolved through negotiation.

The problems of apportioning costs and benefits are intensified when two or more communities are involved in a regional plan. A good example of a developing statewide system is that of Connecticut (see Appendix C. VII). A commissioned study by a major manufacturing company led to proposals for a resource recovery system based on a network of dry fuel and material recovery plants and later, pyrolysis plants. The system, composed of several separate, but major, local areas, (not yet a truly regional approach), is now under construction. A state authority--Connecticut Resource Recovery Authority (CRRA)--was established to set policy and to manage the fiscal aspects of the program. A quasi-government/quasi-public authority, CRRA has no subsidy funds but has power to issue $250 million worth of revenue bonds. The system it operates is entirely voluntary--(though municipalities are responsible by state law for dealing with their solid wastes, they are not obligated to joint the CRRA)--and the bonds have to be paid out of project revenue. CRRA's main problem is to bring together: (a) the municipalities, (b) their utility or other customer, and (c) an RRF operator with suitable technical and management skills.

To attract the municipalities the CRRA had to offer: a reasonable fixed price for handling their solid wastes, competitive with other alternatives; little or no technical risk; and a reliable long-term solution. The fixed price consists of a maximum capital cost, a fixed operating charge with increases only on the basis of general inflation indices and increases in tax and utility rates, and a minimum revenue guarantee. The fixed price can be suspended only on the basis of agreed "uncontrollable forces." The municipalities share in net revenues and income in excess of minimum net revenues and income.

Since recovered fuel accounts for about 80 percent of revenues, a long-term fuel contract was essential. Utilities were willing to buy fuel only on the basis of: no additional costs or risk of additional costs to their customers; little or no risk to their shareholders; and maintaining their reliability of electricity generation. As a result, CRRA agreed to pay for the cost of converting boilers to burn the new fuel and any associated increase in operating costs. Protective clauses were provided in case of irreparable damage to major equipment and significant impairment of reliability.

Agreements were made between the CRRA and the private sector to cover the system construction and operating costs. While CRRA provided sites, industry provides or is responsible for: transfer stations, transportation equipment, the RRF, and power station equipment.

Under the operating agreement the private company is responsible for operating the total system for 22.5 years at a price equal to the operating charge payable by, and agreed to by, the municipalities and in such a manner as to produce recovered products meeting specifications and yield standards. The company is also responsible for marketing the recovered products and paying to CRRA the minimum revenues, a percentage of all revenues above the minimum, a percentage of net income before taxes, and a royalty on dry fuel used in other plants.

In summary, CRRA has found a conservative approach to minimizing risk and demonstrating probable self-sufficiency (as required for the revenue bonds). It places primary reliance on long-term contracts with the municipalities, the utilities, and private industry. And it avoids the general obligation approach or primary reliance on a project feasibility study. The contracts provide for long-term self-sufficiency except in extreme cases, and if the system economies turn out better than projected, most of the benefits flow to CRRA and the municipalities.

INFLUENCING THE WASTE STREAM

While this report is primarily concerned with the technology and systems approach to recovering values from MSW there are other possible or potential, technical or legislative, influences on the waste stream that must be recognized. These fall under the categories of measures to reduce the total waste flow and measures to encourage reuse and recovery.

Mandated Container Return

The Oregon "bottle law," requiring refundable beverage containers and outlawing pull-tab beer cans, has largely succeeded in its primary objective of significantly reducing beverage container litter along the highways. Clearly, to the extent that the law ensures that bottles are reused, it will also have had an effect on the amount of glass appearing in MSW. While more detailed evaluations of the economic, employment, and social impacts of the bottle law are still awaited, the question must be asked whether (if the general conclusion proves to be that it is successful, as well it may be) the precedent has been set for imposing similar requirements on other items, particularly in the container industry. Containers comprise major fractions of MSW, and laws that can lead to more reusable containers and packaging rather than disposable ones could significantly affect the material and energy content of MSW and perhaps make resource recovery less attractive economically. It is essential, therefore, that as new RR techniques are developed and facilities established, they must be adaptable to changing waste compositions. (The problem with changes in composition is that components of an RRF may suddenly be undersized or oversized as a result). From the overall view, reduction in MSW throughputs must be regarded as desirable because it reduces the impact on the environment and the needs for energy; it would be a false sense of priorities to claim that large flows of MSW should be maintained in order to achieve the economies of scale in resource recovery.

It should be noted, however, that the bottle law focuses on return. It does not require reuse. The manufacturer on receiving the returned bottles could place them in the waste stream as he does the cans. It would be an extension of the intent of the law to require reusable containers but this aspect could become a major feature of future legislation which may focus more on conserving material and energy resources, with the prevention of litter a secondary objective. Container standardization is one of the options to be seriously considered. (In this connection it is of interest to note that Denmark is experimenting with standardized bottles).

Product Durability and Repair

Increasing the durability of products and facilitating repair are important strategies for reducing waste streams and the needs for energy and virgin materials. They apply particularly to automobiles, tires, appliances, and other "durable" goods. Most of the day-to-day refuse that makes up the bulk of MSW is of necessity of a short-lived variety--paper and packaging, for example. The scope for reducing the volumes of MSW through measures aimed at increasing product lifetime or service life appears to be limited.

While increasing the durability and repairability of appliances--from refrigerators to electric fans, lamps to television sets, vacuum cleaners to stoves, and so on--could lessen the drain on natural resources (see Appendix C. II.), we feel that it cannot be emphasized too strongly that these considerations are not likely to be the overriding ones in the near-to-medium-term future. The economics and social repercussions could be so great that measures, especially product-specific ones, imposed on industry with the aim of increasing product life should be promulgated, if at all, only after the most careful assessment of their overall effects. Further, if such measures are decided upon, they should be introduced gradually, at a pace which enables society, as well as the industrial and commercial sectors, to make the necessary adjustments without sudden disruptions or dislocations. After the emphasis of the last few decades on cultivating a throw-away attitude it would clearly be a major about-face for society to accord greater priority to durability.

This is not to say that industry itself need not be paying close attention to improving product lifetime. Outside the singular, but important, area of automobiles, there are about 30 million major appliances sold each year. The total stock of appliances in use is about 450 million. Steel is the major materials component (representing about 1.6 percent of total current U.S. demand) in these appliances, but other important materials are aluminum (2.3 percent), copper (4.4 percent), and plastics. Altogether, they represent a material concentration not much less than that for automobiles. Many appliances are at a saturation level in the economy (e.g., refrigerators are found in more than 99 percent of households) with a discard rate equal to the production rate. Under these circumstances, increasing the product life can eventually cause a proportionate reduction in materials consumption.

service life has been increasing somewhat over recent years, and typically lies in the range of 10 to 20 years. In areas other than domestic appliances, product life is often greater--aircraft and telephones, for example, are designed for 20 years, electric and telephone utility equipment 30 to 40 years, and in some extremely critical areas, such as in trans-oceanic communications cables, electronic components are designed for lifetimes up to 100 years. These figures reflect differences in incentives for increased lifetime including difficult-to-quantify factors such as consumer preferences and customs, or concern to minimize total life costs rather than just initial costs when the items are owned and operated by a utility or commercial operator.

Beyond seeking ways to improve the service life directly there is often scope for designing appliances so that they can be more readily repaired. (Black and white TV sets, for example, are now almost cheaper to replace than to repair, and a warranty is provided with a new set, not by a repairman.) Also, unlike the automobile industry, there is little salvage and reuse of parts practiced. Greater standardization of components and modular designs would be useful steps towards encouraging a salvage industry for appliances.

Many of the product design strategies that will become increasingly important fall under the rubric of minimizing the total product-life cost. This is a departure from past attitudes for both producer and consumer alike who, by and large, have usually put highest priority on minimizing first costs.

Product Design and Resource Recovery

Recognition of the desirability of increased recovery of materials from products has led to thought being given to influencing the design and material composition of products to facilitate recovery. This may be feasible for certain, relatively simple items. It is difficult, if not impossible, for instance, to separate the tinned steel bodies of beer cans from aluminum ends. Furthermore, if melted down it is troublesome and expensive to separate the ferrous and nonferrous fractions. All aluminum or all tinplate cans are clearly an easier choice when it comes to recovery, and regulations or standards that require or encourage such rationalizations may be well merited. (Even here, however, different aluminum alloys are used for the bodies and ends as different mechanical properties are needed.)

Regulations have to be considered on an item-by-item basis, however. It would clearly be false economy to stipulate that no products should intimately juxtapose or join aluminum to steel. The same is true for all manner of products, and the more complex or technically sophisticated the product, the more essential it becomes for the product designer to have the freedom to optimize the selection of materials, bearing in mind not only recoverability of material content, but in-service performance and reliability, and life-cycle and first costs as well. In view of the complexity of this area, we believe that it is vital for the manufacturing and emerging resource recovery industries to engage in a continuing dialogue over the development of satisfactory product design guidelines. Professional societies, such as the American Society for Testing and Materials, have an important role to play here. Government agencies can perform the role of initiator and sponsor of such dialogues, where necessary and, where appropriate, might enter into mediation. Once guidelines have been generally agreed to by the industries, incentives might be instituted to encourage the industries to adhere to them, e.g., taxes on designs that fall outside the guidelines.

Guidelines, when agreed to, can cover product design principles and material contents. Besides product designs which are difficult to dismantle and separate into basic components and basic material classes (metals, plastics, ceramics), attention needs to be addressed to such matters as avoiding dispersive uses of the more sparse materials (in coatings, platings, chemicals, and so forth). In particular, we believe much is to be gained by developing such guidelines and standards in consonance with product performance specifications. Also, the guidelines must be sufficiently flexible or re-negotiable that they do not inhibit desirable invention and innovation.

Procurement and Use of Recovered Materials

In line with the necessity of having markets for recovered materials, if resource recovery is to be attractive it is often suggested that such measures as federal and state procurement and/or stockpiling programs for secondary materials would be helpful. Some federal procurement programs specify, for instance, that certain items required by the federal government (e.g., paper, packaging) contain given minimum percentages of recovered materials. As with product design, however, this procedure has to be approached on an item-by-item basis. Some products are less critical as to secondary material content than others. Furthermore, repeated recycling causes a progressive increase in the secondary material content up to a level determined by the base-line percentage of virgin material. The tradeoffs between performance, costs, and material content, as well as the costs of monitoring the related industrial and commercial activity, always have to be carefully evaluated before instituting measures to encourage usage of secondary materials.

Further Thoughts on Influencing the Waste Stream

The measures discussed in this section could provide modest though useful steps in the direction of resource recovery and conservation. But the possibility of dangerous side effects is great. Myopic and over-zealous imposition and enforcement of arbitrary or poorly-conceived standards and regulations could produce economic and social penalties far greater than the resource consumption penalties they were meant to avoid. This whole area of influencing the waste stream through product design, material content, and required markets, needs wide-ranging, in-depth studies before legislative steps are taken. Apart from meeting necessary standards for environmental quality, health, and safety, these are matters that are best left primarily to the industrial and commercial sectors to optimize.

Whenever it is generally concluded, however, that there is a need for legislation, regulation, taxes, or standards in this area, due attention must be paid to how to quantify the laws and standards, how to measure compliance, and to the direct costs to the public of the required bureaucracy and the indirect costs of the inevitable slowing of innovation. Finally, the finite rate at which technology can adapt to and meet new requirements has to be reflected in any legislation.

A VIEW OF THE FUTURE

Underlying the whole of this report is an image of the future. It envisages a society heavily committed to practicing reuse, recycling, and the recovery of energy and materials from wastes. All levels of human ingenuity will be challenged to find ways to use resources effectively and efficiently, to throw as little away as possible at every stage in the materials cycle, to put more emphasis on repair, and to squeeze every possible bit of use out of materials. Such a picture calls for reducing to an absolute minimum the degradation of materials and energy that occurs at every stage in manufacturing, product service, and resource recovery. In other words, the increase in entropy of a material system as a result of manufacturing and process operations must be kept to a minimum. Materials generally need to be kept as close to their original state as possible. Energy must be used as efficiently as possible. To go in one step from an organized material to the disorganized gaseous state, such as in burning paper, *may* be much more wasteful of the chemical energy contained in the material than proceeding through a cascade of secondary uses before the paper is finally fit only for burning. (On the other hand, in the case of paper recycling, the energy needed to repulp and remake the paper has to be weighed against the energy costs of using virgin materials and taking advantage of the stored solar energy that the virgin material represents.)

The immediate need, however, is to launch workable resource recovery operations. It is natural for these to nucleate in the large cities where landfilling sites may be at a premium, but then to spread outwards to embrace regions and states, eventually to become a nationwide system. In this first phase of progress towards the "recycling society," cooperation between local communities, and with the state and federal governments, is vital. It is also imperative for all parties to recognize the need for a coordinated approach rather than a piecemeal, haphazard approach to the development of waste collection and resource recovery systems. It has to be recognized that there is no single, universally-valid, optimum solution; the resource recovery system for a given community or region will reflect many factors which may be peculiar to that community or region. But it is important that activities of one community or region that impinge on those of another should be coordinated and reconciled, predicating the need for some nationally applicable attitudes, standards, and activities.

In a second phase, with resource recovery systems relatively widespread, it would be desirable to extend their capabilities to embrace wastes other than just municipal solid wastes. Sewage and agricultural wastes represent additional sources of fuel, materials, and chemicals, the recovery of which might be most efficiently organized if undertaken within the framework of the systems set up to handle MSW.

In a third phase we foresee increasing emphasis on the totally closed cycling of materials, particularly with a view to containing pollutants whose accumulation in nature would threaten the survival of man.

The nation will be in a better position to meet these challenges of the not-very-distant future if it supports now the establishment and spread of an efficient waste handling system. We foresee such a system as eventually self-supporting, planning its evolution and sponsoring the necessary research, development, and engineering activities in much the same way as does the nationwide telephone system and to an increasing extent, the electrical power system.

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APPENDIXES

The Appendixes comprise a considerable proportion of the data on which the findings and conclusions of the main report are based. They consist of papers presented at a two-day workshop on resource recovery from solid waste held at the National Academy of Sciences on April 3-4, 1975, supplemented by essays contributed by panel members and additional material subsequently provided by participants. Where presentations have been incorporated into the main report, or where they are available in the published literature, they are represented by abstracts or references rather than being reproduced in full. The material has been organized under three topic headings: Appendix A: General; Appendix B: Technical; and Appendix C: Institutional.

The views expressed are those of the individual authors and, unlike the main body of the report, do not necessarily represent a consensus of views of the panel.

WORKSHOP MEETING ON RESOURCE RECOVERY FROM MUNICIPAL SOLID WASTES, HELD AT NATIONAL ACADEMY OF SCIENCES, APRIL 3-4, 1975

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APPENDIX A: GENERAL

A. I: SUGGESTIONS FOR AN "IDEAL" U.S. RECYCLING POSTURE FOR THE YEAR 2000

Franklin P. Huddle

The purpose of this paper is to suggest some ideal patterns of technological, economic, institutional, and management design toward which U.S. policy in the recycling of materials might move. A 25-year horizon is selected as the time frame. The goals toward which the policy needs to move are, broadly, the achievement of a closed cycle of materials flow, at least cost of physical energy and human effort, with least adverse impact on the environment. From this broad statement 10 supporting goals are derived as follows:

1. high retention of all materials in the materials cycle;
2. least use of energy to restore materials from the waste stream;
3. minimum cost of the recycling operation;
4. least possible volume of unrecoverable waste requiring disposal;
5. least possible pollution of land, air, and surface water in the operation of recycling;
6. achievement of the highest feasible level of reuse of each recovered material;
7. prevention of entry into the waste stream of scarcest mineral materials;
8. maintenance of materials throughout the materials cycle, including the waste stream, at the highest practicable energy state;
9. avoidance of contamination through alloying or chemical combination that increases difficulty in recovery of values; and
10. achievement of combined recycling operations towards highest possible total system efficiency, with least requirement for the addition of new quantities of material, and least dollar cost.

A variety of elements today stand in the way of efficient reuse of materials. Some of these invite further research and development but other defects in the system include imperfections in political and social institutions, wasteful practices attributable to industrial and consumer preferences, and economic factors. Among these obstacles are the following:

1. the fragmented and small-scale political jurisdiction with ultimate decision as to the form and technology of the waste management system;
2. the choice of non-reusable over reusable containers;

3. the inchoate configuration of the reprocessing industry;
4. uncertainty of a sound economic base to sustain the recycling phase of the materials cycle;
5. the fixed combination of incompatible materials in items entering the waste stream;
6. the adulteration of the waste stream by materials of large volume and low value;
7. the insufficiency of hard data and documented experience with the wide variety of available technologies for processing wastes;
8. the lack of quantitative information concerning the optimal size of the waste stream to be processed;
9. the lack of technologies for recovering pure elemental materials inexpensively from useless metallic combinations;
10. the consumptive use of scarce metals in unrecoverable forms;
11. the design of durable goods so as to preclude inexpensive disassembly and recovery of materials;
12. the excessive variety of designs of consumer goods so as to preclude recovery and return to inventory of useful components;
13. the needless specification of virgin materials where performance requirements would tolerate use of recycled materials;
14. the variety of metallic alloys and, similarly, the variety of plastic materials with minor differences in composition and properties;
15. the resistance of households and local political jurisdictions to accepting the principle of source segregation of wastes;
16. the absence of functional communication between recycling operators and the designers of consumer items that enter the waste stream;
17. the lack of reserve storage capacity for unprocessed and semiprocessed wastes pending market development;
18. the lack of capital and technical competence to exploit economies of scale in the waste recovery phase;
19. the lack of continuing information about the physical composition of the waste stream;
20. public recognition of the recycling function as an essential element of the closed cycle of materials and ultimately indispensable in the preservation of "life style";
21. the lack of a low cost, effective, and politically acceptable system for source collection, handling, and pre-sorting of wastes; and
22. the existence of competing, and sometimes antagonistic, consumers of waste materials.

Among the questions that need to be answered in order to answer the ultimate question of what the ideal recycling design should be for the United States in the year 2000, are the following:

1. What assumptions should guide the planning of the future design?

2. What are the preferred technological principles to be stressed in the development and selection of processes and methods for recycling of municipal wastes?

3. What extent of public discipline, through taxes, regulatory actions, subsidies, and the like, is to be imposed on the total materials cycle as it relates to recycling?

4. What institutional arrangements are optimal for recycling and to what extent are they politically acceptable and economically practicable?

THE ASSUMPTIONS

It is not necessary, of course, that the assumptions offered below in this format be accepted in toto. They are judged reasonable by the author and collectively provide a picture of the world in the year 2000. To the extent that they are invalid, the picture can be modified.

In addition, there are the usual implicit assumptions of no catastrophic event, natural, diplomatic, economic, or other. The focus is on those assumptions most germane to the subject of recycling, and upon those trends over the next 25 years that are likely to increase public attention to the essentiality of a sound recycling industry in the United States. Among these, the prospect of materials shortages and price increases, on the one hand, and land values in urban areas and environmental quality generally, on the other, warrant emphasis. These seem likely to be secular trends for the long range future.

1. A continuing but slowed-down trend toward increased percentile U.S. employment in services industries; continuing reduction, also slower, in extractive industries and manufacturing.
2. A slight reduction in the population migration from rural areas to urban centers, accompanied by a slight reversal of the outmigration from the central cities to the suburbs.
3. Progressive increase in per capita consumption of all materials in other countries; stabilization and possible reduction in per capita and possibly total consumption of all materials except coal in the United States, as materials price trends continue upward and supplies diminish, with these effects possibly intensified by cartel action.
4. Gradual flattening in the U.S. population curve, approaching zero growth around the year 2000 to 2020.
5. Increased emphasis on product life cost, durability, and maintainability.
6. Reduction in reliance on the automobile, reduction in size and weight of personal transport vehicles, fewer in use, longer operating life, and very substantial reduction in materials and fuel associated with automotive sectors of the economy.
7. Gradual shift of steel industry from emphasis on volume to emphasis on quality and product performance.

8. Progressive increase in pollution prevention and waste recovery research by private industry with substantial tax encouragement for both research and application.

9. Substantially increased federal government intervention in the materials cycle.

10. Closer cooperative relationships and institutions--federal-state-local-educational-private.

In general, the technological principles that should govern the design and functioning of the waste recycling sector of the materials cycle should aim toward completeness, efficiency, ready acceptance of improved methods, and low economic and social costs.

The wide variety of technological options already at hand suggest that as this growing industry advances the competition among the technologies will increase. The technological conservatism of communities in the acceptance of new approaches to recycling is an important obstacle to be overcome by vigorous action at the national level. In addition, the acceptance of new technological approaches requires a positive effort at flexibility, and an assurance to the more venturesome communities that set-backs, malfunctions, and scheduling mishaps do not result in catastrophic backup of the waste flow. Reserve storage capacity and rail/water transport provisions need to be assured in the event of temporary failures of systems.

TECHNOLOGICAL PRINCIPLES

1. Apply systems engineering to the design of the waste stream to facilitate processing and recovery, and prevent entry of harmful contaminants.

2. Design cascades of materials flow of decreasing value, but continuing utility, with the least possible quantity ending up in disposal.

3. Place heavy emphasis on quick replacement of technologically obsolescent capital in recycling industries, with strong federal tax and subsidy encouragement.

4. Emphasize economy of scale and continuous flow over small scale and batch in recycling processes.

5. Seek the widest possible range of inputs to the recycling system instead of permitting concentrations of attention on high-profit material recovery activities.

The kinds and extent of public discipline and federal intervention called for over the next 25 years relevant to the recycling of materials seem unlikely to diminish. On the contrary, the imposition of federal regulations and standards, the use of the federal taxing power, federal support for research and development, the impact of federal procurement specifications, and cooperative federal relations with state and local governments all seem likely to increase. What forms these interventions will take will depend not only upon the trends in materials supply and requirements but also upon the need which local communities and their governments feel (and cannot satisfy unaided) for better waste management facilities and systems.

Technological capability and rate of change as well as economic need and feasibility play a major role in determining political acceptability in this area. The general conclusion seems inescapable that to some extent virtually every form of federal intervention permissible under the Constitution will be invoked during the next 25 years to improve the nation's management of its municipal wastes. The extent of emphasis in each mode of federal intervention will depend upon the political climate at the time the decision is made. The question of what would be an ideal level and direction of this intervention cannot be answered in technical terms. It is possible to identify what technologies are likely to be available, and what control methods can be applied, and to describe an ideal product of their use. But it is not possible to generalize as to whether a subsidy is preferable to a tax easement or vice versa, or that regulation or goverment operation is or is not the preferred way of achieving a desired effect. The following enumeration of governmental mechanisms for encouraging or supporting various recycling approaches is offered, in the recognition that all of them are likely to receive political consideration and probably will be used, but rarely to the full extent possible. The ideal posture is not a question of the federal procedures for obtaining recycling results, but rather the results achieved by some combination of procedures applied at various levels of intensity. Among the possible governmental mechanisms likely to receive legislative or administrative attention are the following:

1. taxes on non-disposables,
2. base load tax rebates to last user,
3. subsidies to municipal waste disposal experiments,
4. support for multi-state regional waste recycling consortia,
5. assistance to railroads and barge lines hauling wastes,
6. government stockpiles of sorted and unsorted municipal waste,
7. government operation of recycling plants, pilot and commercial scale,
8. government contracts to recycling companies to upgrade waste materials in stockpiles,
9. government specifications calling for used or recycled materials,
10. establishment of government centers for technical evaluation and development of processes, and information supply,
11. government preparation or procurement of textbooks and training materials on recycling practice,
12. tax rebates to industries performing inhouse research in recycling technology,
13. loans to municipalities building recycling centers of preferred designs,

14. tuition aids to students taking recycling training courses,

15. conduct of government research and development in recycling problems, and

16. prohibition of items in commerce that make recycling especially difficult or hazardous.

The institutional framework to plan, orchestrate, direct, manage, and monitor the recycling program of the year 2000 is far from complete in 1975. Solid waste is variously considered a problem of materials supply (Bureau of Mines), a problem of urban pollution (Environmental Protection Agency), an industrial problem (Bureau of Standards), an opportunity for energy recovery (Energy Research and Development Administration), and an urban problem (Department of Housing and Urban Development). Similar fragmentation of emphasis is evident in the Congress, where attention is divided among Committees of the Interior and Insular Affairs, Commerce, Public Works, and Science and Technology. Presidential proposals for an omnibus Department of Natural Resources and the suggestion of the National Materials Policy Commission for a Joint Committee of Congress on National Materials policy have attracted little support. The concept of an executive agency to deal with all aspects of materials recycling, or of the entire materials cycle, offers attractive features. Similarly a joint committee, or (more likely) committees in each House of Congress, to oversee the total materials cycle would be most beneficial for the management of this important technical-economic sector. Some form of coherent policy and management structure is needed to enable progress toward the indicated goals.

However, the roles of coherent policy planning and program implementation can be performed by a collection of related institutions, given sufficient coordination in the form of Presidential and Congressional leadership. Such leadership could work toward construction of the various supporting institutions whose collective task would be to design and execute the set of coherent missions required to achieve the goals set forth earlier in this paper. Some illustrative institutions for this purpose are discussed below.

INSTITUTIONAL SOLUTIONS

A. An institution to design, encourage, and support courses in waste recycling technology and management at junior college, college, and graduate levels.

B. A recycling institute for large-scale pilot planting of new recycling technologies, coupled with applied research, information dissemination and collection, preparation of handbooks and manuals, technical consultation, and state of the art reports.

C. An organization to manage and fund the operation of federal stockpiles of wastes being advanced through recycling stages, in association with the commercial recycling and waste recovery industry.

D. An alloy standardization institute to promote simplification in the alloy systems in use in volume applications; a similar institute for plastic materials.

E. An institution at the federal level to assist state and local governments in the planning and implementation of various organizational forms for large-scale management of municipal waste processing, including analyses and recordkeeping to determine reasons for failures and criteria of successful operation. In such an institution, analyses of the composition and quantities of waste materials could also be carried out and statistical data generated. Another function of such an institution could be the contracting of research into economic, social, and political problems of recycle implementation. For example, an intensive inquiry could be mounted in the social sciences on problems of organizing and motivating source separation of municipal wastes.

CONCLUSIONS

The paper has suggested some goals for recycling, has enumerated some of the obstacles to attainment of these goals, and has identified four questions that provide a focus for a planning program to meet the challenge of the goals: basic assumptions, technological principles, the federal role, and institutional arrangements. The omission from this catalog of economic criteria was intentional: economic assessments cannot be undertaken until planning has proceeded through both technological and institutional phases to reach a coherent conceptual design. On a national scale this goal is still a long way off.

However, some illustrative examples were offered to the four questions. These examples may be considered a starting point for a more thorough and detailed analysis of the national problem of materials recycling.

Returning, then, to the assumptions offered in the body of this brief study, it is suggested that there are powerful reasons for mounting an aggressive national effort to achieve the efficient recycling of materials. Shortages can be expected to recur for the indefinite future. Costs of industrial materials are unlikely to remain stable, and are most likely to rise. Problems of disposal of urban wastes are already acute and worsening. Conservation of energy and energy materials is an important benefit accruing from the recycling of wastes. Environmental quality is commanding more and more public attention. For these and other reasons, the recycling of materials appears certain to become a major national enterprise. Either it will become an economically rewarding venture of private initiative or it will be a major service activity of government. Cooperative participation is essential in either case, and those who assume leadership in the cooperative development of programs to meet this certain national need will choose the ways in which it is to be met.

A. II: RESOURCE RECOVERY: THE STATE OF A NEW FOUND ART

Farlan Speer

The art of resource recovery from municipal waste is one which, having once forgotten, we are learning anew; this is reflected in the multiplicity of approaches, both old and newfangled, being taken in the U.S. at this time (see Table II.1), ranging from hand-picking to beneficiation before or after incineration to pyrolysis, composting, or compacting of the organic fraction to generate fuel substances, not to mention pulping and various biodegradation methods. Systems involving all of these techniques, some involving more than one, have reached the pilot-plant stage of development. (See Tables II.2 to II.4.)

The common goal of all approaches to reprocessing of wastes seems to be not so much the recovery of energy or valuable materials from the refuse stream as the need to dispose of wastes in a time of decreased availability of hiding places due to both urban development and increasing citizen concern for the environment--in short, to eliminate the nuisance of city dumps and landfills. The possibility of obtaining some financial return from the recovery and sale of useful commodities is simply another encouragement for further waste treatment.

Because municipalities are not quite certain what they should be getting out of their wastes, there is no uniform approach to their treatment: witness the several attempts to include sewage sludge in the feedstocks of recovery plants, as well as the diversity of approaches taken toward processing of streams of similar composition. What is common to all is that the inadequacy of the waste "management" approach of hiding refuse somewhere out of sight and leaving it is gaining recognition.

Although inadequate, the disposal approach has not yet been fully discredited. (Nor should it be; wastes must be gotten rid of, even if not usefully.) It is still evident in the development of various incinerator-based systems: it is easier to dispose of wastes if their volume can be reduced, and a properly operated incinerator can reduce the volume of wastes by over 90 percent. If it can be done in such a way that heat of combustion is retrieved as merchantable energy--either steam or electricity--then it will be; similarly, if the residue can be processed into a saleable product for a nearby customer, it is another source of valuable residue. Because incinerator-based systems are based on traditional thinking, it is to be expected that they are more highly developed at this time. The Chicago

TABLE II.1 RESOURCE RECOVERY SYSTEMS OFFERED IN THE UNITED STATES

Name–Address	Process Description	Recovery of
All American Engineering Co. Wilmington, Delaware 19899	Shredding, magnetic separation, landfill, paper recovery in future.	Ferrous metals, paper in future.
Allis Chalmers Appleton, Wisconsin 54911	Moltening System: shredding, air classification, landfill, sewage sludge disposal, aerobic decomposition.	Ferrous metals, gas optional.
Americology, Inc. Greenwich, Connecticut 06830	Shredding, air classifying, magnetic, and perhaps aluminum and glass separation.	Ferrous and aluminum metals, glass, landfill, and refuse-derived fuel.
Black Clawson Co. Middletown, Ohio 45042	Hydrasposal/Fibreclaim System: Hydrapulping, metals and glass separation, dewatering for fiber reclaim or refuse-derived fuel.	Ferrous and aluminum metals,[1] glass[1] and paper or steam/electricity.
Browning Ferris Industries Houston, Texas 77001	Shredding, magnetic separation, air classification.	Ferrous metals, and refuse-derived fuel.
Combustion Equipment Associates New York, New York 10022	Shredding, air, magnetic and mechanical separation, optional incineration back-up.	Eco-Fuel® (refuse-derived fuel, ferrous metal, residue.
Combustion Power Company Menlo Park, California 94025	CPU 400: Shredding, air classification, fluidized bed reactor, gas generation, sewage sludge disposal, electrical generation.	Residue and electricity.
Combustion Power Company Menlo Park, California 94025	MRS Option: mechanical, magnetic, and aluminum separation.	Optional ferrous, aluminum, other metals, and aggregate fractions.
Continental Can Company Chicago, Illinois 60620	Shredding, magnetic separation, glass separation, and optional fine shredding for supplemental fuel.	Landfill, ferrous metals, glass, and optional refuse-derived fuel.
Devco Management, Inc. New York, New York 10022	Mechanical corrugated and paper picker, pyrolysis, magnetic separation, aluminum pickers, inert glass fraction, energy recovery option.	Corrugated, mixed paper, ferrous aluminum metals, inert glass fraction, optional energy as heat and cooling.
Ecologenics, Inc. Red Lion, Pennsylvania 17356	Shredding, air and magnetic separation, Insingerating® (combustion) for steam generation.	Ferrous metals, steam/electrical energy.
Engineered Waste Control System Ltd. Winnepeg, Canada R3C ZY4	Uni Hog System: Shredding, metals and glass separation, refuse-derived fuel production.	Ferrous and non-ferrous metals, glass, and refuse-derived fuel.
Envirometrix Incorporated Seattle, Washington 98188	Shredding air and magnetic separation, pyrolysis, gas generation and cleaning, sewage sludge disposal.	Ferrous metals, natural gas.
Garrett Research and Development La Verne, California 91750	Shredding, air classifying, pyrolysis, magnetic separation of steel and aluminum, flotation, color sorting.	Ferrous metals, oil, char, aluminum, glass, plastics optional.
Grumman Ecosystems Corporation Bethpage, New York 11714	Cutting, tumbling, air classifying, mechanical and magnetic separation, pulping, baling, incineration, sterilizing, pulverizing, pelletizing.	Glass, ferrous metal, pulp, energy, animal food.
I. C. Thomasson & Associates, Inc. Nashville, Tennessee 37204	Incineration, waste heat boiler, steam generation, coolant compressors.	Energy: steam and chilled water.
Monsanto Enviro-Chem Systems, Inc. St. Louis, Missouri 63166	Landgard® Process: Shredding, pyrolysis, water quenching, gravity and magnetic separation, steam generation.	Ferrous metal, wet char, steam, and glossy aggregate.
Ovitron Corporation East Stroudsburg, Pennsylvania 18301	Incineration, waste heat boilers, steam generation, electricity generation optional.	Energy: steam/electricity.
Process Plants Corporation College Point, New York 11356	ATI Process: ultra high temperature incineration, waste heat recovery, for optional steam generation.	Steam, frit.
R & M Associates, Inc. Brockton, Massachusetts 02401	J. F. Tracey System: Water and gravity separation, pulping, water filtration and recirculation.	Paper pulp, ferrous, non-ferrous, organic matter, aggregate.
Raytheon Service Co. Burlington, Massachusetts 01803	Coarse shredding, air, gravity, magnetic, and mechanical separation, optical glass sorting.	Ferrous, aluminum, and other non-ferrous metals, color sorted glass, refuse-derived fuel.
Raytheon Service Company Burlington, Massachusetts 01803	Incinerator Residue System: screening, shredding, gravity separations.	Ferrous, aluminum, and copper/zinc metals, glass, aggregate.
SCA Services, Inc. Boston, Massachusetts 02110	Paper picking, shredding, magnetic, mechanical and air separation, refuse-derived fuel production, and cubetting.	Paper, ferrous metals, and refuse-derived fuel.
Sira International, Inc. Los Gatos, California 95030	Shredding, air classifying, screening, ferrous separation, pelletizing.	Ferrous metals, refuse-derived pelletized fuel.
Systems Associates, Inc. Long Beach, California 90802	Shredding, air classifying, screening, magnetic separation.	Ferrous metal, refuse-derived fuel.
Torrax Systems, Inc. North Tonawanda, New York 14120	High temperature incineration, steam generation.	Aggregate, crude metal, glass wool, steam generation.
Union Carbide Corporation Linde Division New York, New York 10017	Purox™ System: Pyrolysis, gas generation, electricity generation optional.	Energy as gas product or electricity.
Waste Management, Inc. Oak Brook, Illinois 60521	Shredding, magnetic separation, paper picking.	Ferrous metals, paper.

SOURCE: NCRR Bulletin *4*, No. 1 (1974).

[1] Uses Garrett separators in Franklin, Ohio, plant.

TABLE II.2 Municipal Resource Recovery Projects--by Type and Product

TYPE/COMMUNITY	MAIN PRODUCT	OTHER PRODUCTS	STATUS	REMARKS
MATERIALS RECOVERY ONLY				
Fort Lauderdale, Fl.	Paper Fiber	Iron, Aluminum	Contract Signed	Residue Incinerated
Franklin, O.	Fiber	Metals, Glass	Operating (Pilot)	Compost Plant closed due to plastic content
Houston, Tx.	Materials		Operating	
Lowell, Ma.	Metals	Glass,	Negotiating	
New Orleans, La.	Glass	Ferrous, Nonferrous	Contract Signed	
Odessa, Tx.	Soil Conditioner		Operating	
COMBUSTION				
Akron, O.	Steam Heat	Ferrous	Testing	Uses paper mill bark boilers
Appleton, Wi.	Steam	Materials	Building	Uses Pyrolysis gas-(below)
Baltimore, Md.	Steam Heat	Metals	Operating (4 yrs.)	
Beverly, Ma.	Steam			Waterwall Incinerator
Braintree, Ma.	Steam		RFP	System Undecided
Chicago, Il.	Steam			Will pyrolyse sewage sludge
Cleveland, O.	High Pressure Steam		Proposals	Some scalping, then recover rest of metals from ashes.
Contra Costa Co., Ca.	Steam	Ferrous, Aluminum		
Dade Co., Fl.	Electricity		Redesign	Emissions Problems
Lexington, Ky.	Iron			
Nashville, Tn.	Steam Heat			
Saugus, Ma.	Steam			
BOILER FUEL & FUEL SUPPLEMENT				
Albany, N.Y.	Shredded Fuel		Planning Proposed	To be burnt in waterwall incinerator 18 mi. away
Ames, La.	Shredded Fuel	Materials	Building	Fuel is for city power plant
Asheville, N.C.	Fuel Pellets		Planning	TVA; Sira Pelletizer
Bridgeport, Ct.	Fuel	Metals, Glass	Building	
Chicago, Il.	Fuel Supplement		Building	
E. Bridgewater, Ma.	Fuel Supplement		Testing	No market for fuel locally (Eco-Fuel I)
Hackensack Meadowlands, N. J.	Fuel Supplement		Negotiating	Eco-Fuel II
Hempstead, N. Y.			RFPs out	
Honolulu, Hi.	Fuel		RFPs out	To use municipal refuse and cane trash
Housatonic Valley, Ct.	Fuel	Materials	Planned	
Lane Co., Or.	Boiler Fuel		Feasibility Study	Municipal boiler, now using wood waste
Los Angeles, Ca.	Fuel Supplement		Talking	For city power plant
Madison, Wi.	Boiler Fuel	Ferrous	Feasibility Study	Recovering from now
Memphis, Tn.	Pumped Fuel Supplement		Design	Will consume sewage-sludge; drying by incinerator
Milwaukee, Wi.	Fuel	Ferrous Corrugated Paper	Negotiating	May become part of state system
Monroe Co., N. Y.	Fuel Supplement		Contracted	
Montgomery Co., Md.	Fuel Supplement	Magnetic Metals	Feasibility Site Study	
Montgomery Co., O.	Shredded Fuel		Investigating	USBM Process
Muscle Shoals, Al.	Fuel Pellets		Planned	TVA Plan
New Britain, Ct.	Fuel Supplement		Proposed	
Paducah, Ky.	Pellet Fuel		Planned	Sira System; TVA Financed and owned.
Palmer Township, Pa.	Pellet Fuel		Awaiting Approval	Fuel is for cement kiln-to be mixed with coal
New York, N.Y.	Fuel Supplement	Ferrous	Proposed	
St. Louis, Mo.	Fuel	Metals, Glass	2000 T/D Built, next 6,000 planned	
Toledo, O.	Fuel Supplement	Ferrous		
Washington, D.C.	Fuel Supplement		Pilot-Building	Fuel to next door power plant, want operational by 9/75
Wilmington, Dl.	Supplementary Fuel Compost		Planning	To use sewage sludge
BIOCONVERSION				
Los Angeles, Ca.			Talking	
PYROLYSIS				
Baltimore, Md.	Gases	Iron, Glass	Building	Burnt directly in steam plant -- see above
Charleston, W. Va.	Gas (300 BTU)		Testing	Pilot Plant
Denver, Co.			Planning	
Knoxville, Tn.	Gas or Solid Fuel	Aluminum, Glass, Ferrous	Feasibility Study	Torra System; TVA-financed
Minneapolis, Mn.	Gas, Oil	Ferrous, Aluminum, Glass, Activated Char	Design	Manual Separation of byproducts
Mt. Vernon, N.Y.	Gas		Plan	Produce and sell electricity; U.C. Purox system
San Diego Co., Ca.	Liquid Fuel		Building (Start '75)	For electric generation
Seattle, Wa.	Methane		General interest	Would convert to methanol; financing touchy
Westchester Co., N. Y.	Gas	Materials	Part of County Plan	Also considering incinerator recovery and thermal reduction. Part of ecology - industrial park with customers next door
OTHER				
Denver, Co.			Regional Planning Feasibility Study	

TABLE II.3 RESOURCE RECOVERY PROCESSES

			State of Development			Process Economics				
Type and Process (Developer)	Main Product	Other Products	State	Location	Capacity T/D	Capital Cost $/T/D	Running Cost $/T	Revenue $/T	Net Cost $/T	Sponsor
Energy Recovery (Direct) CPU-400 (Combustion Power Co.)	Electricity	Metals, Glass, Sand, Fly Ash	Pilot-Starting late '72	Menlo Park, Ca.	80[1] 1,000[2]	9,306	3.23[3,4]	5.78[4]	(2.55)[4]	EPA
American Thermogen, Inc.	Steam	Slag Frit	Pilot		1,650[5]	10,300	4.16[3,4] 6.42[6]	3.01	3.41	Fed. Grant & Developer
TORRAX (Torrax Systems, Inc.)	Steam	Ferrous, Slag	Demonstrator	Erie County, N.Y.	75[7] 300[2]	20,000[7] 15,000[8]	[9]	[9]	[9]	AGA, Fed. State, Local Govt.
Chicago Northwest Incinerator (Ovitron Corp.)	Steam	Magnetic Metals	Commercial since '71	Chicago, Illinois	1,600	14,400	4.00-6.00[10]	[36] 11.00	[9]	City
IBW-Martin, Montreal Von Roll Incinerator										
(Von Roll LTD-Canada)	Steam		Plant completed 1970	Montreal P.Q. Canada	1,200	12,500	7.00[10]	3.50[10,11]	2.00-3.50[10]	City
(Von Roll AG, Zurich)	Electricity Steam		Operational 1969	Zurich, Switzerland	520	[9]	[9]	[9]	[9]	City
(Von Roll AG, Zurich)	Electricity Steam		Operational 1969	Basel, Switzerland	600	[9]	[9]	[9]	[9]	City
Issy-les-Moulineaux Treatment Industrial (des Residues Urbains)	Electricity	Steam, Scrap	Operational 1965	Paris, France	1,500	15,300	7.70	2.88	4.62	City
Munich Norm Incinerator & Power (Benson, Martin)	Electricity		Operational 1967	Munich, Germany	1,056	16,900	5.67[12] 13.97[13]	1.97	12.00	City
Munich South (Kraftwerk)	Electricity, Heat		Operational 1969	Munich, Germany	960	[9]	[9]	[9]	[9]	City
Osaka-Generating Plant (Nissui-Yodo Plant)	Electricity		Installed '66	Osaka, Japan	400	[9]	[9]	[9]	[9]	City
Isogo Refuse Incinerator (Isogo-Yokohama)	Steam		Operating since '68	Isogo, Japan	450	[9]	[9]	[9]	[9]	City
Fuel Recovery Horner & Shifrin	Fuel	Magnetic Metals	Demons. Plant '72	St. Louis, Mo.	650[14]	[9]	[9]	[9]	[9]	EPA, City Union
Kinnet Thermal Recovery System (A. M. Kinney, Inc.)	Fuel	Metals, Glass, Paper, Fiber	Proposed		1,000	5,175	3.92	2.49	1.43	Electric Kinney
Hydrogenation (U.S.B.M.)	Oil (Low-S)		Bench, Pilot		100-500[15]	[9]	[9]	[9]	[9]	USBM
Energy & Materials Recovery (Memphis State U.)	Fuel	Fibers, Ferrous, Glass, Aluminum	Conceptual Proposal	Memphis, Tenn.	3,000	5,025	0.66[16] 2.99[13]	3.95[17]	.95	City
Garret Pyrolysis	Oil Char	Metals, Glass	Pilot '71 Demons. (proposed)	LaVerne, Ca. San Diego, Ca.	2-4 200 2,000[2]	6,960	3.86[18]	5.84	(1.98)	GRDE
Oxygen Refuse Converter (Union Carbide)	Gas	Slag	Pilot '71 Demons. (proposed)		5 200	10,734	4.27[16] 8.44[13]	4.00	4.45	Carbide
Landgard (Monsanto Enviro-Chem)	Gas Fuel	Metal, Glass, Aggregate	Pilot, 1970-72 Demons.	Baltimore, Md.	35 500 1,000[2]	11,620[4]	8.08[13] 5.14[3]	5.31	2.77	Monsanto EPA
USBM, Pyrolysis (USBM)	Oil, Tar, Gas	Char	Lab.	Pittsburgh, Pa.	[9]	[9]	[9]	[9]	[9]	Interior
Battelle Pyrolysis-Incineration (Battelle-Northwest)	Fuel Gas	Slag	Pilot-Operating Demons. (proposed)	Kennewick, WN.	10 100-200	[9]	[9]	[9]	[9]	EPA

SOURCE: Midwest Research Institute, 'Resource Recovery and Catalogue of Process' Report to CEQ, 1973.

[1] Pilot plant.
[2] Commercial plant.
[3] Amortized capital costs not included.
[4] Based on commercial-scale plant.
[5] Proposed.
[6] Including capital cost.
[7] Demonstration plant.
[8] Subsequent plants.
[9] Not reported.
[10] Estimated.
[11] From sale or steam.
[12] Fuel only.
[13] All costs.
[14] Two shifts.
[15] Gal/hr. waste slurry.
[16] Direct costs.
[17] Gross revenues from materials sale.
[18] Excludes depreciation.
[19] Tons/hour.
[20] Magnetics, Al, Cu, Zn, stainless.
[21] Ferrous, Al, Cu-Zn.
[22] Per shift.
[23] Excluding land, interest, auxiliaries.
[24] No allowance for transportation of residue from remote incinerators.
[25] Color sorted.
[26] Disposal fees.
[27] Total.
[28] Plus 230 T/D sewage sludge.
[29] Per ton refuse.
[30] Per ton all inputs.
[31] Per 12 hrs.
[32] Feed: bagasse.
[33] Tons bagasse/month.
[34] Per pound product.
[35] Market value not established.
[36] Per ton metals; steam, value not established.

TABLE II.4 PRODUCTS FROM COMMERCIAL AND PILOT-SCALE RESOURCE RECOVERY PROCESSES (U.S. INSTALLATIONS)

	Metals								Glass				Organics					Energy						
	Nonmagnetic				Others				Colors									Direct		Fuels				Other
Process or System	Mixed	Ferrous	Mixed	Aluminum	Mixed	Copper	Other	Mixed	White	Mixed	Green	Amber	Paper	Fiber	Plastics	Compost	Other	Electricity	Steam	Gas	Oil	Char	Fuel Supp.	
San Francisco Recovery		X		X	X	X	X																	
Black Clawson		X		X	X				X		X	X		X					1					
Garrett Pyrolysis		X	X	X				X		X	X										X	X		
USBM Incinerator Residue Recovery		X		X	X				X	X														
Raytheon		X		X	X			X																
Kinney Thermal Recovery		X	X	1	1			1					X[3]										X	
NCRR		X	X							X	X			X										
Solid Waste Separator		X	X					X					X		X									
CPU-400		X	X					X										X[4]						5
Union Electric		X	X					X															X	
Landgard		X	X																1	1		X		6
BFI		X							X					X										
All American		X														X								
Rust-Milwaukee[7]		X																		X		X[8]	X	
Torrax		X																	X				1	9
Martin System		X																1	X					
Horner & Shifrin		X																					X	
FPL Recovery	X							X						X					X					
USBM Refuse Separator	X																						10	
CEA	1																						X	
Cellulose Bioconversion																	11							
Fairfield-Hardy																X								
Varro																X								
American Thermogen																			X					12
Von Roll System																		1	X					
Battelle Pyrolysis-Incinerator																				X				9
Pyrox Oxygen Refuse Converter System																				X				9
USBM Hydrogenation																					X			
Albany-Ames-Memphis																							X	

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[1] Optional.
[2] Zinc; stainless steel.
[3] Paper fiber recovered in Black-Clawson Hydrapulper Unit.
[4] Pyrolysis gas burned in gas turbine.
[5] Sand.
[6] Aggregate.
[7] Input includes sewage sludge.
[8] Activated.
[9] Slag.
[10] Entire organic fraction as "Mixed combustible."
[11] Protein; cattle feed.
[12] Slag frit.

Northwest incinerator, based on the Martin design, has been operating commercially since 1971, for example.

Incinerators have their problems; most obviously, they can themselves be sources of air pollution. (The Nashville plant, which was to have provided central steam heat, is being redesigned because of emissions problems, for example.) Large cities such as Washington have placed strict restrictions on apartment house incinerators (thus creating an instant market for compactors since the volume must be reduced somehow, storage space in apartment buildings being at a premium) although central municipal incinerators to handle the resulting glut of unburned trash are not necessarily ruled out; if nothing else, it is simpler to handle efficiently emissions at one large plant than in a myriad of small ones. The ash screens generally used on the flues are another trouble source: on the one hand, charred paper fragments clog them and shut off the draft; on the other, hydrogen chloride from burning chlorinated plastics can cause several corrosion problems. Corrosion is also encountered in high temperature incinerators where slag forms and attacks grates; boiler tubes in waterwall incinerators can also be attacked by both hot ash and corrosive gases. A problem arising in systems recovering energy is the need for controlling combustion so as to maintain the desired temperature in the flame; this can call for the use of fossil fuel.

By scalping out deleterious materials--glass, metals, chlorinated plastics--prior to combustion, it is possible to make incinerators as reliable as boilers, or the remaining organic material can be burned in an ordinary boiler as a supplemental fuel.

The organic fraction of municipal solid waste is at best a low-grade fuel--low density, high moisture content, low heat of combustion. If, however, there is a steady demand for steam, whether for central heating or for electrical power generation, boilers can be designed to use this fuel efficiently; or it can be blended with coal and burned in a conventional boiler, in which case the low heat value (about 4,000 BTU/ton) will limit the amount that can be used to about 30 to 35 percent, a composition that, if eastern bituminous coal is used, will give an average heat value similar to that of low-sulfur western coal.

This approach is receiving serious consideration in approximately two dozen municipalities. Union Electric is currently planning to triple the capacity of their St. Louis, Missouri, plant, which has been operating for two years, and several other municipalities are planning on building their own refuse-burning steam plants.

Waste-based fuel supplement can be upgraded somewhat by drying and compacting, but even so it is still too low in heat value to warrant shipping very far and cannot be stored out-of-doors. Further upgrading can be done--generally by pyrolysis--to produce a more concentrated, shippable, and storable fuel. Pyrolysis processes have been developed that will convert wastes to oil-type fuel, to gas, and even to tars and chars which are, however, usually burned on site to provide the heat for pyrolysis. Products of pyrolysis may also be useful as chemical feedstocks. Other fuel-conversion processes involve partial oxidation or hydrolysis and bacterial digestion. The former can produce methanol, glucose, or other chemical intermediates; the latter, methane. Composting has also been attempted repeatedly, but to date such efforts have failed, either because of failure to scalp out plastics or because of lack of market.

To date, the processes that appear most promising have been those which reclaim the inorganic portion--plus polymers, paper fibers, or other useful materials. Separation of ferromagnetic materials is comparatively simple; other separations, however, require more advanced techniques based on methods used in ore-dressing; air classification, sink-float, froth flotation, and high-intensity magnetic separation are all adaptable to waste streams. Hand-picking can be used to sort out readily spotted and easily moved components such as paper and cardboard, and high-speed machines using essentially the same method--inspecting and removing individual particles--are used to color-sort glass cullet and clean it of remaining ceramic and metallic impurities; it is possible that this method will eventually be used to separate the heavier nonmagnetic metallics--copper, especially--from stainless steels. The range of directly useful products obtainable by strictly mechanical procedures extends from paper, cellulose fibers, and plastics through glass of various colors to metals: ferromagnetic alloys, aluminum, copper, and other nonmagnetics. Because mechanical separation involves less energy than smelting, removal of metals is economically attractive for relatively lean feeds--9 to 10 percent Fe compared with 30 percent Fe in taconite ores; 1 percent Al compared with bauxite containing 20 to 30 percent Al; and 0.4 percent Cu, compared with ores being mined today ranging down to 0.5 percent. Even now, the aluminum industry is writing specifications that will enable them to make maximum use of the mixture of aluminum alloys found in municipal waste; similarly, the glass industry is rewriting specifications for reclaimed cullet. Ferrous metals reclaimed from raw refuse find a ready market as #2 dealer bundle scrap; incinerated ferrous scrap may be used in ferro-alloy smelting and copper cementation.

The next logical step would appear to be to minimize mixing of wastes; however, this is not the case. Assuming that clean separation is possible, segregation at the source requires total public cooperation, which is unlikely. Anything short of clean separation will necessitate installation of a complete sorting system. In large cities, where sheer volume of refuse and compactness of habitat may be used to justify separate or special pickups, some pre-sorting of papers, or of appliances (which are rich in metals and glass) is feasible, but suburban and rural trash collectors are unlikely to be easily able to do the same in their territories, at least where separation is not already an ingrained habit. As shown by the composition figures in Table

II.5, many communities do provide separate collection of food or yard wastes, but the general case may be expected to involve a thoroughly mixed trash stream.

The net effect of presegregation on the volume and composition of the stream is shown in Tables II.6 and II.7. As can be seen, only in the case of containers and appliances, combined, are the inorganic components both available in significant amounts and concentrated to any appreciable degree. Containers, however, include glass bottles and cans, which are too often discarded on the street or elsewhere rather than into the general trash stream. The so-called bottle legislation will have the same effect on the trash stream as roadside littering: the glass and aluminum content of the stream is depleted. The net effect of any depletion is, of course, to reduce the value contained in the main stream and thus the incentive to attempt materials recovery.

The institutional structure supporting solid waste recovery is unsettled. Seventeen states have involved themselves officially in resource recovery (Table II.8), using nearly as many different organizational approaches. Table II.9 lists some 40 municipalities (cities, counties, townships, regional bodies) and the TVA, which are considering planning, building, or operating resource recovery systems, backed by various combinations of federal, state, and local grants, loans, and taxes with private financing by both institutions and the recovery contractors themselves. A more detailed description of state and local activities is provided by Table II.10.

Outside areas with large, concentrated populations, regional authorities will most likely become the rule, drawing on as large an area as the economics of trash transportation--and the local voters--will permit. Regional to statewide organization of waste recovery and disposal is a prominent feature of most state plans. The typical state role is that of overseer, setting standards for operation of local authorities and plants and, generally, lending or granting funds to the municipalities involved. Notably in Connecticut, the size and operating budget of the state body is limited by statute, confining the state's role to financing and general oversight. At this time, the only states west of the Mississippi which have established statewide resource recovery bodies are California, Hawaii, and Washington. In other western states, population is more scattered and thus there is less incentive to combine municipalities into regional bodies.

The chief economic deterrents to resource recovery are transportation, taxation, and marketability, the last being related to the first, since marketability is enhanced if sufficient supply exists to warrant a lower freight rate, or, conversely, if a guaranteed market exists, railroads will adjust rates somewhat. The chief factor in the relatively high freight rates for scrap and reclaimed materials compared with virgin metals and concentrates is the relative quantity in which each is produced at any plant and the distance to market. In general, secondary materials recovery plants are too small and too close to

TABLE II.5 SURVEYS OF THE COMPOSITION OF MUNICIPAL SOLID WASTE IN THE U.S.

Study	Food	Yard	Misc.	Glass	Metal	Est. Ferrous	Ferrous	Al.	Non-Ferrous	Paper	Plastics	Textiles	Wood	Leather Rubber	Source
Oceanside, N.Y.	9.6	33.3		9.7	8.0	7.0				32.8		3.0	1.2		1
	10.2	19.0		9.5	8.2	7.2				39.8		3.3	6.6		1
Cincinnati, O.	28.9	6.4		7.5	8.7	7.7				42.0	1.6	1.4	2.7		2
Oceanside, N.Y.	16.7	0.3		11.9	10.6	9.6				53.3		2.2	1.5		1
Flint, Mich.	29.1	26.7		12.7	14.5	13.5				13.0		0.3	1.0		2
Johnson City, Tenn.	21.1	0.9	0.6	7.0	7.5	6.5				59.8	0.9		0.3	0.6	2
San Diego, Cal.	0.8	21.1		8.3	7.7	6.7				46.1	0.3	3.5	6.4	4.7	2
Berkeley, Cal.	12.5	12.5	7.1	11.3	8.7	7.7				44.6	1.9	1.1		0.3	3
Raleigh, N.C.	31.8	8.4		11.9	9.2	8.2				38.9					4
Santa Clara Co., Cal.	2.1	34.5	0.5	10.9	7.4	6.4				36.2	1.5	1.3		1.1	5
Flint, Mich.	36.0	0.3	0.7	23.2	14.5	13.5				21.1		0.8	0.8		2
Weber Co., U.	8.5	4.2	5.9	4.6	8.4	7.4				61.8		2.0	2.2		2
Johnson City, Tenn.	34.6	2.3	0.2	9.0	10.4	9.4				34.9	3.4	2.0	0.8	2.4	2
New Orleans, La.	18.9	9.2		16.2	12.2	11.2				39.4		2.6			6
Alexandria, Va.	7.5	9.5	3.4	7.5	8.2	7.2				55.3		3.7	1.7		2
Atlanta, Ga.	12.3	1.6	3.4	10.3	8.6	7.6				58.6		1.8	0.4		2
	17.5	2.8	3.4	6.5	8.8	7.8				53.2		2.0	3.2		2
New Orleans, La.	18.9	9.2	1.5	16.2	12.2	11.2				39.4		2.6			2
				13.0			8.8	1.0			3.8				7
Tampa, Fla.	9.1	41.5	6.1	6.0			4.8	0.8	0.3	24.1	2.4	2.8	1.5	0.6	8
Wilmington, Del.	16.5	9.0	2.9	14.7			5.7	0.6	0.3	33.7	3.3	8.9	2.5	1.9	8
San Diego, Cal.	0.8	21.1		8.3	7.6	6.6				46.2	0.3	3.5	7.5	4.7	9
Madison, Wisc.	15.3	13.8	9.0	10.1	6.7	5.7				42.4		1.6	1.1		10
Purdue, U. of	12.0	12.0	15.4	6.0	8.0	7.0				42.0	0.7	0.6	2.4	0.9	11
Kaiser, E.R.	8.4	6.9	12.0	7.7	6.9	5.9				53.5	0.8	0.8	2.3	0.8	12
Little, A.D.	16.6	12.6	1.7	8.5	8.7	7.7				44.2	1.2	2.3	2.5	1.7	13
Battelle Institute	14.0	5.0	3.0	9.0			7.5	1.0	0.5	55.0	1.0		4.0		14
Averages	14.6	12.5	4.5	10.3	9.2	8.2	6.7	0.9	0.4	42.7	1.7	2.4	2.5	1.8	

Source: NCRR Bulletin, 3 No.2 (1973)

TABLE II.6 EFFECTS OF SOURCE SEPARATION ON COMPOSITION OF WASTE STREAMS (NATIONAL AVERAGES SOURCE)

	'71 Total Disposed		(1) Printed Matter Only		(2) Containers and Packaging		(3) Papers, Containers, Packaging		(4) Food Products		(5) Food and Papers Only		(6) Food, Papers, Containers		(7) Appliances Only		(8) Appliances, Containers, Packaging		(9) Papers, Appliances, Containers		(10) Food, Papers, Appliances, Containers	
	10^6 tons	%	10^6 tons	%	10^6 tons	%	10^6 tons	%	10^6 tons	%	10^6 tons	%	10^6 tons	%	10^6 tons	%	10^6 tons	%	10^6 tons	%	10^6 tons	%
Main Stream:																						
Paper	47.3	37.8	37.0	32.3	26.9	32.4	26.9	37.0	47.3	44.1	37.0	38.1	16.6	30.1	47.3	38.4	26.9	33.2	16.6	23.6	16.6	31.3
Glass	12.5	10.0	12.5	10.9	1.4	1.7	1.4	1.9	12.5	11.6	12.5	12.9	1.4	2.5	12.5	10.2	1.4	1.7	1.4	2.0	1.4	2.6
Metal	12.6	10.1	12.6	11.0	6.5	7.8	6.5	8.9	12.6	11.7	12.6	13.0	6.5	11.8	10.7	8.7	4.6	5.7	4.6	6.5	4.6	8.7
(Ferrous)	(11.3)	(9.0)	(11.7)	(9.9)	(5.8)	(7.0)	(5.8)	(8.0)	(11.2)	(10.5)	(11.2)	(11.5)	(5.9)	(10.7)	(9.6)	(7.8)	(4.2)	(4.2)	(5.9)	(5.9)	(4.2)	(7.9)
(Aluminum)	(.9)	(.7)	(.9)	(.8)	(.3)	(.4)	(.3)	(.4)	(.9)	(.8)	(.8)	(.8)	(.3)	(.5)	(.8)	(.7)	(.2)	(.2)	(.2)	(.3)	(.2)	(.4)
(Other Non-Magnetic)	(.4)	(.3)	(.4)	(.3)	(.3)	(.4)	(.3)	(.4)	(.4)	(.4)	(.4)	(.4)	(.3)	(.5)	(.3)	(.2)	(.2)	(.2)	(.2)	(.3)	(.2)	(.4)
Plastic	4.7	3.8	4.7	4.1	2.2	2.6	2.2	3.0	4.7	4.4	4.7	4.8	2.2	4.0	4.6	3.7	2.1	2.6	2.1	3.0	2.1	4.0
Rubber, Leather	3.4	2.7	3.4	3.0	3.4	4.1	3.4	4.7	3.4	3.2	3.4	3.5	3.4	6.2	3.3	2.7	3.3	4.1	3.3	4.7	3.3	6.2
Textile	2.0	1.6	2.0	1.7	2.0	2.4	2.0	2.7	2.0	1.9	2.0	2.1	2.0	3.6	2.0	1.6	2.0	2.5	2.0	2.8	2.0	3.8
Wood	4.6	3.7	4.6	4.0	2.8	3.4	2.8	3.8	4.6	4.3	4.6	4.7	2.8	5.1	4.6	3.7	2.8	3.5	2.8	4.0	2.8	5.3
Food	17.7	14.2	17.7	15.4	17.7	21.3	17.7	24.3	0	0	0	0	0	0	17.7	14.4	17.7	21.9	17.7	25.0	0	0
Yard Waste	18.2	14.6	18.2	15.9	18.2	21.9	18.2	25.0	18.2	17.0	18.2	18.8	18.2	33.0	18.2	14.8	18.2	22.5	18.2	25.7	18.2	34.3
Misc. Inorganic	1.9	1.5	1.9	1.7	1.9	2.3	1.9	2.6	1.9	1.8	1.9	2.0	1.9	3.4	1.9	1.5	1.9	2.3	1.9	2.7	1.9	3.6
Total Weight	125.0		114.7		83.1		72.8		107.3		97.0		55.1		122.9		81.0		70.7		53.0	
Minimum Number of Streams Generated	1		2		2		2		2		2		3		2		2		2		3	
Side Streams:																						
Paper	NO SIDE STREAMS		10.3	100	20.4	48.7	30.7	58.8	–	–	10.3	36.8	TWO SIDE STREAMS: FOOD (Col. 4) AND PAPER AND CONTAINERS (Col. 3)		–	–	20.4	46.4	30.7	56.5	TWO SIDE STREAMS: FOOD (Col. 4) AND PAPERS, APPLIANCES, CONTAINERS (Col. 9)	
Glass			–	–	11.1	26.5	11.1	21.3	–	–	–	–			–	–	11.1	25.2	11.1	20.4		
Metal			–	–	6.1	14.5	6.1	11.7	–	–	–	–			1.9	90.5	8.0	18.2	8.0	14.7		
(Ferrous)			–	–	(5.4)	(12.9)	(5.4)	(0.3)	–	–	–	–			(1.7)	(81.0)	(7.1)	(16.1)	(7.1)	(13.1)		
(Aluminum)			–	–	(1.6)	(1.4)	(.6)	(1.2)	–	–	–	–			(.1)	(4.8)	(.7)	(1.6)	(.7)	(1.3)		
(Other Non-Magnetic)			–	–	(.1)	(.2)	(.1)	(.2)	–	–	–	–			(.1)	(4.8)	(.2)	(.5)	(.2)	(.4)		
Plastic			T	–	2.5	6.0	2.5	4.8	–	–	T	–			.1	4.8	2.6	5.9	2.6	4.8		
Rubber, Leather			–	–	T	–	T	–	–	–	–	–			.1	4.8	.1	.2	.1	.2		
Textiles			T	–	T	–	T	–	–	–	T	–			–	–	T	–	T	–		
Wood			–	–	1.8	4.3	1.8	3.4	–	–	–	–			–	–	1.8	4.1	1.8	3.3		
Food			–	–	–	–	–	–	17.7	100	17.7	63.2			–	–	–	–	–	–		
Yard Waste			–	–	–	–	–	–	–	–	–	–			–	–	–	–	–	–		
Misc. Inorganic			–	–	–	–	–	–	–	–	–	–			–	–	–	–	–	–		
Total			10.3		41.9		52.2		17.7		28.0				2.1		44.0		54.3			

TABLE II.7 MAXIMUM RECOVERY TO SIDE STREAMS BY SOURCE SEPARATION, BY PERCENT

	AFTER PRESEGREGATION OF															
	Papers Only		Containers & Packaging Only		Papers and Containers Combined		Food Only		Food and Papers Combined		Appliances Only		Appliances & Containers Combined		Papers, Appliances & Containers	
	Main	Side	Main	Side	Main	Side	Main	Side	Main	Side	Main	Side	Main	Side	Main	Side
Paper	78.3	21.7	56.9	43.1	35.1	64.9	100	-	78.3	21.7	100	-	56.9	43.1	35.1	64.9
Glass	100	-	11.2	88.8	11.2	88.8	100	-	100	-	100	-	11.2	88.8	11.2	88.8
Metal	100	-	51.6	48.4	51.6	48.4	100	-	100	-	84.9	15.1	36.5	63.5	36.5	63.5
(Ferrous)	100	-	51.3	48.7	51.3	48.7	100	-	100	-	83.2	16.8	37.2	62.8	37.2	62.8
(Aluminum)	100	-	33.3	66.7	33.3	66.7	100	-	100	-	88.9	11.1	22.2	77.8	22.2	77.8
(Other Non-magnetic)	100	-	75.0	25.0	75.0	25.0	100	-	100	-	75.0	25.0	50.0	50.0	50.0	50.0
Plastic	100	-	46.8	53.2	46.8	53.2	100	-	100	-	97.9	2.1	44.7	55.3	44.7	55.3
Rubber, Leather	100	-	100	-	100	-	100	-	100	-	97.1	2.9	97.1	2.9	97.1	2.9
Textiles	100	-	100	-	100	-	100	-	100	-	100	-	100	-	100	-
Wood	100	-	60.9	39.1	60.9	39.1	100	-	100	-	100	-	60.9	39.1	60.9	39.1
Food	100	-	100	-	100	-	-	100	-	100	100	-	100	-	100	-
Yard Waste	100	-	100	-	100	-	100	-	100	-	100	-	100	-	100	-
Misc. Inorganic	100	-	100	-	100	-	100	-	100	-	100	-	100	-	100	-
TOTAL	91.8	8.2	66.5	33.5	58.2	41.8	85.8	14.2	77.6	22.4	98.3	1.7	64.8	35.2	56.6	43.4

TABLE II.8 STATE RESOURCE RECOVERY INVOLVEMENT

	Grant/Loan Authority	Planning and/or Regulation	Operating Authority
California	X	X	
Connecticut		X	X
Florida	X	X	X
Hawaii		X	
Illinois	X		
Maryland	X		
Massachusetts		X	
Michigan	X	X	X
Minnesota	X	X	
New York	X	X	
Ohio	X	X	X
Pennsylvania	X	X	
Rhode Island		X	X
Tennessee	X		
Vermont		X	
Washington	X		
Wisconsin		X	X
TOTALS	11	13	5

TABLE II.9 COMMUNITY RESOURCE RECOVERY ACTIVITIES - STATUS

System Operating	System Under Construction		System Selected — Construction not started		Planned or Committed - No System Decision	Other Communities
		Expected Start up		Construct Start		
Braintree, Ma.	Ames, Ia.	11/74	Hempstead, NY.		Akron, O.	Appleton, Wi.
Charleston, W.Va.	Baltimore, Md.		Lowell, Ma.		Albany, NY.	Asheville, NC.[1]
Chicago, Il.	Bridgeport, Ct.		Milwaukee, Wi.		Cleveland, O.	Boston, Ma.
E. Bridgewater, Ma.	Broward Co., Fl.		Monroe Co., NY.	1975	Contra Costa Co., Ca.	Berkeley, Ca.
Franklin, O.	Chicago, Il.		New Britain, Ct.		Dade Co., Fl.	Brevard Co., Fl.
Nashville, Tn.	New Orleans, La.		St. Louis, Mo.[2]		Housatonic Valley, Ct.	Denver, Co.
Odessa, Tx.	Saugus, Ma.		San Diego Co., Ca.		Memphis, Tn.	Hackensack Meadowland, NJ.
Saugus, Ma.					Milwaukee, Wi.	Honolulu, Hi.
St. Louis, Mo.[3]					Minneapolis, Mn.	Houston, Tx.
					Mt. Vernon, NY.	Knoxville, Tn.
					New York, NY.	Lane Co., Or.
					Palmer Township, Pa.	Lexington, Ky.
					Toledo, O.	Los Angeles, Ca.
					Westchester Co., NY.	Madison, Wi.
					Wilmington, Dl.	Montgomery Co., Md.
						Montgomery Co., O.[4]
						Muscle Shoals, Al.
						New York, NY.
						Onondaga Co., NY.
						Paducah, Ky.
						Seattle, Wn.
						Washington, D.C.

Source: Hopper, 1974

Notes:
1/ Tennessee Valley Authority Project
2/ Plant Expansion
3/ Domestic Plant
4/ Dayton

TABLE II.10 MUNICIPAL RESOURCE RECOVERY PROJECTS: CURRENT STATUS

Region, State, Municipality	Status	Main Product	Other Products	Project Type or Plans Type	Capacity T/D	Capital Cost $1,000	Financing	Remarks
NEW ENGLAND								
Connecticut								
Connecticut Resources Recovery Authority (C.R.R.A.)	Enacted			State Authority: Planning, financing, regulation, rate setting.	[1]	250,000[2]	Revenue bonds	Community participation voluntary. Design, construction, and operation by private sector.
Berlin (Greater Hartford)[3]	Contracted	Fuel for boiler						Contractor: Combustion Equipment Associates (CEA)
Bridgeport[3]	Contracted	Fuel, 1,000 T/D	Metals, glass, plastics	Separation & pyrolysis	1,800	29,000	C.R.R.A.	Contractor: Garrett Research & Development (GRDC)
Housatonic Valley	Contracted	Fuel for boiler	Materials		1,500	35,000[4]	C.R.R.A.[5]	Contractor: C.E.A.
New Britain	Proposed	Fuel for boiler			1,800	22,000	Revenue bond	Contractor: C.E.A.
Massachusetts								
Mass. Dept. of Public Public Works, Bureau of Solid Waste Disposal				Statewide Plan				Facilities to be privately financed & owned, state controlled
Greater Lawrence Area	RFPs being prepared							First region to come under state plan
Beverly	RFPs being prepared	Steam	Dry fuel, ferrous, aluminum, glass, paper[41]		500[40]			
Braintree	Operating	Steam-used offsite		Water-wall incinerator	240	2,500	G.O. bonds	Incinerator starting 1971; steam sales began 1973-4
Brockton Lowell	Operating, contracted	Fuel, metals, & glass, 40,000 T/Y		Beneficiation of incinerator residue	250	3,177	Joint[6]	Contractor: Raytheon
Saugus	Building	Steam, used offsite		Water-wall incinerator	1,200	30,000	Private	Contractor: Resco,[7] completion 1995. Will take refuse from 16 communities, Boston area.
Rhode Island								
R.I. Solid Waste Management Corp.	Enacted			Planning of facilities; financing operation & regulation			Revenue bonds	Modelled on Connecticut. Features: Community participation voluntary; contract with both public & private sector
Vermont								
State Solid Waste Plan	Not yet enacted							Failed to pass in 1973. Calls for 4 facilities to be built; source reduction scheme requires separation of wastes by house householders.
Chittenden County	Planning							Pilot version of state plan; sched. operation 1976.
MIDDLE ATLANTIC								
Delaware[8]								
Wilmington	Planning; no RFP	Fuel (oil-type)	Metals, glass	Composting, pyrolysis, materials recovery	500[9]	20,000	Joint[10]	Will handle sewage sludge. Contract signing sched. summer 1975
Washington, D.C.	Pilot (under construction)				600-1,300			Using NCRR equipment in pilot plant
Maryland								
Maryland Environmental Services (MES)				Funding: Grants & loans			State appropriation	
Baltimore (City)	Construction	Steam, used offsite (city heating & cooling)	Ferrous metals; glassy aggregate[13]	Shredding & pyrolysis to gas; gases burnt directly; solid residue beneficiations.	1,000	16,000	Joint[14]	Contractor: Monsanto Enviro-Chem Systems (MECS). Sched. completion 11/74. City owned & operated feed includes tires.
Montgomery County	Site selection	Shredded waste-fuel	Magnetic metals	Shredder, magnet	1,200	16,000[14]	G.O. bonds	Contractors Pope, Evans & Robbins[15]
New Jersey								
Hackensack Meadowlands	Proposals	Supplementary fuel						Contract signed for 200 T/D fuel
New York								
Environmental Board	Voter-approved			State grant program—up to 25% funding for waste disposal, up to 50% for resource recovery		175,000[16]	G.O. bonds	All projects must be consistent with a comprehensive regional plan[17]
Albany	Seeking grant	Shredded waste-fuel	Magnetics	Shredder, magnet, air classifier	600	6,000	Joint[18]	City-owned, privately built & operated. Design: Smith and Mahoney

TABLE II.10 (Continued)

Region, State Municipality	Status	Main Product	Other Products	Project Type or Plans Type	Capacity T/D	Capital Cost $1,000	Financing	Remarks
Hempstead	RFP out			Not specified in RFP but 97% vol. reduction required	2,000	45,000	[19]	Proposals due 10/74
Monroe County	Contracted	Shredded fuel			2,000	25,000[20]	Joint[21]	Contractor: Raytheon; will operate first 5 yrs.
Mt. Vernon[22]	Proposed	Electricity		Purox System (pyrolysis)	400			Union Carbide proposed for contractor
Westchester County	County plan			Incinerator improvements USBM incinerator recovery; thermal reduction		105,000		Includes Mt. Vernon Ecology – Industrial Park, customers next door.
New York City	Proposed	Fuel supplement	Ferrous; non-combustible			2,100		State Power authority to building 700,000 kw plant on Staten Island
Pennsylvania								
Division of Solid Waste Mgmt.	Law			State loan program to approved local programs				Considerations: Tonnage, environmental benefit, population served, resource recovery
Palmer Township	Feasibility study done	Solid waste as fuel (mixed w/coal)		Shred, pelletize, mix, pulverize, burn in cement kiln	500[23]	2,000[24]	Joint[25]	Consultant: Eco & Rhodes
SOUTHEAST								
Florida								
Resource Recovery and Mgmt. Council (RRMC)	Law			Planning-development of statewide program				One-year deadline
Board of Pollution Control (BPC)	Operating							Must adopt RRMC Plan but has veto powers
Dept. of Pollution Control (DPC)				Technical assistance, interagency cooperation planning & promoting resource recovery; energy-from-waste; grants & loans				Implements BPC Program. Private sector must be called on. Shall encourage development of waste-based industry. User fees charged. May own or build facilities, sell products. All counties must adopt DPC approved local plans.
Brevard Co.	Planned		Ferrous	Shredder			Bonds	
Fort Lauderdale	Contracted	Paper, fiber		May-Separator	400-500	[37]	Contractor[37]	Contractor: Environmental Resource Corporation
Miami (Dade County)	Bids in	Electric power	Metals	Waterwall incinerator	3,000	100,000[18]	[39]	
Gainesville	Closed	Compost						No market
North Carolina								
Asheville				Sira pelletizer	600[27]	[27]	TVA debt	
West Virginia								
S. Charleston	Testing	300-BTU gas		Gas pyrolysis	200		Private	Contractor: Union Carbide Pilot Test of Process
SOUTH CENTRAL								
Alabama								
Muscle Shoals		Fuel pellets		Sira pelletizer	1,000[27]	[27]	TVA debt	1975 planned implementation
Kentucky								
Paducah		Fuel			1,000[27]	[27]	TVA debt	1975 planned implementation
Louisiana								
New Orleans		Ferrous, non-ferrous metals, glass, paper		Materials recovery	650	5,700	Private[26]	Contractor: Waste Management, Inc. Tech. Advisor: NCRR
Tennessee								
Knoxville (Watts Bar)	Planned	Gas or pellets	Aluminum, glass, ferrous	Torrax system	2,000[27]	[27]	TVA debt	Also serves Chattanooga; refuse rail-hauled planned for 1975
Memphis	Planned	Pulped fuel	Materials	Dryer (fueled by industrial waste)	600[27]	10,000[27]	TVA debt	Contractor: L. S. Wegman Co. Waste & sludge piped in.
Nashville	Built	Steam for heating & cooling		Waterwall incinerator	720	18,500	Revenue bonds	Now burning fossil fuel to meet steam contract due to emission problem. NTCC is a public authority created by & independent of city.
Tennessee Valley Authority	Planned	Fuels	Some materials	Fuel recovery, various processes	7,400	20,000	Own debt	Various Contractors
(Plants at Muscle Shoals, Paducah, Knoxville, Memphis)								Implementation sched. 1975. Plans for abt. 6 units at coal-fired plants: supply 7% of total energy need.
MIDWEST								
Illinois								
State Solid Waste Office	Staffing up			Grant program		6,000	Grants-in-Aid	Money available for planning & resource recovery

TABLE II.10 (Continued)

Region, State Municipality	Status	Main Product	Other Products	Project Type or Plans Type	Capacity T/D	Capital Cost $1,000	Financing	Remarks
Chicago	Building Operating	Fuel, steam		Waterwall incinerator	1,000	14,000	G.O. bonds	Contractor: Ralph Parsons Martin System
Iowa								
Ames	Building	Fuel		Combustible Power Co. recovery system	200	2,800	Revenue	Feeds City owned power plant
Minnesota								
Minnesota Pollution Control Authority	Underway			Grant program matching-funds (up to 50% of project cost)		3,500	Appropriation	Eligibility: Must be consistent with state-approved plans
Minneapolis	Designing	Gas, oil	Activated carbon from char: steel, aluminum, glass	Pyrolysis unit – sewage sludge & solid waste	360[28]	15,000		Pilot unit: will handle 15% of city's sludge. Contractor: Rust Engrn.
Ohio								
Ohio Resource Recovery Authority	Proposed			Financing & operation of recovery systems: dev. state plan waterwall incinerator				$1.5 M study recommended
Akron	Final state of design; boiler bids let	Steam, central heating		Waterwall incinerator	1,000[29]	18,000	Municipal revenue bond	Designer: Glaus, Pyle, Schomer, Burns & DeHaven. Supplier: Babcock & Wilcox (Boilers) constructed binding 10/74
Cleveland	RFP	High pressure steam (power generation)			1,500			Cancelled after proposals in. New RFP not out yet.
Franklin	Completed 6/71; in test	Fibers, glass	Ferrous, aluminum	Pulping & beneficiation	50[9]	3,177	Joint[30]	Contractors: Black-Clawson glass container mfg. inst.
Montgomery County (Dayton)	Preliminary investigation	Shredded waste: fuel		Investigation of USBM heavy-fraction separation	600		G.O. bonds	
Toledo (Greater Toledo Area)	Planned	Fuel supplement	Ferrous		1,000		Revenue bonds	
Wisconsin								
Wisconsin Solid Waste Recycling Authority	Organized			Development of state program: planning, design, finance, construction, acquisition operation, maintenance of regional systems			Revenue	Three regions established features: Mandatory compliance in region; cost guarantees; site purchase from municipality, private sector use.
Madison	Feasibility study	Shredded fuel	Iron	Shredder-magnetic separation (underway)	200	3,000[31]	G.O. bonds[31]	Iron recovery underway now; waste of landfill.
Appleton	Testing	Steam						
Milwaukee	Contracted	Fuel	Aluminum, iron, corrugated paper, glassy aggregate	Shred-classify-magnet	1,200	18,000	Public improve-bonds	Probable contractor: Americology. May become part of state system (see above) starting mid-1976
Kansas City	Contracted	Paper	Ferrous			3,000	Revenue	Contractor: Browning-Ferris Industries
SOUTHWEST								
Texas								
Odessa	Running	Soil conservation	Ferrous	Shredder; magnetic separation	250–300		Bonds	Contractor: Newell mfg. co.
ROCKY MOUNTAIN								
Colorado								
Denver (Metro. Area)	Proposed			Regional plan development	600–1,200[32]	73,000[32]		Possibilities being assessed
PACIFIC BASIN								
California								
State Solid Waste Mgmt. Board	Enacted 1972 plan drafted & under review			Development plan: (state direction demo. program, product change procurement incentives policy study, disposal taxes pilot projects)				
Contra Costa Co.	Planning (bench-tested)	Heat, steam	Ferrous, aluminum	Dry separation, incineration, pyrolysis	775[39]		EPA, State,	Contractor: Brown and Caldwell-, Enviro-tech. Will use waste as fuel to pyrolyze sludge and make steam & aerate sewage
Los Angeles	Discussions initiated	Shredded waste as fuel to Cim Power Plant						Mayor, sanitation & health depts. involved
Los Angeles	Experiments	Methane						

TABLE II.10 (Continued)

Region, State Municipality	Status	Main Product	Other Products	Project Type or Plans Type	Capacity T/D	Capital Cost $1,000	Financing	Remarks
San Diego County Dept. of Sanitation & Flood Control	Design: Construction 1975	Liquid fuel, 1 Bbl/T		Bioconversion	200	6,400[33]	Joint[35]	Contractor: GRDC-NAS
Hawaii								
Office of Environmental Quality (OEQ)	Plan completed, 1973			State plan development waste inventory & market study (ongoing)	100[34]	100[34]	Joint[34]	
Hawaii Waste Recovery Authority	Enabling bill pending							
State Legislature	Bills			Tax incentives for recycle facilities; bottle legislation	1,500	100[35]		
City & County of Honolulu	Preliminary design	Energy		Feed: refuse & sugarcane Trash		100[35]	Joint[35]	Contractor-consultant Sun. low, Tom & Hara
Oregon								
Lane County Solid Waste Division	Study of feasibility	Waste as fuel, municipal boiler			600–1,000	1,400	G.O. bonds[36]	Boiler uses wood waste now, for heating system. Design: Wilsley & Ham. Procurement expected soon.
Washington								
State Dept. of Ecology, Seattle	In force Proposed	Methane & methanol		Grant & loan program pyrolysis & oxidation		30,000	Appropriation	Financing questionable, city interested

SOURCE: R. Hopper, "A Nationwide Survey of Resource-Recovery Activities" EPA Memo, 1954.

[1] By 1985, will have 10 facilities handling 85% of State's waste.

[2] Bond authorization.

[3] State facility.

[4] Plant, $22 M; Steam facility, $10 M.

[5] Money requested; entire sum unavailable until F.U. 1976.

[6] Federal, 75.8%; State, 19.5%, Local, 5.7%.

[7] Joint venture: DeMatteo Construction Co. and Wheelabrator–Frye (Refuse Energy Systems Co.).

[8] $9 M Grant awarded 1972.

[9] Per shift.

[10] EPA, 65%; state G.O. bonds, 35%.

[11] Pilot capability 10–15 T/D.

[12] EPA, 37.5%; State (M.E.S.), 25%; City, 37.5%.

[13] 160 T/D (50% Moisture) to landfill.

[14] For processing facility; $4 M for receiving a firing not arranged yet.

[15] Interim plan: railhaul refuse for strip mine reclamation.

[16] For waste disposal and resource recovery, out of total environmental bond issue of $1,100 M.

[17] All plans must: (1) assure coverage of all municipalities within region; (2) provide for inter-municipal cooperation; (3) define collection service areas and time of service provided; (4) meet local needs and optimize resource recovery; (5) provide phased implementation to meet *short and long-range* needs.

[18] State, 50%; City G.O. bonds, 50%.

[19] Probably revenue bonds.

[20] Plus retrofit and storage facility.

[21] At least $9 M from state; rest public improvement bonds.

[22] Also serving Pelham and Pelham Manor.

[23] 24-hr. basis; or 150T/shift.

[24] Estimated.

[25] State, 50%; local, 50%.

[26] By contractor.

[27] Total capacity, all TVA projects, 7,400 T/D; total capital cost, $20 M.

[28] Solid waste; also, 100-tons wet sludge.

[29] Expandable to 1,400 T/D if steam market justifies.

[30] Federal, $2,177 M; City, $0.50 M; GCMI, $0.2 M; Black-Clawson, $150 M.

[31] Anticipated: under study.

[32] Total funded: EPA, $8 M; County, $2 M; GRDC, $3.5 M.

[33] For study only.

[34] City, $50 K; AMFAC Corp., $50 K.

[35] Voters have approved $3.5 M issue.

[36] Fixed-price contract: $6/ton over next 20 years.

[37] Upper limit.

[38] Undecided; revenue bonds preferred if tax-exempt. Possible state grant: possibly by creating resource recovery authority. $50 M in G.O. bonds authorized, but may be reserved for landfilling.

[39] Plus sludge.

[40] Expandable to 1,000.

[41] Depends on market.

consumers to generate sufficient ton-mile demand to justify lower freight rates.

The proximity of the customer to the resource recovery plant is the obvious key to the transportation cost problem. Location of the recovery plant near a power generation station or in a downtown area can provide a ready market for shredded fuel or steam, the latter being useful for central heating and cooling as well as for power generation. An alternative approach is being taken in Westchester County, New York, (see Appendix C. V) where an industrial park, to be leased to customers using reclaimed materials, is being developed around a resource recovery plant. Such developments could be financed through revenue bonds for the purchase of needed land or through careful interpretation and rewriting of tax laws.

The chief tax advantage held by primary materials is the percentage depletion allowance on mined substances, which does not apply to scrap. In effect, virgin materials are subsidized by this amount. There are other, more subtle tax advantages for mines also: being located in less built-up areas, land tax rates are less than for waste storage areas, for example. A thorough study of federal, state, and local tax structures will doubtlessly reveal many opportunities for manipulating taxes so as to equalize the tax burdens on primary and secondary materials.

Besides affecting transportation costs, the economies of scale also affect directly the prices of materials. For this reason, resource recovery facilities should serve as large an area as the economics of transportation of refuse and marketing of recovered products will warrant. In this way, some of the benefits of scale that normally accrue to mines and smelters may be realized in resource recovery. Regional planning is therefore needed, so that small plants do not compete for the limited supply of wastes available in any given area and reclaimed products may be generated in sufficient quantities and reliability, to satisfy potential markets.

In the long run, the institutional constraints will be more important in determining the usefulness of wastes in the national economy than further development of technology for resource recovery.

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A. III: TECHNOLOGY IMPACTS OF INSTITUTIONAL ISSUES IN RECYCLING

S.L. Blum and S.G. Lewis

INTRODUCTION

The area of solid waste management is one in which many issues surface. Nearly everyone has an opinion in this area, not necessarily because it is paramount in their minds, but rather because it fits into the experience level to which most can relate. Everyone uses things that are thrown away somewhere in their life cycle, from food to automobiles to buildings. Most of us see refuse piles in the city or rural areas and recognize the simple cycle of produce-purchase-use-discard as a way of life. It, of course, has not always been a way of life and clearly may not be a way of life in the future. Why is this? Is it because we have all recognized a puritan ethic of "waste not," or is it because we have all "got the religion" of environment?

It turns out, according to our thesis, that it is a combination of factors. We have been sensitized to the problems of environmental insult, we recognize the problems of obtaining raw materials, and we presently see the result of collusion of foreign powers in the oil crisis. Is not there then a persuasive logic that leads to recycle? Unfortunately, it is not that simple. Although we are moving toward that direction we still have a long way to go. We are faced with problems of an economic nature. For example, who will do the recycling if it is not economical or does not fit an existing industry or market? Has our technological genius solved all the problems of processing or have we identified the significant technical problems? And finally, have we identified the institutional problems and do we know how to deal with them?

The first thing this paper will try to do is put the problem in perspective. We can relate the elements of the problem, technology-institutional-economics, to each other by a diagram shown in Figure III.1.
This is presented in the style of a condensed tri-axial phase diagram where every part within the triangle can be defined by the three components shown. The area shown by the circle has coordinates of 60 percent institutional, 20 percent technical, and 20 percent economic. It is a crude estimate of where the problems rest in municipal solid waste management. From this vantage point in time it appears that the problems or barriers are primarily institutional in nature.

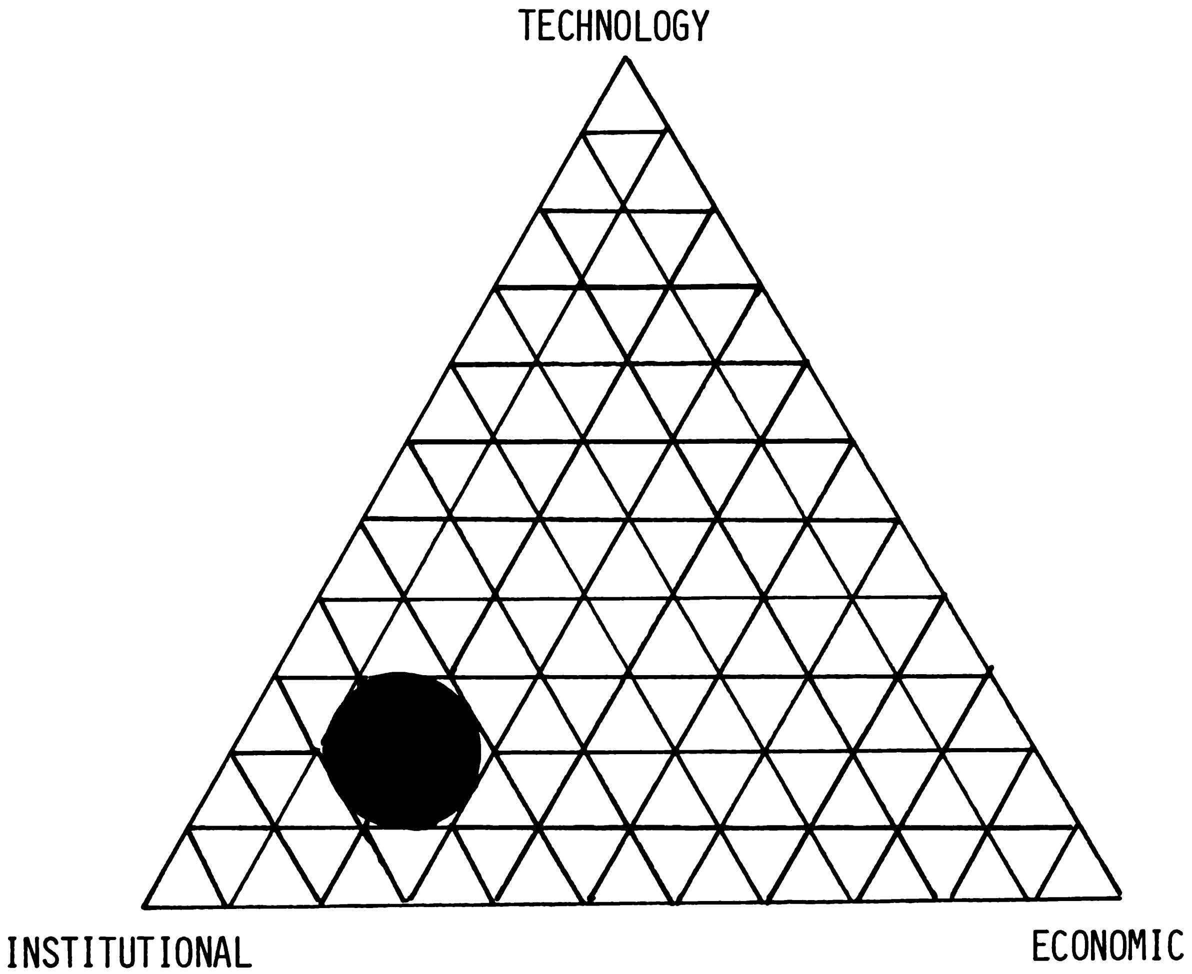


Figure III.1 Tie Factors

Source: Blum (1974)

If we look at the way recycling has developed in the past, we may get some insight into the future. In the very distant past, recycling was oriented primarily towards the benefit of small communities that were materials limited; as communities developed it became an occupation and involved a buyer-seller relationship. A new component has been added to the recycling scene now, community benefit. The concept of community benefit is understood by most, treated well by Hardin (1968) in "Tragedy of the Commons," but difficult to quantify.

The materials cycle involves a broad system that starts with prospecting and mining, runs through fabrication of products, and finally involves disposal and perhaps recycle. The concept of recycle is quite old and the degree of recycle tends to follow scarcity of commodities or lowest cost procedures for obtaining materials. Industries have been developed to concentrate on recycling and in most cases are logically concerned with a rapid payoff. Our concern in this paper is primarily focused on future payoffs. The concept of societal benefit as derived from the "Tragedy of the Commons" can be handled philosophically but quantification is difficult. What is the value of decreased pollution, aesthetics of land usage, and increased security of materials availability? Many societal problems normally have a technical component in their solution. Snow (1959) described the overlap of two cultures in the community, the scientific and humanistic. There have been arguments in the literature (Crowe 1969) emphasizing the insular nature of these two cultural communities and the difficulty of them coming together to handle societal problems. There have been many failures in this area because of oversimplification by both the "hard" and "soft" sciences postures of the problem solvers. The total system is complex and, as we will attempt to show in this paper, selected solutions are reasonable.

It is the intent of this paper to describe the framework of institutional problems existing at present in municipal solid waste management, and to discuss what some of the future institutional problems might be, how they could develop, and the role of technology in solving them. We are not going to solve the institutional problems of the future now, but describing what the nature of the present problems are might broaden our technological base to give options for future problem solving.

OVERALL WASTE MANAGEMENT STRATEGIES

Providing solid waste disposal services has always been the responsibility of local governments. They now spend $6 billion a year to collect and dispose of solid wastes; this is the third largest public expenditure funded solely from local revenues. Waste collection is labor intensive, labor costs are escalating, and the productivity of most municipal collection systems is low (EPA 1974). A recent study by the National League of Cities (NLC

1973) indicated that one half of the nation's cities will be running out of current disposal capacity in from one to five years, and there is also a sharp decline in the availability of land in urban areas for disposal sites. Another NLC survey (1974) indicated that of 28 major urban problems, municipal officials stated that solid waste disposal is the most urgent problem facing municipal government today (NLC 1974). Recent EPA estimates indicate that post consumer waste generation in the U.S. in 1971 was 125 million tons and growing at a rate of 3.0 to 3.5 percent per year. The solid waste generation rate is increasing five times the population growth rate, and this year about 140 million tons of post consumer wastes will be produced. Thus, what is normally referred to as the "solid waste problem" as we know it today, is characterized by increasing costs of collection and disposal, by increasing quantities of refuse generated, and by the disappearance of suitable disposal sites.

The fundamental and linked problems of resource conservation, solid waste management, and environmental preservation can be attacked through many strategies. The large number and important interrelationships of these approaches, in fact, contribute to the difficulty of pinpointing the issues and setting priorities for action. The approaches can, in general, be thought to be grouped into those that focus on the materials production, thus affecting preconsumption, and those that affect such postconsumption activities as recycling or resource recovery. Both sets of strategies are complex, and both can significantly overhaul established institutions and practices. Actions within both sets of approaches can involve legislation which imposes new taxes, regulates, limits, or bans, or legislation which reduces existing taxes or other perceived barriers to change. Actions may also be voluntary as the benefits of a new design or production practice, or a resource recovery operation become apparent.

Waste Reduction

An initial approach involves the reduction of waste. This may be accomplished by decreasing the quantity of a material or product through legislation or design, or by enhancing the recyclability of a material or product. These strategies are illustrated in Table III.1 as objectives, alternative actions that can be taken to meet the objectives, and some possible barriers and/or effects of the actions. In our definition, the barriers are, for the most part, institutional.

One of the key issues here is that decisions to produce products or consume materials have been made without regard for the environmental and economic consequences associated with collection and disposal after discard. Thus, any action that seeks to insert this new criterion in these decisions involves significant change in practices. It is believed important to discuss this now because it seems clear that federal legislation

TABLE III.1 WASTE REDUCTION STRATEGY AND ACTIONS

OBJECTIVE	MEANS	ALTERNATIVE ACTIONS	BARRIERS/EFFECTS
PRODUCT REUSE	TAXES OR CHARGES	PRODUCT CONTROLS	MARKET DISTORTIONS
	DEPOSITS	SOURCE SEPARATION	
REDUCED RESOURCE INTENSIVITY	BANS OR QUOTAS	DESIGN FOR RECYCLE	
		INTERNATIONALIZATION OF DISPOSAL COSTS	SALES VOLUME CHANGES
INCREASED PRODUCT LIFETIME	DESIGN REGULATION	TAX INCENTIVES	INDUSTRY DISLOCATION
		REUSABLE PACKAGING	REGULATION PROBLEMS
		MATERIALS TAXES	EMPLOYMENT IMPACT
DECREASED PRODUCT CONSUMPTION		PACKAGING REGULATION	CONSUMER PRICES
		CONSUMER EDUCATION	
		MATERIAL OR PRODUCT SUBSTITUTION	

(Committee on Commerce 1974, Bullis 1974) in this area will be passed within the next two to three years. Such legislation might provide a subsidy to firms using postconsumer recovered products, or a tax on the use of competitive virgin materials--or both. For the sake of illustration, assume that the collection and disposal cost for waste materials is $25 per ton or 1.25¢ per pound. One type of action might be to impose a 1.25¢ tax on each pound of virgin material entering consumption that will ultimately require disposal. Such an action may have to be tempered by the following conditions:

- Weight is not the most relevant parameter associated with disposal cost--volume probably is.
- All classes of materials and products do not have the same collection and disposal costs. Other parameters such as combustibility, leachability and bulk density, etc., are crucial. Shifts to lighter materials might be environmentally degrading.
- The tax would be quite different if it was applied to producers or consumers.
- The tax might be regressive since lower income levels would pay a higher percentage of their income as the tax.
- The tax would be quite difficult to administer. It is logical to assume that the tax receipts would be distributed to local governments to offset disposal costs, but it is very difficult to insure that this would, in fact, happen.

It is interesting to think about some of the changes being sought by legislation that taxes virgin materials or subsidizes the use of post consumer secondary materials, and the technological implications of these changes. Consider, for example, the paper industry where such taxes and subsidies seek to cause the recovery of more wastepaper by stimulating a demand for it through expansion of industries that currently use wastepaper, by conversion of plants from virgin paper to wastepaper, or by construction of new wastepaper plants.

Most of the wastepaper used today is separated at the source--corrugated containers from commercial and industrial establishments and newspapers from homes. An increase in demand for such wastepaper will cause an increase in these separation activities. But home separation of newspapers is a difficult process to institutionalize on a widespread continuous basis. It has been estimated that it is practically feasible to double the approximately 2.5 million tons of newspapers now being recycled (approximately 12 million tons of wastepaper was consumed in the U.S. in 1973) (Lingle 1974). In relation to domestic consumption of newsprint, this constitutes about a 25 percent recycling rate. An important point to make here is that this recycling rate could be increased considerably if the technology were available to recover wastepaper of the required quality from the mixed municipal waste stream. The availability of such technology would practically eliminate the institutional problems associated with source reduction and hand separation.

One available process, the Hydrasposal/Fibreclaim wet fibre recovery process at Franklin, Ohio, (Arella 1974) recovers a pulp output being used in the manufacture of roofing felt. But the quality of the output is not suitable for paper mills, particularly because of such contaminants as wood, plastics, and metals.

Other related issues and problems can be found in converting mills from virgin to secondary pulp, in transporting paper products, and in extending the manufacture of products made with recycled paper.

One consideration might involve new concepts of waste paper use. Several years ago some experiments were done using waste paper as a cattle feed. With sufficient but inexpensive additives the cattle can get nourishment but the newsprint gave some digestive trouble. Is the future solution tied in some way to edible newsprint?

It is interesting to note that these same relationships exist between technology and institutional issues in the recycling of other products such as cans, bottles, tires, and plastics. The issues are related to the following areas:

- Current manufacturing processes.
- New processes based upon recycled materials.
- Resource recovery systems.
- The logistics of the new materials stream.

Resource Recovery

Since enactment of the Resource Recovery Act of 1970, there has been an important movement toward the development of resource recovery systems that can accept mixed municipal, commercial, and industrial waste materials as inputs, and separate and recover material and energy products in forms that are of a sufficient quality to have economic value at the marketplace.

Municipal solid waste management has always been a problem, and the problem is usually described in terms of the tons of waste material that are being generated and thus must be disposed of. Such disposal represents an expense, and because of new environmental standards, that expense is climbing. So there is a natural incentive to look for a new disposal option. But the realities are that the incentive does not stop there. The solid waste management problem is different today because the expectations of people are different today. Only a few years ago people were content with dumps, even burning dumps. They knew nothing of the leachate problem. Refuse was viewed as an undesirable waste to be disposed of, and the key method of disposal was landfill.

The 1975 citizen, however, will not stand for an open dump even if his government will. When the old landfill is full he wants his government to come up with a better solution, as he has been led to believe others have found. He is concerned about leachate from landfill because he now knows what it is. He has been told that while our nation's sewers and other point sources create annually a BOD (biological oxygen demand) loading of 7 billion pounds in rivers and streams; our landfills create a BOD loading of 6 billion pounds. He is acutely aware of the energy problem and he believes resources should be conserved, not buried. And he is aware of the resource content of solid waste. He is making his point: find a better solution and it must involve resource recovery. Much of the technology for resource recovery is here, what remains is the not so easy job of putting it into place.

One interesting question is, how many resource recovery facilities will there be? Experience to date has shown that within the more heavily populated regions of the country a large facility will support a population of approximately 1,000,000, a relatively small one, 400,000. If 70 percent of the nation's people live in heavily populated areas, we might expect 200 to 500 such facilities. With an average capital expenditure of $40 million this represents an expenditure of some $8 to $20 billion, possibly within the next 15 to 20 years.

RESOURCE RECOVERY: PRESENT AND FUTURE

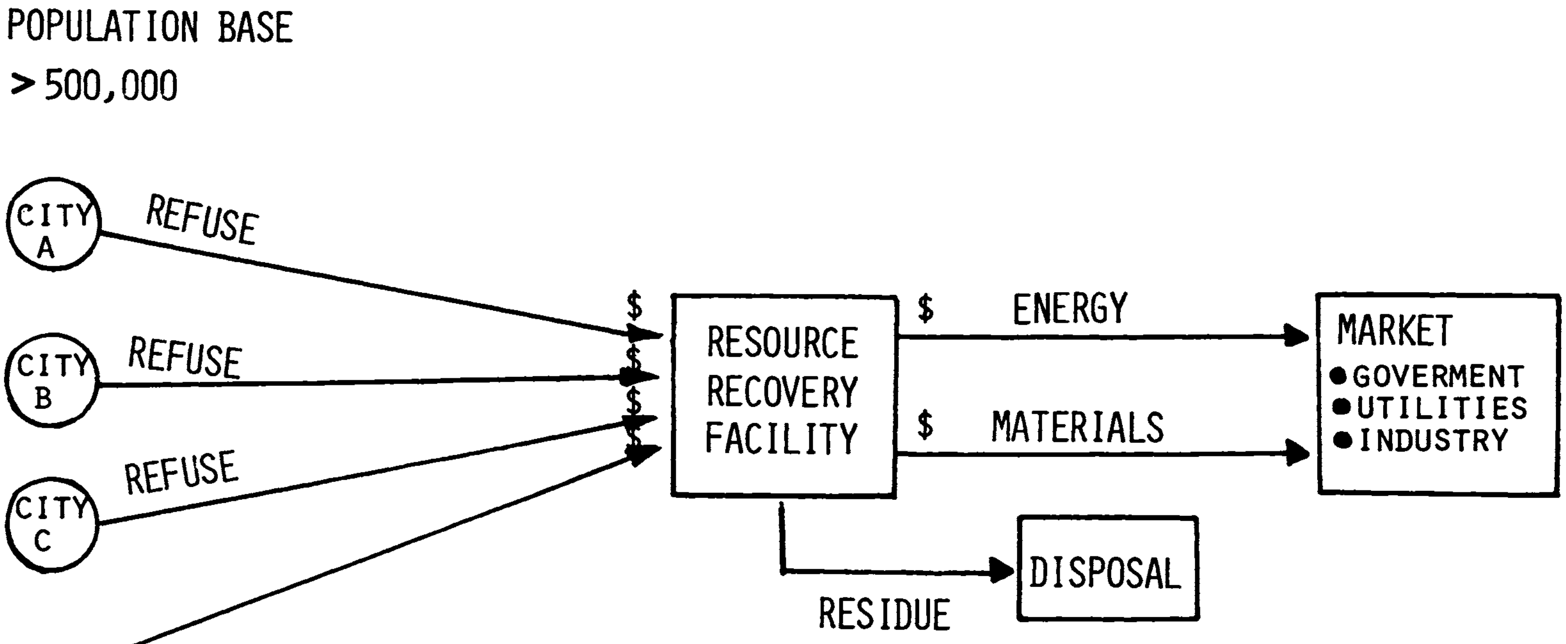
The Resource Recovery Facility Environment

The resource recovery system environment is depicted in Figure III.2 showing sources of waste materials, the key characteristics of resource recovery systems, and potential markets for recovered materials and energy.

In studying the figure we note that the facility should probably be of a size to process at least 1,000 tons per day of mixed refuse to reach the necessary economies of scale of a facility that will cost between $20 and $100 million. The facility may be owned, operated, and/or financed by either public or private means.

A number of municipalities is involved in collecting and transporting refuse to the facility since, with the exception of larger cities, few municipalities have the population base to generate the refuse tonnage needed by the facility. Collecting and transporting refuse may be accomplished by the municipality itself, by a contract with a private firm, or by a combination of these. A fee is paid for the disposal service provided by the facility.

The resource recovery facility can produce materials (ferrous and nonferrous metals, glass, and paper pulp) and/or energy (pyrolytic oil or gas, steam, electricity, or a combustible fuel



- SIZE ≥ 1000 TONS PER DAY
- COST \$20M - \$100M
- OWNERSHIP - GOVERNMENT OR PRIVATE
- OPERATION - GOVERNMENT OR PRIVATE
- FINANCING - PUBLIC OR PRIVATE

Figure III.2 Resource Recovery Systems: Overall Structure fraction) for sale. These materials and energy products can be marketed to government agencies, public utilities, or private industry, and the amount paid for them provides a second key source of income for the facility.

A point made by the figure is the institutional complexity represented by this environment:

- the need for a number of local governments to join together and commit themselves to long term agreements for refuse disposal,
- the need to select the technology appropriate to the local conditions,
- the need to finance, design, construct, operate, and own the facility,
- the need to establish a long term and stable market for recovered materials and energy, and
- the need to allocate risks properly among all parties involved.

One of the difficulties of discussing institutional issues is that they are very large in number and can be grouped into many different classifications. One way to discuss institutional problems involved in the implementation of resource recovery systems is to specify the organizational agreements that must be reached. Some of these organizational agreements are:

- a host community who will have the system erected and operated within its jurisdiction: this community may own and may operate the system,
- an industrial firm who will develop the system, who may own it, and who may operate it,
- businesses (or possibly units of government) who will make long term agreements to purchase materials and energy produced by the system for their use or for resale, and
- a group of communities and businesses who will agree to deliver refuse and purchase disposal services.
- A group of people or firms who will agree to provide financing for the system.

In addition to these organizations, there may be other organizations who are responsible for collecting the refuse, for transporting recovered materials from the resource recovery facility to the markets, management and engineering consulting firms, and government agencies who may assist local units of government in planning and implementing the system. Buried within these organizational agreements are a number of institutional issues that must be resolved, such as:

- determining the appropriate size of the region (the number of communities to be involved) and overall logistics.
    - facilities siting,
    - markets for products and energy,
    - capital financing,
    - ownership and operation responsibilities,
    - government acquisition (procurement) methods, and
    - incentives and risks.

Related Technology Issues

There are indeed many technology issues that affect the institutional problems in implementing resource recovery. One of the most important of these is the comparative ease of obtaining an agreement with a host community for a regional resource recovery facility as compared with a regional landfill operation. In a recent experience in Massachusetts (MITRE 1974) all communities involved in the initial planning of the system offered candidate sites for consideration and lobbied heavily for their selection. This same group of communities had fought bitterly for years over which of them would accept a regional landfill--none would.

The technology of resource recovery has significantly affected the decisions regarding government or private industry ownership and operation. For many years municipalities have owned and operated both landfills and incinerators. At this time government appears to recognize that the technological complexities of materials separation and energy recovery, involving in some cases new and complex chemical processes, may require skills and flexibility of management and operation not readily available to them. Thus, they are deciding in favor of private ownership and private operation under what may be termed a franchise agreement. Acquiring this franchise agreement under some government procedures for competitive procurement is a new challenge.

Long term agreements for the purchase of materials and energy are a key requirement for project initiation, funding, and profitable operation. With today's resource recovery technologies, these agreements are difficult to reach because consistent product qualities cannot be predicted to the degree required. This can be further complicated by the vast amount and variety of information necessary to establish a basis for an agreement. An important issue which has surfaced here is the purchase and ownership by electric utilities of a refuse-derived fuel. Figure III.3 illustrates the steps and information required by both the sponsoring government and the utility to arrive at the point where detailed technical feasibility can and should be investigated. In other words, the steps shown are needed to determine interest and gross economic feasibility. Interesting

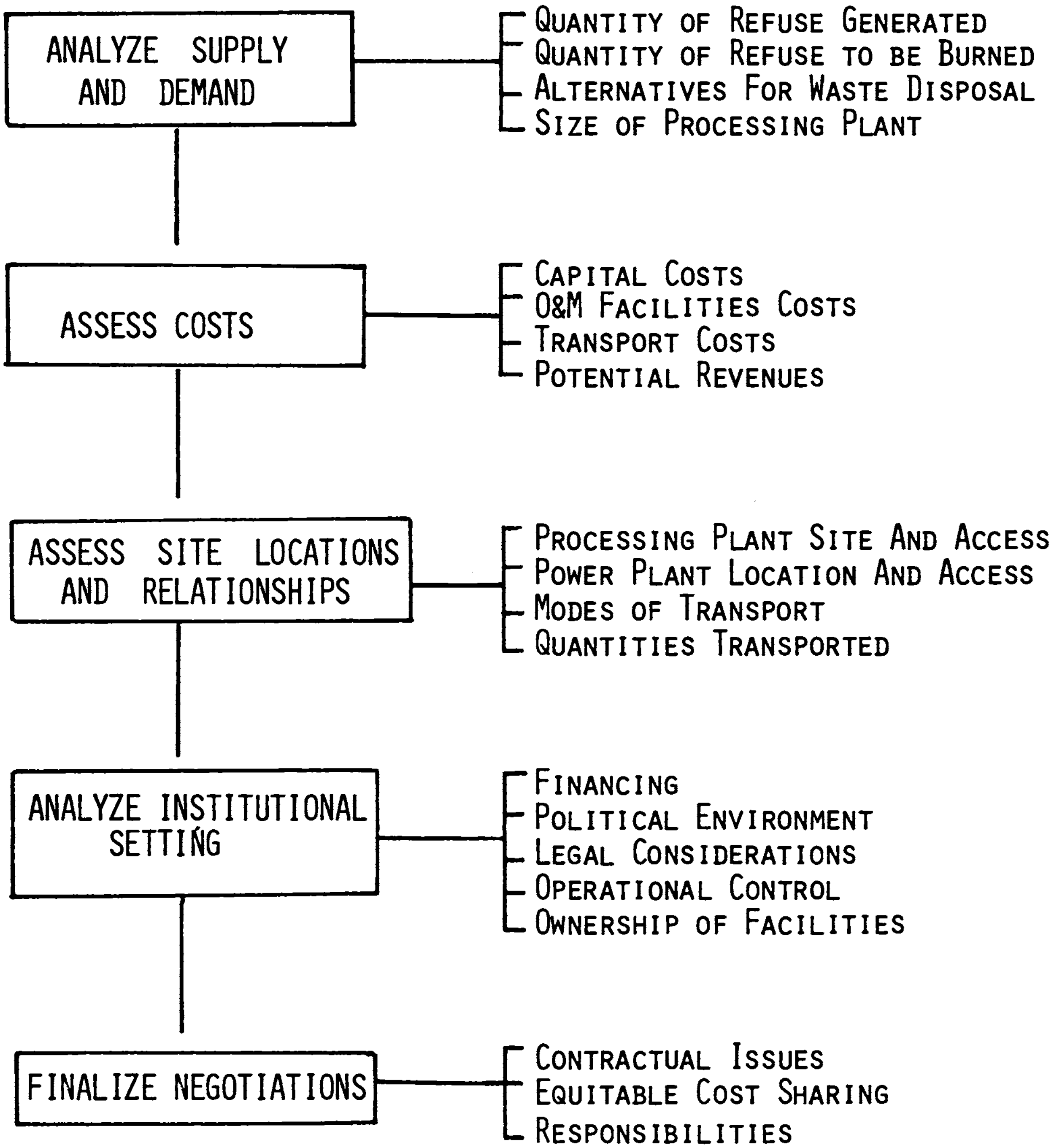


Figure III.3 Structure For Planning a Refuse Fuel System questions emerging from this planning process include who pays how much for what and who will accept what responsibilities and risks.

A special case exists when the resource recovery facility provides electric power for sale to the utility. In this case operational control, ownership, and financial accountability for various elements of the technology can be affected by rules and regulations. This can, in turn, affect the way the technology develops and is implemented.

The region size (and thus number of communities) necessary to achieve reasonable economies of scale is quite large in most areas. Obtaining the large number of municipal agreements is a key institutional barrier. A technology solution is to develop modular systems that achieve their economies at smaller scales. Some of the pyrolysis processes have this characteristic. But this, in turn, presents market problems in which quantity is needed to justify the economics of a shift to waste-based resources and energy.

An Evolving Recycling Network

An interesting speculation about resource recovery concerns the evolution of the individual resource recovery systems into a larger regional, state, or even national network. Such a network is depicted in Figure III.4 which postulates energy recovery (and possibly major ferrous recovery) at the local level; smaller amounts of ferrous, aluminum, and glass at the next level (possibly state); and recovery of other metals at still another level. As discussed earlier there might be 200 to 500 resource recovery systems at the local level. At the regional level there might be 40 to 60 systems, and at the national level 6 facilities could exist across the country--other than aluminum--from the residue produced by the local and regional systems from mixed municipal waste. Such major facilities would also become available to "clean up" or beneficiate nonferrous scrap from industry sources as well; they also may make feasible recovery of precious metals from electronic devices.

We are painting the picture of resource recovery system evolution because, to some extent at least, we believe it is going to occur. Without any guidance or planning to create this larger "system," the 200 to 500 local systems will be planned, designed, and developed as purely individual, isolated resource recovery facilities to meet local needs and circumstances and, most important, a local (and only current) materials and energy market. By doing this we may throw away 20 to 40 percent of the ferrous and aluminum portion available for recovery, most of the glass, and virtually all the other products available in solid waste.

It is perhaps useful to speculate about some of the implications of attempting to plan for growth of resource recovery in this fashion.

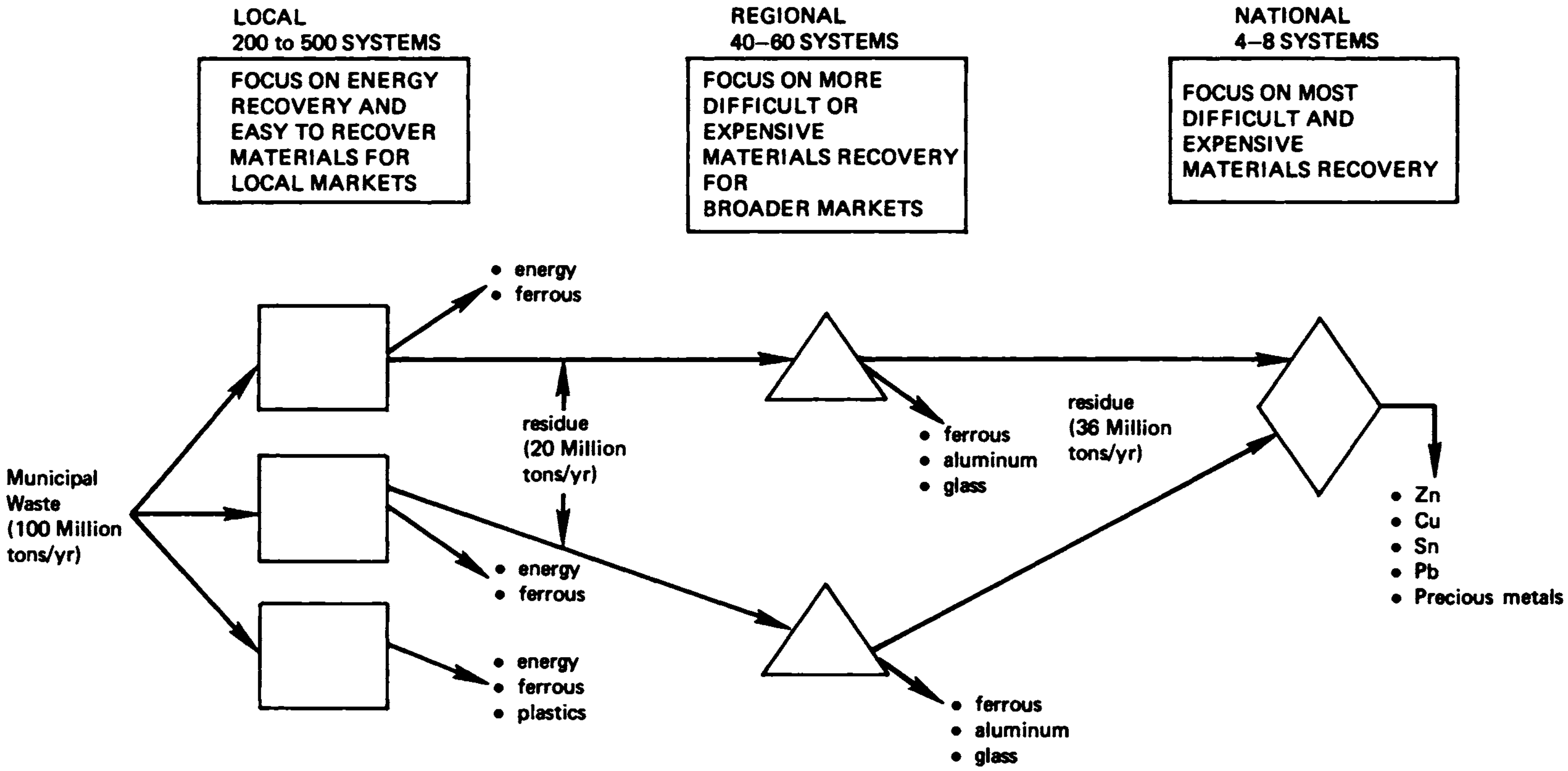


Figure III.4 An Evolving Recycling Network: Three Levels of Resource Recovery

One immediate issue concerns the "matching" of the recovery technologies used at each level. If, for example, slagging processes are used at the local level, then this may very well destroy the value of the residue for further processing at regional or national facilities. The alloying of tin with ferrous material at incineration temperatures certainly changes the nature of later processes designed to recover the ferrous portion at a quality level needed by most steel mills. Some pyrolysis processes are designed as slagging systems, involving very high temperatures in the pyrolytic reactor and which produce a slag by-product that has little value beyond that of an aggregate.

On this same topic it is important to consider that perhaps all of these systems or facilities at each level do not represent new systems. Existing materials processing capabilities within private industry can probably perform many of the materials recovery tasks at the middle or regional level.

Another issue is the technology for materials processing. At this point in time the state-of-the-art of materials recovery from mixed municipal waste is adequate for ferrous (about 80 percent recoverable), aluminum, and glass. Technology development will be necessary to recover economically the remainder of the ferrous and nonferrous materials. But perhaps such technology development can be justified when we conceive of systems of the scale represented here. We can envision approximately 360,000 tons of materials passing to the projected six processing systems at the national level. The materials emerging from these systems, which will primarily be zinc and copper, might have a value of $700 per ton at today's market or a total of over $250 million/yr. This kind of potential can indeed justify technology development. It can also provide incentives to existing industry to participate in the network.

A final thought is that the mere existence of 60,000 tons per year of zinc, copper, and tin existing at one location (assuming six processing systems at the national level) is a strong force for the development of satellite manufacturing firms that will be designed to use those "waste" materials.

Plastics: Present and Future

Issues

The plastics industry, as a relatively young and rapidly expanding sector of our nation's economy, serves as a prime example in illustrating the theme of this paper.

In light of the recent energy crisis, the conservation and reclamation of plastics is important, since the basic feedstocks used in the manufacture of plastics come from petroleum and natural gas. Today, over 3 percent of all crude oil used in the United States is used as petrochemical feedstock (McGraw Hill 1960). Plastics fabricators are experiencing difficulty in obtaining these supplies and are searching for substitute materials and new methods of reclaiming plastic scrap. Indeed, in a recent Senate study on materials shortages, it was noted that, "...by far the most universal shortage was in petrochemicals" (Committee on Government Operations 1974).

In addition to the problem of petrochemical shortages there is the increasing demand for plastic materials. Plastics have found wide application in a number of diverse industries, primarily by displacing materials such as metal, glass, paper, and wood. Plastic materials are used in a host of products including packaging, containers, toys, appliances, furniture, and automobiles. In 1968 plastics had a market of about 50 lbs per new car; now an automobile contains an average of over 150 lbs of plastic material (Department of Commerce 1968). In the twenty-year period between 1950 and 1970, plastics production has averaged a growth rate of 8.6 percent, and this rate is expected through the year 2000 (Society of the Plastics Industry 1973).

The total sales of U.S. plastic for 1972 were 24.2 billion pounds as compared to 1971 sales of 19.9 billion pounds (Holman et al. 1974). This represents an increase of over 20 percent. By 1980, production of synthetic resins is expected to exceed 38 billion pounds (Department of Commerce 1973).

As a consequence of plastics shortages and increased useage, manufacturers are scrambling for plastic scraps and this has resulted in higher scrap prices. The cost of polystyrene scrap, for example, increased from its usual level of about 3 cents a pound to 20 cents per pound in 1973 (Anon 1973).

The increased production of plastics has had a tremendous impact on the physical and chemical characteristics of municipal solid waste as well as on refuse disposal. Decreased density of municipal refuse due to the presence of plastics wastes has meant increased volume even though plastics represent less than 2 percent of the total municipal waste stream. Land disposal operations have been hampered by the resilience and non-degradability of plastics. Incineration of wastes containing plastic materials yields an atmosphere conducive to the formation of corrosion producing elements. This is not a serious problem in properly designed and operated facilities; however, less than 30 percent of the existing municipal incinerators in the U.S. are adequately designed and operated (De Bell and Richardson Inc. 1970). It appears, therefore, that as competitive demands for petrochemical feedstocks accelerate (with attendant price increases) and as the solid waste disposal problem increases, the recovery of plastic materials from municipal solid waste may become economically viable.

Strategies for Increased Plastics Reclamation

If we assume that, in fact, national priorities are established for the conservation of plastic materials, there are a number of alternative strategies which might be taken. These strategies may focus either on the manufacturing process, thereby influencing preconsumption, or on the disposal process which may influence postconsumption activities. In either case, measures taken to conserve plastics will invariably meet with institutional resistance; it is therefore important that strategies are selected such that technology will minimize institutional resistance.

Many technical strategies have been proposed to conserve plastics. These strategies have not, however, addressed the concomitant institutional problems which the technologies must confront. To do so would require a truly integrated systems approach to plastics conservation. Such an approach is depicted in Figure III.5.

Preconsumption One means of preconsumption conservation of plastics is by source reduction through such approaches as use of larger containers, elimination of overpackaging, reuse of plastic containers, or limitations on plastics. The plastics industry has made it quite evident that excessive restrictions placed on plastics production will adversely affect numerous allied industries.

The net result will be a significant decline in sales and will necessitate changes in production methods, thereby causing unemployment and depressing the economy. It was reported, for example, that a 15 percent cutback in petrochemical feedstocks to plastics producers would result in a layoff of 562,000 workers and cut production of finished products by nearly $23 billion (De Bell and Richardson Inc. 1970: 4,6).

It can further be argued that source reduction counters a free market, and by limiting free choice, is inconvenient to consumers. Traditionally, attempts at source reduction have required legislative mandates. Consequently, other strategies, shown on the left side of Figure III.5, may be approached through the following concepts:

Built-in recyclability as a product design factor Design for recycling to facilitate manual separation may be based on color or special coding, size designations, shape, or density. For instance, if all PVC was made blue, and all PP green, source separation could easily be performed by the householder, or if chemically tagged could be separated elsewhere automatically.

Design for environmentally sound disposal or energy recovery As the solid waste disposal problem increases and stricter federal and state pollution control laws are passed, plastics manufacturers, especially in the packaging area, may be forced to develop products which are amenable to either reclamation or environmentally acceptable disposal methods. This may be approached by developing biodegradable or photodegradable plastics and by intensifying energy values of plastic materials.

Product substitution Paper, glass, and metals may be used in lieu of plastics in packaging, containers, and in the

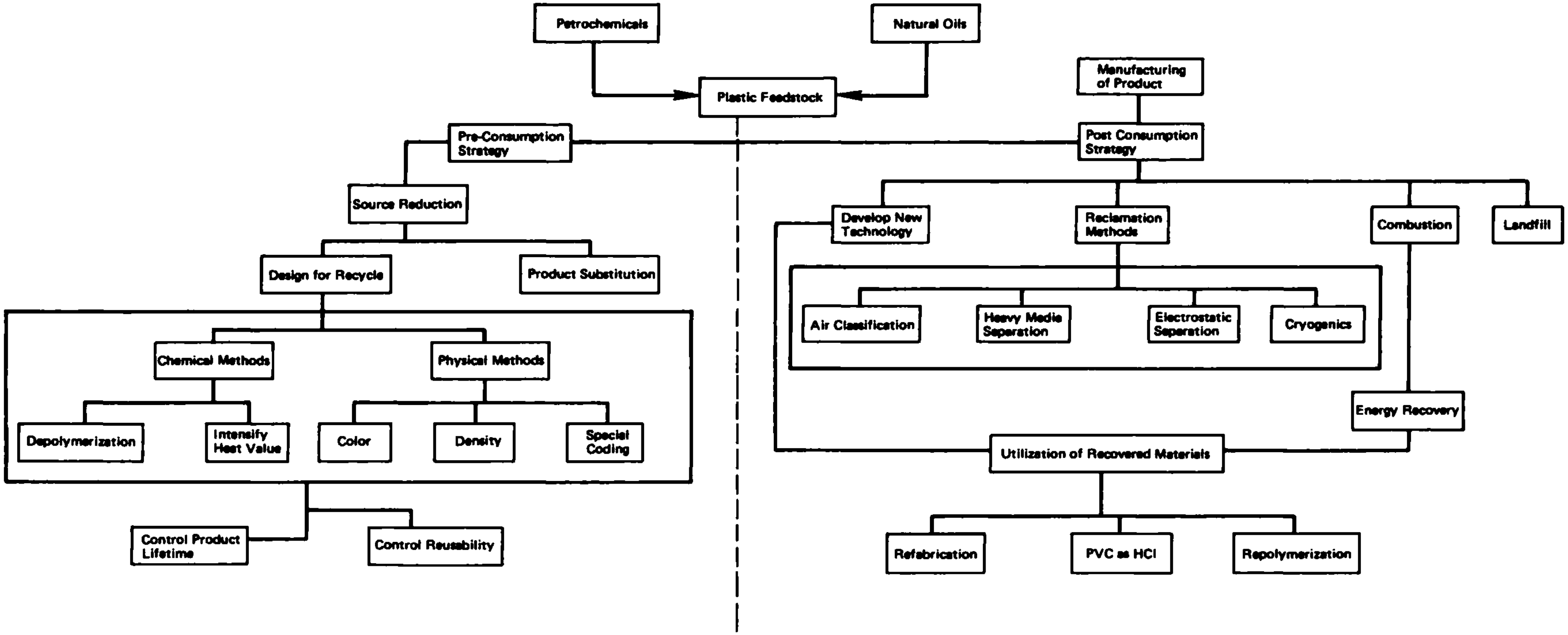


Figure III.5 Conservation of Plastics: A Systems Approach manufacture of finished products. The use of paper in packaging, however, is not always practical since some products, especially foodstuffs, must be stored for long periods and unless packaged in plastics, would be subject to moisture, fungus, and bacterial attack. Use of substitute materials can increase the weight of municipal refuse and may decrease product safety, for example when metal is used in toys.

Postconsumption Postconsumption strategy for the reuse of plastic materials (shown on the right hand side of Figure III.5) is partially limited due to the absence of available technology.

Technical problems associated with the development of new reclamation technology are compounded by existing institutional barriers. Technological advances are dependent upon adequate exchange of technical know-how. At present the dissemination of information is hindered by proprietary rights and by the absence of a suitable agency or data gathering base. New technology is capital intensive and is characterized by high risk. Initiatives should be taken at all levels of government to encourage research by private industry. The effects of existing federal policies, including freight rate policies and various provisions of the tax credits, should be reevaluated to provide secondary materials users with the same benefits currently realized only by the virgin material production sectors.

Other problems associated with the development of new reclamation technology are requirements for highly trained personnel and specialized equipment which is largely unavailable. The time lag between development of innovative technology and implementation constitutes another barrier.

Plastic Types Postconsumption strategy, aimed at separating plastics materials by type, is becoming feasible as processing systems capable of producing plastic concentrates from raw urban refuse are being developed. A discussion of plastic types is worthy at this time. Basically there are two types of plastics--thermoplastics and thermosets.

Thermoplastics are varieties of polymeric materials which are permanently fusible, alternately melting or softening when heated and hardening when cooled. These can be molded, extruded, and shaped by various techniques. Thermosets, on the other hand, may be made permanently infusible and cannot be remolded or reworked with the present state of technology. Some typical plastic products are shown, by type, in Table III.2. Figure III.6 shows U.S. production volume of plastics from 1970-1974. Another class of plastics, combined plastics or laminates, contain both thermoplastic and thermosetting plastics, whose molecular structures are incompatible. Fabrication of new products from combined plastics is also not possible.

The most common thermoplastics found in municipal refuse (in decreasing order of quantity) are: polyethylene, polyvinyls (particularly PVC), polystyrene, and polypropylene.

TABLE III. 2

TYPICAL PLASTIC PRODUCTS

Plastic Type: Thermoplastic

Article	Chemical Name	Trade Name
Toy	Cellulose acetate	Tenite 1
Golf tee	Polyethylene	Bakelite
Vacuum cleaner part	Ethyl cellulose	Ethocel
Bathroom wall tiles	Polystyrene	Styron
Steering wheel medallions	Methyl methacrylate	Plexiglass
Pipe	Polyvinyl chloride	PVC

Plastic Type: Thermosetting

Article	Chemical Name	Trade Name
Ash tray	Melamine-formaldehyde	Melmac
Buttons	Urea-formaldehyde	Plaskon
Fire alarm covers	Urea-formaldehyde	Plaskon
Cap & base of atomizer bottle	Urea-formaldehyde	Beetle

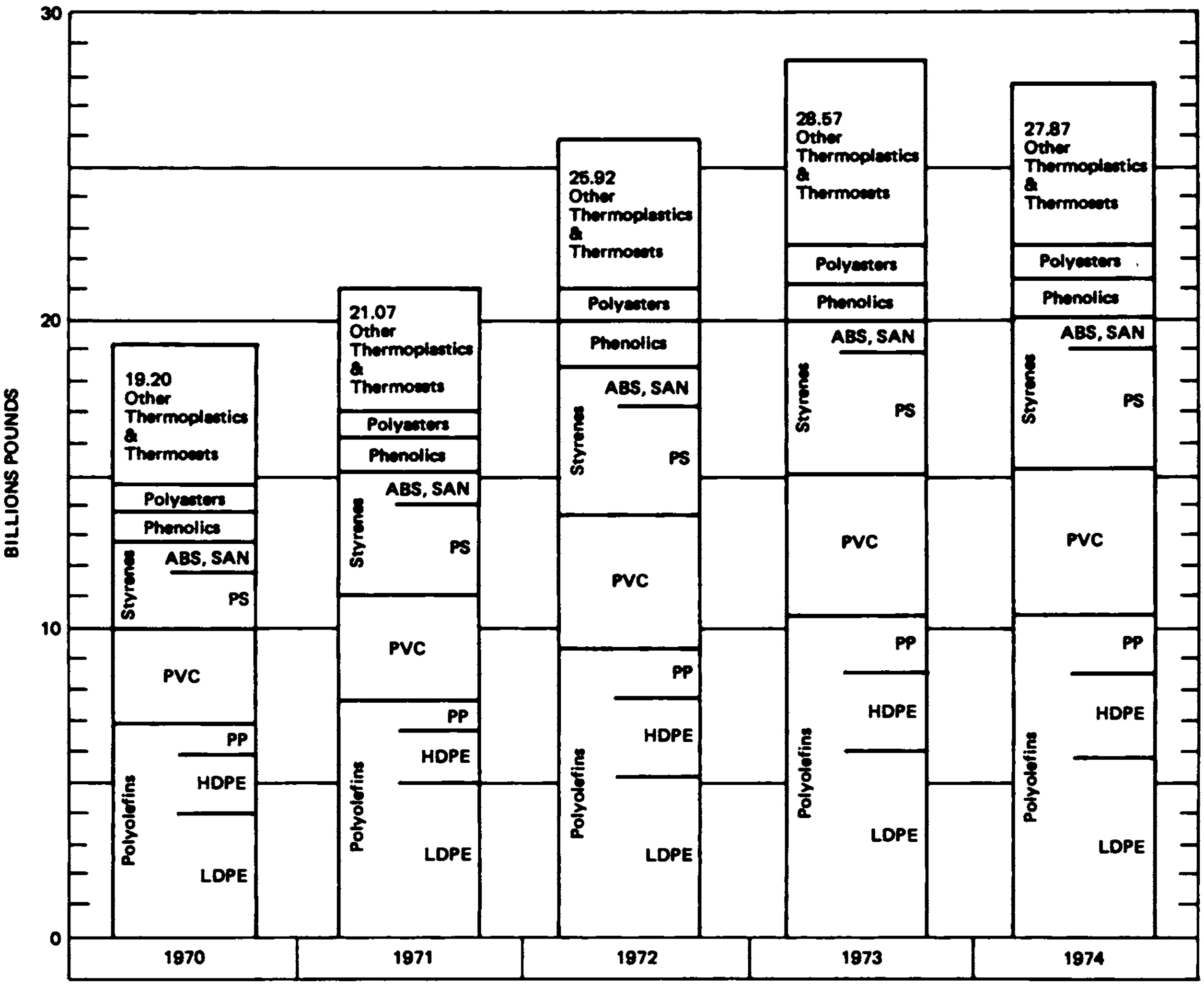


Figure III.6 Synthetic Thermoplastics and Thermosets, U.S. Production

Source: 1970-73 - U.S. Tariff Commission, 1974-Estimate

Current Reclamation and Reuse Current activity in the reclamation of plastics is centered on separation of thermoplastics by type. Much of the work done in this field has been developed by the Bureau of Mines. Separation techniques and systems presently under investigation are based on variations in density, size, and electrical properties and include air classification, liquid media methods (sink-float), and electrostatic separation for the concentration of wire insulation tailings. A proposed flow diagram of a processing system for reclaiming waste plastics is shown in Figure III.7 (Stephenson et al. 1973). Other reclamation technologies are being studied including chemical methods and cryogenics.

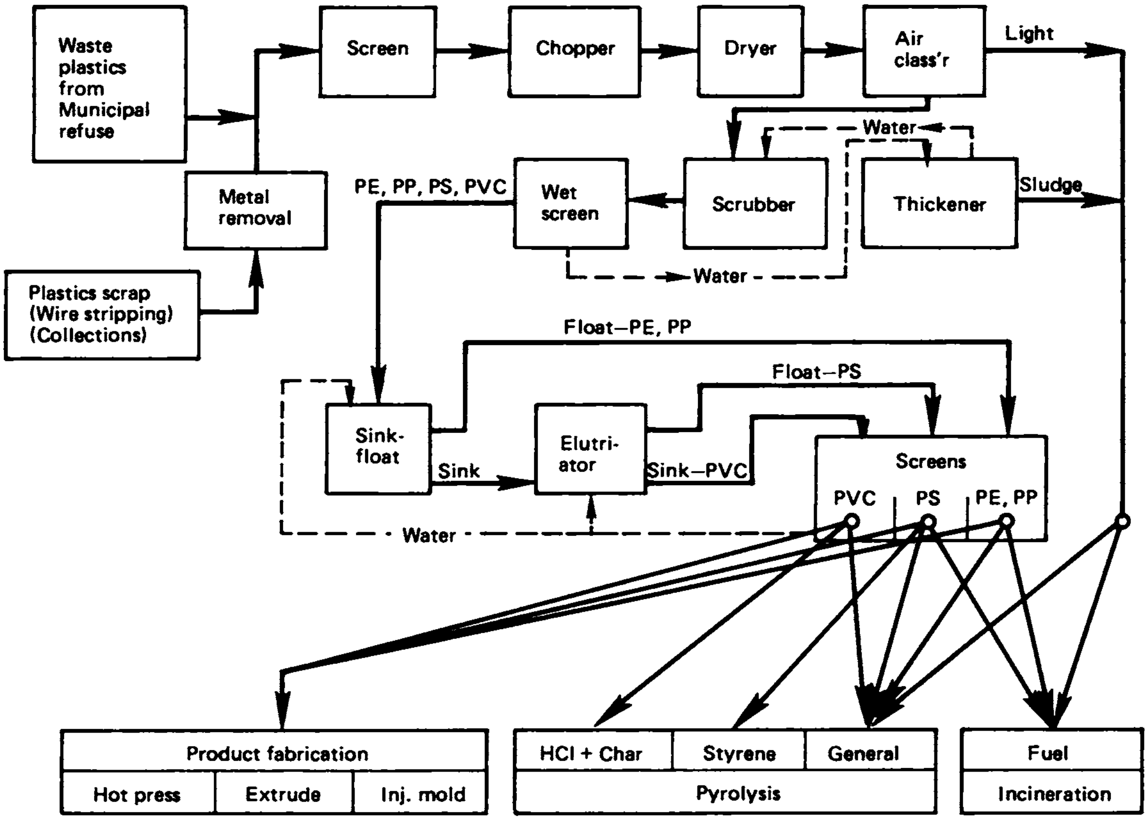


Figure III.7 Proposed Flow Diagram of Processing System For Reclaiming Waste Plastics

Source: Stephenson et al. (1973)

In the context of existing technology and economics, thermochemical recovery from mixed plastic wastes in a system such as pyrolysis or combustion for energy recovery represents the most viable end use for secondary plastics. Combustion of municipal wastes in waterwall incinerators for steam recovery is both technically proven and economically attractive. Raw urban refuse, generally taken to have a latent energy of about 5000 BTU/lb, becomes more valuable as a fuel source when the plastics content is increased. The heat value of plastic wastes ranges from 10,000 BTU/lb for PVC to more than 16,000 BTU/lb for polystyrene and polyethylene (IRTC 1973: 37).

Recent investigators in pyrolysis have concluded that this method of disposal of plastic wastes may have an economic advantage by generating more by-product fuel gas than is needed to supply heat for the reaction. In addition, the remaining products of plastics pyrolysis have been shown to have a heat value of more than 12,000 BTU/lb. Thermal decomposition experiments on waste PVC have indicated that every ton of PVC is a potential source of 600 to 1,000 pounds of HCl, convertible to 1800 to 3000 lbs of hydrochloric acid when combined with water (Holman et al. 1972). The remaining hydrocarbon residue could be used for fuel. Advantages to producing HCl in the form of dry PVC rather than as HCl gas include the following: flexibility in supply, storage, and use; reduced hazards in shipping and storage; and lower cost of shipping. The Bureau of Mines notes that per pound of HCl gas, the cost of shipping PVC is less than half the cost of shipping hydrochloric acid. This excludes the added cost of producing PVC and the liberating of the HCl gas from PVC at the destination.

Refabrication of recovered plastic wastes into useful articles is another promising alternative. Waste production in the fabrication of the two basic types of plastics is quite high--from 5 to 15 percent for thermoplastics and from 10 to 30 percent for thermosets (Darnay and Franklin 1972). About 1 billion pounds of scrap plastics are processed by reprocessors annually (EPA 1973). Mechanical methods for refabrication include hot pressing (compression molding), injection molding, and extruding.

The use of waste plastics in refabrication, however, faces certain institutional barriers. The first attempt at recycling postconsumer plastics was made in 1970 by a California firm that used high density polyethylene milk bottles, collected from housewives, in the manufacture of agricultural drainage tile (Stephenson et al. 1972). Although this was a potentially commercially viable program, it was halted by federal regulations requiring that "only clean reworked material generated from the manufacturer's own production may be used..." (Anon 1970). The failure of the program can be partially attributed to intransigence of standards. Similarly, regulations exist prohibiting the reuse of plastic waste materials in the packaging of food products. If utilization of waste plastics is to be encouraged, reasonable specifications of plastic material quality should be established commensurate with specified end use.

This is only one example of how recognition of existing institutional barriers can direct courses which technology might take to alleviate future impediments. The same approach could be used for other materials whose conservation is vital to the preservation of natural resources.

Future Options for Reuse

Innovative long range planning is resulting in the development of unconventional technologies in the manufacture and reuse of plastics. Because of numerous institutional, technical, and socioeconomic barriers, it is questionable whether these technologies will ever achieve widespread use. However, certain extraordinary conditions, such as total unavailability of petrochemicals for use in plastics or future regulations mandating the use of degradable plastic containers, may necessitate radical departure from conventional approaches.

Two emerging technologies, still at very early stages of development, will be presented to indicate the level of research which is presently being conducted. They are:

- substitution of petrochemical feedstocks used in making plastics by natural oils, and
- depolymerization to produce a fragment-molecule or monomer which may be used as a building block for plastic materials.

Natural Oils The concept of using natural oils as feedstock in plastics is obviously a preconsumption strategy since it is an action taken prior to the manufacture of a finished product. Research on this subject is presently being conducted by the U.S. Department of Agriculture and at various universities (Weismantel 1975).

USDA efforts have been, in part, directed at making a plasticizer based on a fatty amide made from the oleic fraction of cottonseed oil. Such a product would take the place of plasticizers derived from petrochemicals in PVC. It must be noted that while this process is expensive with cotton, the fact that the oleic molecule is present in most oils (Table III.2) might enhance the economics when an oil other than cottonseed is used.

A commercial process to make nylon from natural oils has been operating in France for 15 years. The product, called Rilsan, is made from castor oil which has ultimately been depolymerized to produce a monomer. Polycondensation of this monomer provides the polymer, nylon-11. Further processing of nylon-11 results in a fine powder, tradenamed Rilsan 11, used for molding and extrusion formulations.

The potential for vegetable oil feedstock offers many advantages in case of materials shortage. However, since the areas most suitable for vegetable oil acreages are outside of the U.S., it is impossible to predict reliability in the long range. In addition, the necessary acreage might be prohibitive. One calculation, made for cotton, is pertinent to illustrate the point: approximately 40 million acres of land suitable for growing cotton would be required to replace the more than 20 billion pounds of synethetic fibers presently being manufactured.

Reconstituting Existing Polymers Depolymerization of plastics to produce monomers which can be used as building blocks for new plastic materials can be considered either a preconsumption or postconsumption strategy. Design for naturally decomposable plastics is preconsumption planning while depolymerization technology employed using plastic wastes is postconsumption strategy. As stated previously, plastics are varieties of polymeric materials. As such, they may be decomposed into fragment-molecules or monomers. The chemistry of waste plastic depolymerization is similar to the polymerization of materials. However, more energy is needed for the former than for the latter. Decomposition is accelerated by heat, air, radiation, and mechanical methods.

All vinyl polymers, such as polystyrene and polyethylene, tend to depolymerize. However, the formation of a monomer is hampered by competing reactions including cross-linking and other activity by the polymer radical and chain transfer. Stable radicals produce monomers while reactive radicals, for the most part, cross link. The radical may be stabilized by the presence of hydrogen atoms which enhances the distribution of electronic charge, and enables adjacent bonds to be broken before the radical can cross-link. Polyethylene polymers may be decomposed in the presence of oxygen by self-propagating reactions of the free radical. Cross linking in this context results in a brittle substance. In management of plastic wastes brittleness may be desirable since it facilitates size reduction, such as shredding or milling.

The potential applications of monomer formation and repolymerization into new plastics have been tested by Zerlaut and Stake (1974), and require that the condition of chemical compatibility be met. It would be important to develop techniques to separate plastics so that the detractors which prevent the chemical reaction from proceeding be removed. In addition, the role of additives as polymer weakening agents to enhance the recovery of mixed plastics may affect their shelf life and produce less mechanically stable products.

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A. IV: RECYCLING OVERVIEW: ENERGY SYSTEMS COMPARISON

David A. Tillman

STATEMENT OF PREMISE

Recycling's principal application is as a method for disposing of solid waste; that it makes a contribution to materials supply is an important, but secondary consideration. The summary recycling recommendation of the National Commission on Materials Policy, (NCMP 1973) 1.9 states:

> We recommend that
>
> 1.9...a national resource recovery system be established through public and private sector cooperation to achieve three objectives (Chapter 4D and 4E):
>
> •discourage dumping and encourage resource recovery as a means of turning waste into a national resource;
>
> •encourage disposers to prepare waste for recovery rather than dumping; and
>
> •create markets for recovered materials by recycling technology, by federal procurement policies, and by equitable tax and transportation rates for virgin and secondary materials.

Clearly, that recommendation implies the primary and secondary priorities associated with recycling.

The opening statement carries broad ranging implications for technology selection. But, while those broad policy objectives are clear cut, the consequences in terms of choosing and implementing recycling systems, at the local and national level, are less immutable and straightforward. Yet the opening statement implies that recycling's primary competition comes from open dumping, landfilling, and incineration; comparative benchmarks, therefore, can be established.

COMPOSITION OF URBAN WASTE

The composition of as-received municipal solid waste averages about 84 percent organics including paper, plastics, garbage, yard wastes, wood, and other diverse materials; 8.5 percent glass, 6.5 percent ferrous metals; and 1 percent nonferrous metals including aluminum, copper, and zinc, among others. These values vary from area to area depending upon local consumer preferences, such as for bottled beer, and upon legislation giving preferences to specific types of containers. Presented below are values calculated by the National Center for Resource Recovery, on the basis of as-received solid waste (rather than on a dry weight basis):

TABLE IV.1

Material	Percentage
Paper	36.9
Glass	8.5
Ferrous metal	6.5
Aluminum	0.8
Tin	0.05
Copper	0.16
Lead	0.0017
Textiles	1.9
Rubber	0.7
Plastics	1.1
Food, Animal, Plant and Other Wastes	43.4
TOTAL	100.00

The disposal problem is more large-city than rural in orientation; this is due not only to the gross generation of waste, but also the habits of the metropolitan dweller. The National Commission on Materials Policy found that the city dweller generates 20 percent more waste than his rural counterpart. He reads more magazines and newspapers, consumes more goods generally, relies more on convenience products and packaging, and has a higher disposable income. Finally, the problem is more metropolitan because land is scarcest in that environment.

Organics constitute the largest volume of wastes and, more than any other material, determine the disposition method required. If they decompose in the ground, and if water leaches the resulting chemical compounds into a water supply or aquifer, pollution may result. The organics may interact with the metals to produce more toxic or polluting substances. The National Commission on Materials Policy defined the problem in the following manner:

> Most collected solid wastes go into open dumps that are breeding grounds for flies and rats, an attractive nuisance for scavengers, and a source of noxious odors and fumes. Sanitary landfills, which reduce these hazards, are handicapped by operating costs and the scarcity of suitable sites. Gases generated by decomposition in landfills form odor nuisances and explosive hazards. Further, if ground water rises into or surface water passes through solid wastes, such water may carry pollution to wells or reservoirs.

The United States Geological Survey (USGS), in its paper, "Hydrological Implications of Solid Waste Disposal," (USGS 1970) was more specific. It documented the following pollution problems:

> Leachates from open dumps and sanitary landfill usually contain both biological and chemical constituents. Organic matter, decomposing under aerobic conditions, produces carbon dioxide which combines with the leaching water to form carbonic acid. This, in turn, acts upon metals in the refuse and upon calcareous materials in the soil and rocks, resulting in increasing hardness of the water. Under aerobic conditions, bacterial action decomposes organic refuse, releasing ammonia, which is ultimately oxidized to form nitrate. In both landfills and open dumps, where decomposition is accomplished by bacterial action, the leachate has a high biochemical oxygen demand (BOD).

The USGS documented cases in Krefeld and Schirrhof, Germany; Surrey, England; and DuPage County, Illinois, to demonstrate specific hydrologic actions.

Given those hazards, recycling has gained favor as a method to keep waste--or the vast majority of it--out of the ground where it operates as a potential source for pollution; and by returning the materials to the productive stream of the economy. Since various technologies emerged, they merit review as performance systems.

TECHNOLOGY SELECTION

Numerous recycling technologies are evolving to handle urban waste; they vary in fundamental approach, process system, and product output. Each recovers a fuel and some material, but their similarities begin to disappear. Communities must evaluate these approaches to recycling; since each produces a fuel plus associated material coproducts, the product overlap makes objective analysis more difficult than it initially appears. Analysis must be made consistent with the composition of waste--84 percent organics, 7.5 percent metals, and 8.5 percent glass--and with the problems associated with the organics, plus their interaction with metals, when such waste is buried.

Sets of criteria emerge from the problem definition; these consider the gross problem of waste disposal plus the chemical reactions which occur during decomposition in the ground. Finally, they take into account supply augmentation potential.

Evaluation Criteria

1. What percentage of incoming material is removed from landfill by recycling?

2. In what condition is the material which still must go to landfill?

3. What is the volume and utility of the products produced?

4. What is the net cost of recycling operations?

The evaluation criteria can be recast, for system selection purposes, into two cost categories: producer costs and user costs. Producer costs include the capital investment required to install the systems, the manpower and energy required to operate the system, costs associated with downtime for maintenance and repair, and the costs associated with landfilling such product outputs from the recycling system which cannot be sold. Producer costs are offset by the price paid to the recycler for his output of usable products; producer costs are affected by the (organic) nature of residues heading for landfill. User costs include the following: additional equipment required to handle the recycling fuel, including pollution control equipment for stack gas cleaning and ash handling purposes; thermodynamic losses due to elements such as moisture, ash, diluent gas, or inorganics inherent in the fuel product; boiler de-rating due to fuel quality; and additional operating costs.

The installation of any recycling system mandates, to a large extent, the trade-offs between optimizing the producer costs and optimizing the user costs. Without reasonable user costs, no recycling product can be marketed; hence, no values can be returned reasonably to society and the waste disposal system is unimproved. Without reasonable producer costs, waste disposal may be more expensive than landfilling and the objectives of recycling will not be served.

Generic Process Characteristics

Four groups of technologies have emerged at various stages of development: dry mechanical, wet pulping, thermal processing, and biological conversion systems.

Dry mechanical processing approaches the problem, first, with pulverization or shredding; valuable products can then be liberated from the urban ore mass. Segregation of individual constituents proceeds by utilizing the different characteristics of the individual material types. Separation results from capitalizing upon differences in specific gravity, magnetic or electrostatic susceptibility, conductivity, friability, and surface chemistry. Output streams can include shredded paper and plastics, heavy organics, light and heavy ferrous metals, glass, aluminum, and heavy nonferrous metals.

Wet processing employs paper making comminution technology plus liquid cyclones for specific gravity liberation of organics.

Output streams include metals, glass, and a 50 percent solids homogenized fuel (or fiber recovery).

Thermal processing means pre-treating wastes by pyroprocessing prior to their sale in the form of usable products. Direct mass burning, incineration, is the traditional technique. Materials recovery may follow. Pyrolysis, destructive distillation of organics in the absence of oxygen, offers one alternative; hydrogenation, treating organics with carbon monoxide and moisture under high pressures and elevated temperatures, offers a second possibility. Product streams include ferrous metal and fuels. These two alternatives emerged from coal refining research.

Biological conversion capitalizes upon the susceptibility of cellulosic materials to enzyme attack. Cellulose may be converted to methane, glucose, or single cell protein; lignin and other heavies remain as a sludge, with the lignin usable as a fuel. Mechanical, wet, and thermal processing have been demonstrated on large (150 tons per day or more) scales; biological conversion remains at laboratory scale and needs larger demonstration prior to critical analysis as a tool for meeting community needs.

Commercially, dry mechanical processing gained the initial lead in community acceptance; at large scales this process recovers the paper and plastics as a utility boiler fuel supplement, and produces a ferrous co-product. The Union Electric, St. Louis, Missouri, 500 ton per day project, now on line, may be employed as an example for comparative purposes. Wet pulping gained impetus from the Black Clawson Fibreclaim 150 TPD demonstration plant in Franklin, Ohio; this technology will be built in Hempstead, Long Island, with a 2000 TPD capacity. Pyrolysis has achieved successes as an acceptable thermal treating system. Again energy and ferrous recovery are primary design objectives. The 200 TPD Union Carbide system in South Charleston, West Virginia, offers the principal comparative example from a data availability point of view. While employing these three technologies as primary examples, this paper will make comments on direct incineration and other systems.

Commercial Process Comparisons

The three commercial process trains available for comparison exhibit some similarities, particularly at the goals level; at the same time the approaches differ radically. The present Union Electric St. Louis system shreds solid waste, passes it through a vertical drop air classifier to remove the paper and plastics, magnetically removes the ferrous wastes, and sends some of the heavy organics, glass, and nonferrous products to landfill. The light fraction is burned as a supplement to coal; the ferrous is sold to a steel manufacturer.

The Black Clawson system pulps all waste in a 97 percent water, 3 percent solids medium. After removing large objects with a junker, the remainder is reduced to particles less than one inch in size. Inorganics are removed by a liquid cyclone; organics are processed and mixed with sewage sludge. For fuel production they are dewatered to 50 percent prior to combustion.

In the Union Carbide system, the incoming waste is shredded, the magnetics are removed, and the entire remainder is pyrolized using a three stage vertical reactor. The top zone is the drying zone. The second, or reaction zone, is oxygen deficient and has a temperature of 1200 to 1800 F. Pyrolysis occurs here, and the off-gas is removed. The char falls into a combustion zone and is fed pure oxygen to achieve a firing temperature of 3000 F. The pyrolytic gas, passed through a Venturi Scrubber, has a value of 300 BTU/scf.

Waste Disposal Characteristics

Evaluation of recycling systems can be handled through a uniform application of the criteria. The first two selection criteria deal with waste disposal: the volume and characteristics of residues going to landfill. Dry mechanical systems exemplified by the Union Electric St. Louis system send 10 to 15 percent of the incoming trash to landfill, primarily heavy organics and glass. Their purchaser, the power plant, also sends bottom ash and fly ash resulting from waste combustion to landfill. Wet systems, such as the Black Clawson plant being built in Hempstead, Long Island, homogenize all organics for combustion and send virtually no material to landfill. Pyrolysis systems consume all but 2 percent of the input solid waste; that residue heads to the disposal site.

Residual wastes vary markedly in composition and hazard. Dry mechanical systems discard heavy organics; they reduce markedly, but do not eliminate, the potential hazards described by the USGS. Wet systems eliminate this hazard. Pyrolytic systems such as the Purox unit discharge a quenched slug previously treated at 3000 F; it is sterile, inert, and may be dumped as well as land-filled without hazard.

Product Utility

The attractiveness of any product determines its acceptability to industry; a marginal desirable product may not find market viability and may end up, again, in the landfill. Since organics constitute 84 percent of the solid waste stream, and act as the primary pollution hazard in the landfill, fuel chracteristics form the critical product area for detailed analysis. Problems which determine product utility include the following: (1) storage problems, (2) transportation problems, (3) combustion problems including impact on boiler efficiency, and (4) pollution problems associated with recycled fuel combustion in a boiler or kiln.

Storage of mechanically shredded waste is no simple matter. Since it contains between 20 and 30 percent moisture, storage may cause partial decomposition and product reformation in a solid mass. Cold climates may freeze the mass of waste. Thus storage time should be minimal. Pyrolytic gas is difficult to store, and is probably best handled by sale or immediate combustion. Pyrolytic oils offer the best storage characteristics.

Transportation is the second major problem; some fuels can move farther than others. Dry solid waste, moved by unit train or barge, can be transported for several miles; wet wastes are not so flexible. Pyrolytic oil can be moved almost at will, much as petroleum moves. Unless pyrolytic gas is methanated, at considerable expense in efficiency and water, its transportation range is severely limited by its lower heating content (vis a vis natural gas) and lower pressures.

Combustion characteristics of any fuel are determined by its physical and chemical composition. Three types of components exist in recycling fuels; valuable fuel elements (i.e., carbon and hydrogen), boiler inhibiting elements (i.e., moisture), and potential pollutants (i.e., ash). Table IV.2 compares the fuels from dry mechanical systems, wet systems, and oxygen fed pyrolysis. Coal is presented for comparative purposes.

Combustion of shredded fuels may well appear as the best route if the local utility has a base load coal fired station. But the utility will pay a thermodynamic price; the moisture content in the fuel can reduce boiler efficiency. The coal fired boiler's efficiency can drop significantly if the feed is 85 percent coal, 15 percent refuse on a heat basis. The bark burner used to combust wet homogenized fuel operates at a 65 percent efficiency rating. PUROX and Garrett fuels, pyrolytic gas and oil, do not have such effects. Overall efficiencies of solid waste fuels, the BTUs released as usable energy are shown in Table IV.3.

The numbers in Table IV.3 are calculated as follows

Gross input minus:

- mechanical conversion losses
- chemical conversion losses
- system operation energy requirements (including supplementary fuels)
- fuel combustion inefficiencies (inherent plus those created by such problems as increased moisture)

YIELDS

Net usable energy

Clearly, the pyrolytic gas route provides as efficient a route as dry mechanical shredding followed by air classification. Its chemical conversion losses are matched by the dry system's losses in air classification and in increased boiler inefficiency. General Electric (1973), in its plan for the State of Connecticut, concluded:

TABLE IV. 2

		Percent Content			
		Coal	Union Electric	Black Clawson	Union Carbide
H_2O	Moisture	8.96	26.04	50.0	0
C_2	Carbon	63.31	27.23	23.26	-
H_2	Hydrogen	4.75	3.85	3.3	33
CO	Carbon Monoxide	-	-	-	47
CO_2	Carbon Dioxide	-	-	-	14
CH_4	Methane	-	-	-	4
C_2H_X	Hydrocarbon	-	-	-	1
N_2	Nitrogen	1.02	0.28	0.33	1
Cl	Chlorine	0.12	0.20	0.72	0
O_2	Oxygen	9.98	21.49	17.26	0
	Ash	11.28	20.63	5.6	0
S_2	Sulphur	3.38	0.26	0.09	*

*Trace

TABLE IV. 3

Fuel Type	Estimated Efficiency
Dry Shredded	60-65
Gas Pyrolysis	60-65
Wet Pulping	50-55
Oil Pyrolysis	40-45

A review of the pyrolysis systems shows a greater spread in yields. The highest energy yield is obtained from the fuel gas process. Energy yield is of the same order of magnitude as that of the solid fuel preparation processes, while the only material recovery is an innocuous frit suitable as a construction aggregate or for direct landfilling.

Pollution problems associated with urban refuse based fuels are associated only with particulate emissions; these fuels are low in sulphur and nitrogen. Incineration faces the most severe problems; it has a high ash fuel with a lack of stochiometric air control. Shredded refuse, with a 20.63 percent ash content, also suggests problems. At Union Electric, preliminary tests indicated inlet dust loadings of 2.2904 grains/scf. Precipitator efficiency decreased from 97 to 93.5 percent when refuse was increased from 0 to 30 percent of the boiler feed. These results must be considered preliminary; more definitive testing may prove or disprove the magnitude of ash control problems indicated presently. Ash in wet homogenized fuel is but 5.6 percent; it necessitates bag houses, but offers fewer problems. Pyrolysis process trains eliminate ash prior to fuel sale.

Net Costs

Net processing costs, the difference between capital and operating expenses and the sale of products produced, constitutes the final consideration. In the gross cost area, shredded refuse processors gain a distinct advantage with lower capital outlays and simple process trains. Although pyrolytic fuels are more valuable, it appears doubtful that they can reverse the economic advantage of the dry mechanical process train. Competitive bids, to date, have indicated net cost advantages for the dry mechanical systems. This advantageous position for the dry mechanical system is predicated upon the existence of coal fired utility boilers with ash handling capability. National energy policy, with its emphasis on coal, is increasing this advantage of shredded fuel systems. The advantage varies, however, from region to region.

Application of the criteria, then, suggests numerous trade-offs. Mechanical systems appear to have a cost advantage, sacrificing some disposal pollution hazards and fuel quality characteristics. Thermal systems may maximize both disposal solutions and fuel quality but incur a cost penalty. And more subtle trade-offs occur within each system type--and between the generic categories--as communities seek to optimize flexibility of fuel, disposal alternatives, or yet another category.

Future Technologies

The Bureau of Mines raw refuse pilot plant, now ready for scale-up, will bring dramatic improvements to the dry mechanical system by eliminating the landfill problem and making recovery of glass and nonferrous metals more economical. Hydrogenation, also developed by the Bureau of Mines and being tested by ERDA, suggests improvements in the storage and transportation areas for thermally processed fuels. And biological digestion appears on the horizon as yet another generic type waiting for development. Conscious application of the latest technologies for mineral beneficiation and refining will bring continued improvements to the waste disposal problem as they are transferred to the new ore--municipal solid waste.

COMMUNITY ACCEPTANCE

Despite the plethora of technological advances constantly emerging, many communities will not wait; they cannot afford to. Landfill space is in short supply, and relocating the city dump is an extremely trying process at best; nobody wants this new neighbor. Thus communities from Milwaukee to Miami, from Baltimore to San Diego, have opted for recycling. At present some 32 cities or regions have selected recycling systems to process 15.8 million tons of urban waste per year. The vast majority of approaches involves a dry shredded fuel. The largest single system, being built by Union Electric, will process 8,000 tons per day--nearly 3 million tons per year. Pyrolysis, however, is gaining ground rapidly.

Recycling of refuse will save a lot of land. At the same time, it will generate enough energy to replace 46,500 barrels of oil--or 260 million cubic feet of gas per day. That will not solve our oil import problem, but it will heat General Electric's Lynn, Massachusetts, plant. It will generate electricity in St. Louis; Hempstead; Ames, Iowa; Bridgeport, Connecticut; and Milwaukee, Wisconsin. The recycling of steel will save another 100 million cubic feet of gas per day; other recycling--aluminum and glass where recovered--should make additional supply contributions. In total, over one hundred trillion annual BTUs will be provided by presently committed recycling systems.

In addition to the 32 cities committed to recycling, 18 have entered the discussion stage. Assuming, for the moment, that they move favorably, by 1980 some 24 million tons of refuse will be recycled annually. That represents a 20 percent savings on landfill space--a great savings indeed. Recycling of urban wastes has moved from a novel technology, and a nice idea, to a rapidly growing technique for eliminating the hazards of waste disposal.

While recycling remains a metropolitan oriented approach, some more rural areas will probably enter the resource recovery arena. Smaller communities and regions will base their decisions, to some extent, on economics. But for many, environmental ethics, the prestige of participation in a national movement, and other socio-political factors will also be powerful stimulants. While landfill might remain, for these areas, the most economical solution, it may not be politically acceptable. On this basis, Vermont continues to consider recycling; other rural areas are doing the same. The rural area, faced with a less urgent problem and a lower volume of waste, may opt for partial front-end systems or may include selected supplemental industrial wastes (i.e., wood waste) as the system becomes tailored to the area's requirements.

CONCLUSION

Recycling is not the way of the future; it is the disposal technique of the present. It solves the growing need for an alternative to open dumps and landfills--particularly in cities and regions with 250,000 or more people. Those cities generate enough trash to make the approach viable; they also exhibit the most severe disposal problems. Rural areas must solve the problem in other ways, possibly using organic industrial wastes (e.g., wood) as a supplementary feedstock, or through some form of citizen participation. Rural areas, with plentiful land, may be able to use highly engineered landfills to minimize hazards.

Recycling is not a major supply system. It does make a minor contribution to the energy picture; and those small contributions are significant. Its major contribution is in the area of land savings. Presented below are two graphs (Figures IV.1a and IV.1b) taken from the Final Report of the National Commission on Materials Policy. They illustrate the maximum contribution which urban waste recycling can make to the total supply of steel and aluminum. In the case of steel, the highest contribution would be 10 percent. The total possible contribution to energy supply is estimated at 1.25 percent.

Finally, recycling systems are selected based upon the handling of organics. That defines both the major product produced, energy fuels, and answers the waste disposal criteria. The production of energy eliminates or significantly reduces the volume of organics being landfilled; in some processes this energy production renders the residue inert, sterile, and safe. In summation, four generic types of technology are developing rapidly to compete with the older, outmoded, dumping practices. Specific technological and economic trade-offs--at the community level--will determine individual process selection.

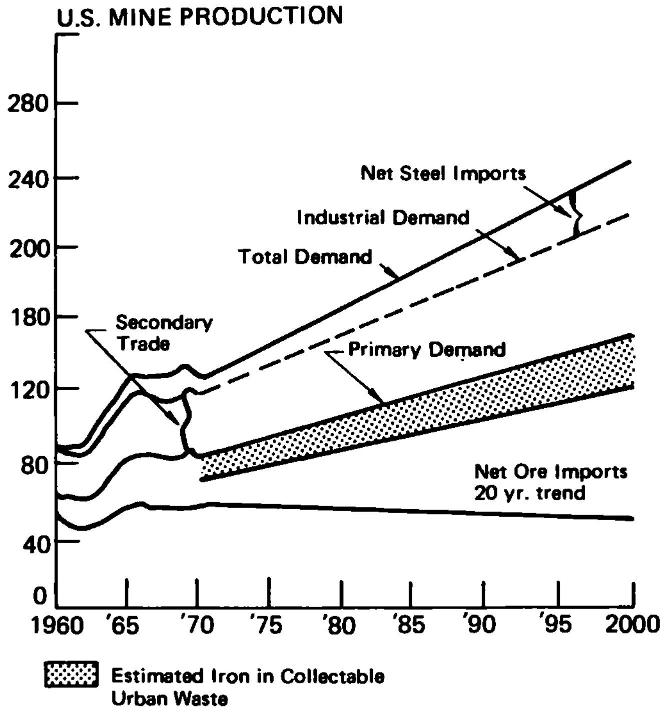

Figure IV.1a Iron Collectable Urban Waste Related to U.S. Iron Demand and Supply 1970-2000 (Million Short Tons Contained Iron)

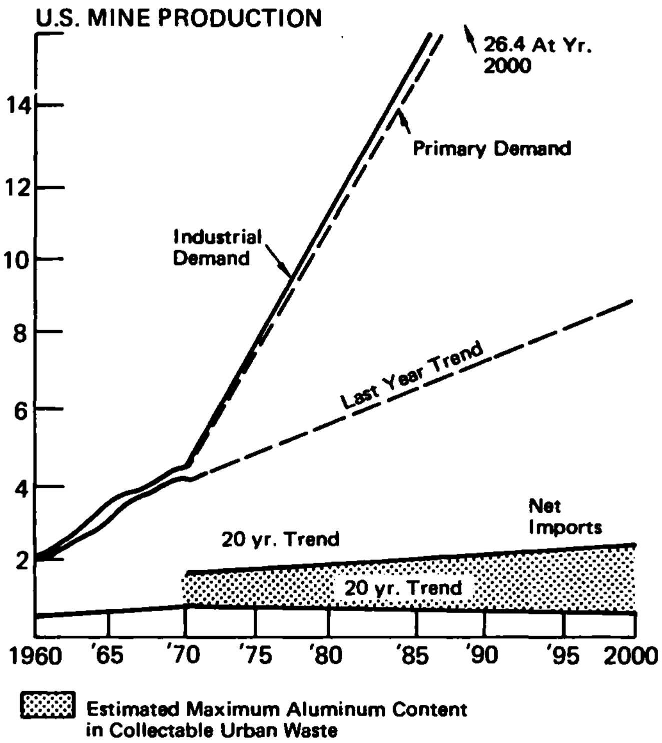

Figure IV.1b Aluminum Content in Collectable Urban Waste As Related to U.S. Aluminum Demand and Supply, 1960-2000 (Million Short Tons)

REFERENCES

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A. V: SWEDISH EXPERIENCE IN MUNICIPAL SOLID WASTE RECYCLING

Carl Lindstrom

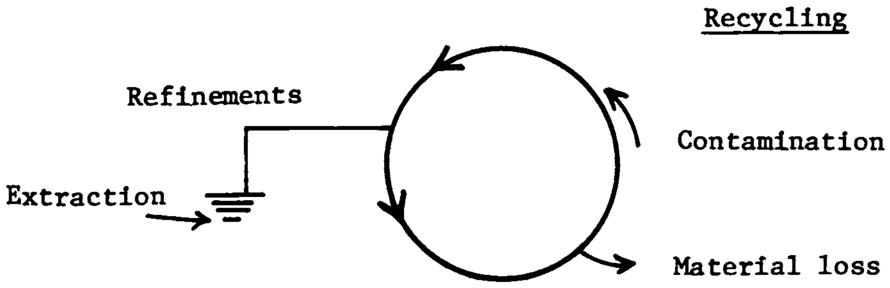
THE PROBLEM

The definition of the word waste is in itself a crucial question. It is, for example, important to clarify for whom a material is waste, especially if we are talking about resource recovery.

Waste or not waste can many times be a legal question; does for example a material cause harm to nature, health, or is it for specified land use purposes? All these problems suggest that we need criteria, for full cycle designs, which anticipate the availability of scarce basic resources and which minimize pollution of commodities outside that cycle.

This might sound like a truism but it is a fact that most of the new existing and widely used waste treatment systems were designed during times when resource recovery was not the primary goal, or was not even in the discussion at all.

As clean air, clean water, and nutrients for food production become scarce with a growing population--the problem does in fact embrace full cycles of basic resources in general. Utterly simplified, such a cycle can be illustrated by this figure:



The resource availability from household waste is largely determined by the technology used in the processes of consumption, collection, transportation, waste treatment, and in which order the last three processes take place. Or, in other words, the implications of the treatment on site or centrally.

Material losses from a cycle suggest that more energy must be spent on extraction, refinements, transportation, and so on, and contaminations (defined as the mixing of materials that so mixed have no value for either of the materials) suggest energy for separation processes.

The real issue is, or should be, the net energy balance for all processes involved in a full cycle.

In January 1974 a special working committee was formed by the Department of Agriculture in Sweden to investigate certain areas within the field of waste handling. During June 1974 their suggestions for resource recovery from wastes were presented in a report called "WASTE, Increased Recovery and Better Handling." Their unanimous proposals are listed below.

(1) Household waste consists of valuable resources which as far as possible should be reused or recycled.

(2) To increase the rate of recycling the different resources should mainly be separated with a view to the type of treatment necessary. Magazines and newspapers, for example, should be segregated in the household.

(3) The committee suggests that national subsidies with up to 50 percent of the treatment facility costs shall be made available for demonstration plants as well as for resource recovery plants in full scale. (From environmental points of view it is necessary that the treatment of waste is improved. Therefore, the committee suggests national subsidies to such facilities also, however, with lower percentage.)

(4) The committee suggests that the terms "dumping site" and "destruction plant" in the present laws shall be exchanged to "storage site" and "treatment plant" respectively, in order to correspond better to the committee's view of waste as a commodity.

PAPER WASTE

(1) The committee here proposes that the collection of recyclable paper mainly shall be done within the framework of the community waste treatment monopoly law. For reaching the best effect this collection should be based on segregation at the source of the paper waste production. For the households, this means that newspapers and magazines should be kept separate from other types of waste.

(2) The government has authorization to extend segregation of other waste products, such as glass, metals, and organic waste.

(3) It is suggested that professional activities in largescale paper collection without authorization from the community shall be regarded as a criminal offense, which is to say that the paper in newspapers and magazines no longer is wholly private property, but rather a rented or leased resource. This approach has in

a way been practiced for returnable bottles (a retrievable cost for the bottle at the return).

(4) The community can give authorization to non-profit organizations to handle collection for recycling or to authorize companies, offices, and private business to arrange for collection on a central basis, as long as the recycling purpose is satisfactorily achieved.

The report includes proposals concerning chemical waste, industrial waste, hospital waste, and sludge from municipal sewage treatment plants based on experiences and present research results.

Waste from industry is regulated by the Swedish Environmental Protection Act from 1969 only if the nature of the industry is characterized as "environmentally hazardous." The act contains definitions of potential pollution impact on water, air, as noise or as other disturbances as a consequence of land use, use of buildings or plants.

The implementation of this act has meant a great deal for resource recovery, even though this was not the primary purpose of the law.

One example is the fiber recovery from paper and pulp plants as a consequence of the effluent requirements. Another example is the waste exchange market which developed in the Scandinavian countries mainly because of the environmental protection act.

One of the leading principles in the Swedish approach is that the responsibility for waste generated during the production of goods or articles is put on the producer. Before an article is produced one should be conscious of what waste products there will be and how they shall be treated as well as how the article itself shall be disposed of after it is used up.

Planning for a new product should in other words include impact on resources and pollution as well as effective reuse or recycling at the end of the process after consumption.

The objective is to decrease the amount of waste as much as possible using available or new technology and plan ahead for the utmost reuse of generated waste.

In 1972 the Swedish National Environmental Protection Board decided to assess a full scale municipal compost plant with the emphasis on the environmental impact caused by different uses of that end product. This plant is now in operation in Laxa (south Sweden) and receives mixed solid household waste which is first shredded and then mixed with different sewage sludge to provide a better carbon/nitrogen ratio. This solid waste sludge mixture is then composted for one week in a seven-step reactor made by Carel Fouchet, France.

The end product is anticipated to have a heavy metal content that makes it unfit for food production but it could possibly be used to fertilize forest land, roadsides, and so on. The interest in this process is great in Sweden mainly because of the need for stabilization of the huge amount of sewage sludge generated as a consequence of the rapid achievement of a tertiary treatment program for the sewage treatment plants. (More than 60 percent of the urban population is connected to tertiary treatment.)

The sludge--this curiously unanticipated product--has lately caused a discussion about new future policies. One common view is that the construction of sewage treatment plants was a logical step considering the existing infrastructure of a waterborne waste transportation system, and that it was necessary to provide protection for lakes and other bodies of water. But since it now has become clear that municipal sludge can neither be safely burned (air pollution precipitation), put on land (heavy metal problems and ground water damages), nor go into water (self-evident unless deep ocean dumping), it is necessary to develop new systems for handling both solid and waterborne waste.

Such systems should focus on the simultaneous resource recovery and protection of the environment, and gradually on a long-term basis substitute for the present ones. As an example of this I wish to refer to one project proposed to the Swedish Environment Protection Board and funded also for preliminary investigation by the National Board for Technical Development and the Swedish National Board for Building Research.

The project is described in Sodergren (1975) but some comments might be proper. Main principles of basic resource recovery will be demonstrated in practicable technologies and assessed. The priorities are put on:

(1) heat conservation and recovery;
(2) water use and reuse;
(3) nutrient recovery; and
(4) recycling of paper, metals, and glass (bottles).

The waste products are grouped in such a way that the mix of materials still constitutes a valuable basic resource, and are processed on site until they are harmless regarding both health and environmental impact. The techniques practiced are such that "doing right" is easier or as easy as doing wrong, thus anticipating that the failure percentage of the waste segregation will be small.

The lifetime of the various systems is designed to last the lifetime of the house. Again it might be worth pointing out that on site segregation systems must be thought of in a long-term perspective and judged with regard to the priorities in resource recovery.

The projects here discussed are limited to fields where I see rather unique differences from the U.S. experiences. I should mention that the National Swedish Board for Technical Development presently supports different projects for solid waste separation and treatment.

A pyrolysis plant is for example built in Gislaved, but it is my impression that the U.S. technolcgy is more or equally advanced in this field.

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A. VI: TRASH DISPOSAL IN GERMANY

Burkhard Strumpel

According to a study by Battelle Frankfurt (1973), the following quantities of household trash were generated in Germany during the early 70s: approximately 0.15 metric tons or 0.7 cubic meters per inhabitant of rural communities and 0.32 tons or 2 cubic meters per inhabitant of the metropolitan areas. The specific weight of trash is highly dependent on the size of the community, declining with size from 0.235 for communities below 20,000 inhabitants to 0.19 for communites of more than 50,000.

Household trash contains 25 to 35 percent water. After eliminating that component, the following composition has been calculated: "kitchen garbage" 10 to 16 percent; paper and cardboard 30 to 40 percent; plastics 3 to 5 percent; textiles, wood, leather 3 to 6 percent; glass, stone 15 to 17 percent; metal (more than 90 percent iron) 3 to 10 percent; and ashes, sand 10 to 36 percent.

It will be shown later that "one-way" disposable bottles are still used only for some beverages. It has been calculated that the complete substitution of one-way bottles for multiple-use bottles would raise the trash volume per capita to 0.42 to 0.45 metric tons (metropolitan areas). This would increase the proportion of glass in the garbage to about 50 weight percent and thus would exceed the technical limit for combustion and compression.

TRASH DISPOSAL

There are three major methods of trash disposal used: deposition; combustion; and compression. The first annual report of the Council of Ecological Advisers (1974) to the German Federal Government recommends as a first priority government subsidies for the elimination of old-fashioned deposit sites including the construction of combustion and compression plants. The Council is skeptical about placing high priority on the development and implementation of new processes for trash disposal, in particular those that are explicitly geared toward recycling. It considers trash disposal as optimal if and when "a combination of plants with different processes (deposition, compression, and combustion) is implemented on the basis of joint agreement of a number of municipalities."

About one-quarter of the trash is being disposed of by combustion plants and approximately 2 to 3 percent by compression plants. There is an effective trend toward drastically reducing the number of public deposit sites to around 5 percent of the many thousand sites existing before. Many of these smaller sites do not have complete fencing, no toilets, no fire protection equipment, no equipment for control and observation and no personnel for daily covering the trash.

In deriving conclusions from the facts outlined above, the Council of Ecological Advisers deplores the lack of data impairing planning and control of trash disposal. It recommends systematic monitoring of trash generation and disposal. It believes that increased recycling in the near future cannot solve the problems, or at best only in a limited way. The first priority should be, in the short- and medium-range future, to secure the orderly disposal of all generated trash and to prevent grave consequences from non-orderly disposal. This strategy, so the Council says, includes a systematic clearing or recultivation of "wild" (i.e., illegal) deposit sites. Reuse of trash should not be accorded the character of a goal competing with other goals in the trash disposal field. It rather deserves the role of a means. The decision whether certain components should be reused or disposed of otherwise should depend on considerations of optimization considering ecological, economic, and temporal perspectives.

In the long run, the Council declares that the trash disposal sector can make its contribution to improving the environment only if a reduction of trash quantities and an improvement of the composition of the trash can be achieved to a high degree. It advocates the principle of causation implying the internalization of costs of trash disposal and/or damage to the environment in the price. It recognizes that this principle can only be implemented slowly as long as dispsal plants are unavailable and undesired reactions ("wild" deposits) cannot be prevented. As a later and supplementary step the Council advocates a differentiated tax on products and production processes depending on the ease or difficulty with which the product can be absorbed by the disposal system.

PAPER AND CARDBOARD DISPOSAL

Table VI.I shows the proportion of paper recycling in various countries. On the left-hand side it shows the recycling/fiber input ratio containing the proportion of recycled paper out of the entire fiber input; the second column exhibits the recycling consumption ratio containing the proportion of recycled paper out of the whole paper consumption of the country. The difference between the two figures is due to the varying proportion of imported paper. For instance, in 1973 Germany consumed 8.4 million metric tons. It produced only 6.4 million tons. Consequently paper exporting countries like Sweden and Finland exhibit a low use quota (first column). In Germany, the use quota has increased from 42 to 48 percent between 1960 and 1973, the recycling rate from 26 to 30 percent. The rate of reuse (recycling) is higher for those countries that are more densely populated. This relationship also applies to differences within a country: in small communities below 30,000 inhabitants only 8 percent of the paper is recycled, in big cities exceeding 500,000 inhabitants 43 percent. This relationship is accentuated by the much higher paper consumption in metropolitan areas (about 3.5 times as high as in the smaller communities). The recycling is concentrated in the centers of paper consumption.

TABLE VI.1

PAPER RECYCLING IN VARIOUS COUNTRIES 1970

	Recycling Fiber input (%)	Consumption (%)
West Germany	49.3	31.4
United Kingdom	39.7	28.7
Japan	37.3	38.4
Ireland	34.5	9.0
Netherlands	34.0	39.6
France	32.2	27.5
Denmark	32.0	18.1
Switzerland	30.6	30.0
Spain	30.1	27.6
Italy	28.8	20.5
Greece	28.7	18.5
Austria	24.6	29.8
United States	21.7	21.9
Belgium	21.0	30.3
Norway	6.7	19.1
Sweden	5.3	22.2
Portugal	4.8	2.3
Finland	4.6	22.2
Canada	4.0	13.3
Average (unweighted)	23.2	25.5

Source: Pothman, Altpapiervertwertung, in: Wochenblatt fuer Papier-Fabrikation, 1973, s. 941.

THE KEY IMPORTANCE OF THE ONE-WAY BOTTLE

The German glass industry does not have any trouble in buying raw materials. Nor can it save larger quantities of energy by the reuse of bottles. Nevertheless the industry has good reasons to advocate the reuse of bottles. Used glass containers because of their heavy weight and their large volume are particularly conspicuous as a component of household trash. Moreover, in 1967 the industry started a propaganda campaign in favor of the one-way bottle with the slogan "ex und hopp" (out and away). This slogan was bound to encounter heavy resistance on the part of the educated public during a period characterized by a sharpened consciousness in matters of environment. The glass bottle--highly visible and ubiquitous--became the symbol of both waste and pollution and the "super trash generator" of the future. In 1972 a law was passed by the Bundestag empowering the government to prohibit the production of packaging materials and containers whose disposal causes disproportionately high costs. At the same time the Parliament charged the government to develop strategies and to facilitate production processes that take into account the recycling of waste products as well as facilitate waste disposal. Furthermore, it asked the government to work out proposals for compensatory taxes on the producers of goods that cause disproportionately high costs for later waste disposal.

Reacting to these signals, the glass industry has stopped its original promotion of non-returnable bottles. It now anticipates no further increase of the market share of non-returnable bottles.

In 1973, the German glass industry produced 4.8 billion bottles amounting to two-thirds of the total glass production. Of those, approximately 3.25 billion bottles were non-returnable. Since 1967, bottle production has doubled; the production of non-returnable bottles increased fivefold. For beer and soft-drinks, the proportion of non-returnable bottles sold amounts to only 4 to 5 percent of the sales.

At present the glass industry favors a reuse of used glass (not used bottles) possibly based on industrial automatic separation of bottles from the household trash. Unfortunately, these processes require a high amount of energy. Due to the higher energy costs in Europe compared to the United States, these processes are subject to a higher threshold of profitability. Another procedure contemplated by the glass industry is separation by households, requiring special containers for each household as well as special transportation. Switzerland, Sweden, and Belgium tried this procedure for quite a while. In Switzerland, there are more than 300 municipalities collecting glass by separate vehicles. In Belgium, the glass industry takes charge of the collection in 50 municipalities.

DISCARDED AUTOMOBILES

Visible automobiles abandoned by their owners have become rarer in Germany owing to recently increased prices for scrap metal. Used cars became an economic good instead of an ecological problem. Only 5 percent of discarded cars are being disposed of illegally by their owners. The remainder goes directly to scrap metal dealers.

HOLLAND AS "EUROPE'S TRASH MAN"

Because of conspicuous scarcity of raw materials, the Dutch have traditionally pioneered in developing recycling methods. However, this aspect of the Dutch economy is heavily under-publicized. The Dutch do not want others to know what high economic value is hidden in the seemingly worthless materials they are often being paid by foreign business to import to their country. Typical example: cars after accidents. They are being carried to the Netherlands, repaired, and later sold as used cars. In 1972 the Dutch developed a plan for the construction of an island in the North Sea exclusively devoted to trash disposal. The island is planned to extend to about .5 square kilometers and is supposed to cost about $250 million. It is to include a power plant, a harbor, and complex machinery for trash separation. It is the goal of the project to process trash coming from households and industry under conditions optimal for environmental protection. The difficulties and obstacles delaying the project are mainly of a legal nature. It is doubtful if establishing such a plant is legally feasible considering the internationally valid restrictions against private use of the open seas.

DISPOSAL OF AUTOMOBILE TIRES

There is an ultra-modern plant (Mayer) in Landau, West Germany, specializing in recycling or combustion of new and used tires, respectively. All components arising from the process are being utilized. The manager describes the process as "100 percent recycling." Details of the process are available from me upon request.

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A. VII: MUNICIPAL WASTE RECOVERY IN THE UNITED KINGDOM

T.M. Moynehan

A comparison of the situation in our two countries is bound to be marked more by similarities than differences; societal organization is basically the same and differs mainly in its overall scale. In the technological field there is obviously much international collaboration and exchange and the only differences can be in the degree of practical application of new advances.

The basic figures for the United Kingdom are that the collection of municipal solid waste amounts to about 20 million tons per year (equivalent to about 1 ton per household) and the major constituents are:

Paper	35 percent
Cinders, Ash, etc.	20 percent
Vegetables and Putrescibles	18 percent
Glass	10 percent
Metals	9 percent
Plastics	2 percent

I think that this is similar to the breakdown of typical U.S. urban refuse except for the higher proportion of cinders and so on which results from the greater dependence upon coal for domestic heating. The trends in the recent past, which are likely to continue in the future are toward a larger proportion of paper and plastics and less cinders and ash.

The pressures in the UK to increase the recovery of resources from this waste and from industrial wastes are similar to those in other developed countries, accentuated by the fact that a large proportion of the raw materials used in these consumables (including energy) are imported and require expenditure of foreign currency.

THE RECLAMATION INDUSTRY

This is already active and flourishing and has been so for many years. Although the more sophisticated elements are directed toward the recovery of industrial wastes, the value to be derived from domestic refuse has not been ignored. The hey-day of the totter (the "rag-and-bone man") may have passed but the multi-tiered structure of the industry ensures that avenues exist for the recovery of most types of waste of immediate economic value.

The organization of industries in this field, the Waste Reclamation Industrial Council, has been traditionally concerned more with activities in the recovery of industrial and trade waste but, in recent years, has directed attention to the increasing potential and problem of domestic waste recovery.

An important early question to ask is why--given a healthy industry--should government not permit the normal market forces to control the whole process of waste disposal? Since it is obviously nonsense to attempt to reclaim everything, why not recycle only that which makes immediate economic sense in a free market? There are of course several obvious and compelling answers--most importantly the control of pollution, resource preservation (and the reduction of imports) which will not be considered by a free market with a short-term perception. There are also imperfections in the market which will deter its development and will respond only to external influence. These relate to the instability in demand and in supply which are bound to inhibit all constituents of the cycle from expanding their involvement. End users require assured supply of consistent quality material before they will invest in the development of manufacturing processes which will make use of these reclaimed materials. The constituents of the reclamation industry, particularly the small members, require an assured market before they will invest capital to process waste to produce this uniform product, and place with their suppliers the long-term contracts which are essential to ensure a consistent steady supply of basic waste. Finally, the initial suppliers--be they local authorities or voluntary organizations--need the assurance of long-term contracts with stable prices before they will set up the necessary collection and processing organization. Short-term high-level activity at any of these points leads to initial favorable response in other sectors which can end in disillusionment and reluctance to participate further. To achieve a permanent successful recycling operation, an initial coordinating effort is needed at a high level.

One additional difficulty arises as a result of the fragmented nature of the reclamation industry which consists mainly of fairly small units lacking the capital and resources themselves to develop the new technologies needed to solve the recycling problems efficiently and economically.

RECENT GOVERNMENT ACTION

That the government has clearly recognized the need for central review and action is illustrated by the events listed below:

<u>Control of Pollution Act 1974</u> A considerable part of this act is concerned with the management of solid waste disposal, and clear responsibilities are placed upon the local authorities (discussed below).

Green Paper - "War on Waste" 1974 This deals with all types of waste but recognizes that domestic waste is a very important part of the whole. The paper sets out a number of proposed actions and points for discussion.

Royal Commission on Environmental Pollution This was set up in 1970 and its Fourth Report, "Pollution Control: Progress and Problems" December 1974, makes considerable reference to the need to control the handling of waste and to increase the level of recycling and reclamation. It draws attention to the limited expenditure of government funds on R&D in the field of waste collection and disposal and recommends that this be increased. (It estimated the expenditure in 1973-74 at about £400,000, expected to rise to £1 million in 1974-75. However, this was a somewhat restricted view of research in the field, since the figure related to a period covering local government reorganization and the introduction of new legislation and also failed to give due weight to the large amount of privately funded research on waste management topics. A recent survey has shown current expenditure on waste management research in all sectors to be about £3 million per annum, of which nearly £2 million is government expenditure.)

Although the level of expenditure was limited, a considerable amount of successful development work has been carried out in recent years; the major direct effort is at the Warren Spring Laboratory of the Department of Industry, but other programs are being financed at universities and in industry.

Waste Management Advisory Council This council was appointed by the Government in December 1974 with terms of reference:

> To keep under review the development of waste management policies in the United Kingdom having regard to the need to secure the best use of resources, and the safe and efficient disposal of wastes; to give particular consideration to ways of reclaiming materials from waste, recycling techniques, the inter-relationship of waste utilization and waste disposal, and the reduction or transformation of waste arisings; to consider the technical, economic, administrative and legal problems involved; to consider the program of research and development; and to make recommendations.

Several standing committees and working groups appointed by the Council have started work to appraise the markets and study the economics and technical possibilities of reclaiming more materials. The results of these studies will begin to be translated into improved practices in the near future.

THE ROLE OF LOCAL AUTHORITIES

In the past the local authorities' main function has been to ensure the efficient and hygienic disposal of domestic and commercial wastes. Many have entered the field of reclamation, but keeping well in mind their duty to serve the needs of ratepayers and to make the best use of capital and current expenditure to this end.

The Control of Pollution Act 1974 designates the new county authorities as Waste Disposal Authorities and places upon them the duty to carry out surveys of the wastes arising in their areas and to make comprehensive plans for their disposal. It specifically requires them to consider possibilities for reclamation when drawing up these plans and confers upon them powers to engage in reclamation activities.

The very acts of carrying out detailed surveys of waste arisings may well lead to the identification of areas ripe for reclamation activity.

COLLECTION OF WASTE

As in the United States, a number of schemes and experiments have been carried out involving sorting by the householder and collection of the separate constituents for reclamation. The Department of the Environment (DOE) Standing Committee on Research into Refuse Collection Storage and Disposal has been investigating possible methods of encouraging the householder to separate refuse in the most useable manner.

Past experience has shown that the only material for which practicable results are readily achieved is waste paper, and even for this, real organization and planning is required to sustain an effective system which collects a significant proportion of the material available. It is generally agreed that in organizing separation at source the aim should be to reclaim more than one material--proportionately more difficult to organize and sustain.

In view of the many other demands upon the resources of local authorities it has been recommended that they assist and encourage the development of efforts by voluntary bodies and individuals and coordinate these into a single scheme for the area.

A sizeable collaborative scheme has recently been launched by the charitable organization Oxfam at Kirklees in North England with the cooperation of the local authority. It is proposed that Oxfam will provide containers for separate items and organize the collection. The progress of this project will be followed with great interest since the future of this type of scheme across the country could depend upon its success.

SPECIFIC MATERIALS

Paper At present only about 0.3 million tons per year of domestic waste paper is reclaimed, representing a very small proportion of that potentially recyclable.

The government appointed a Waste Paper Advisory Group in 1974 which is charged with finding methods of increasing the amount reclaimed (both industrial and domestic). Government encouragement is being given in a number of ways including the support of work to develop improved newsprint de-inking plants.

One major problem is that of fluctuating demand which is particularly difficult in the present general economic recession since it followed a period of peak demand. The manufacturing industry now has a total stockpile of about 200,000 tons of waste paper and, because of liquidity problems, current purchases cannot be more than present production usage. Such a situation inevitably leaves the collection organizations in a financially embarassed and demoralized state.

The Department of Industry is considering the feasibility of a scheme proposed by the industry for central government purchase and stockpile of waste paper to overcome this problem.

Metal Containers Nearly one million tons per year of tin cans are deposited in domestic refuse and only a very small proportion is recovered. De-tinning is carried out on a considerable scale on process scrap and the British Steel Corporation, Metal Box Limited, and others are carrying out work to develop improved methods capable of dealing with the contaminated waste cans which could be economically retrieved from domestic refuse; this has now reached pilot plant stage.

Glass There is a real economic barrier to large-scale recycling of glass from domestic refuse. The raw materials for glass manufacture are cheap and in essentially inexhaustible supply in the UK so that at present the costs of collection probably exceed the savings in energy obtained by using more cullet in bottle manufacture. However, the glass manufacturers trade association, conscious of the desirability of recycling where practicable, are studying ways of economically acquiring and using a larger proportion of waste. In addition, studies are in progress into the possibility of making greater use of glass cullet in other applications--mainly in the building industry.

The most conservative method of recycling glass is obviously to reuse the containers. In the UK the normal method of supplying milk is in returnable bottles and this process continues to work satisfactorily because the industry is equipped and all points in the cycle accept it as the norm. The same applies to beer although in recent years there has been an increasing use of one-trip bottles and cans. However, there would probably be little practical difficulty in reversing this trend since the industry is equipped and conditioned to the process.

There is more difficulty in recycling other types of bottles because the scale is so much smaller and, in many cases, the cost of sorting and cleaning would be higher than the price of new bottles. The introduction of metric sizing of containers in the UK should provide an opportunity for variety reduction--at least for containers of related types of material--and the industry is considering this as a means of increasing the scale so that recycling would be simpler and cheaper.

DEVELOPMENTS IN WASTE HANDLING AND RECYCLING

There is a continuing exchange of information and experience at the technical level on this subject so that it would not be appropriate to describe recent developments in the UK in detail here. The main areas of current interest are:

Tipping and Landfill The introduction of high density baling methods to improve the control of tipping operations.

Incineration There are a number of schemes in operation or under development for heat recovery either for conversion to electrical power or for use in district heating schemes.

Physical sorting of waste Warren Spring Laboratory has now installed a pilot plant for dry sorting of refuse which is not dissimilar from processes developed in the U.S. They aim to avoid the very expensive front end shredding operation if possible.

Pyrolysis Several processes have been studied at WSL; the type involving process gas recycling, which was developed there, is considered most promising and a full-scale pilot plant is now being built.

Biological/Chemical Treatment of Organic Wastes Several programs are being carried out to study processes such as hydrolytic or bacterial conversion to protein or ethanol or methane. It is probable that this type of process will, in many cases, be the most suitable means of reclaiming energy from the organic portion after sorting--particularly from wet processes such as the Black Clawson.

A. VIII: RESOURCE RECOVERY FROM MUNICIPAL SOLID WASTE IN JAPAN

Sukehiro Gotoh and Michio Nakajiku

(A paper presented to the Second Japan-U.S. Conference on Solid Waste Management, September 1974, Washington, D.C.)

ABSTRACT

The paper consists of essentially two parts; the first deals with a general overview of resource recovery in Japan, and the second with the resource recovery research and development project currently underway at the Agency of Industrial Science and Technology, MITI.

In the first part, the historical background of the resource recovery concept in Japan is reviewed, followed by the current status and future trends with particular emphasis on legal, social, institutional, and economic aspects. Recent technological developments of processing systems aimed at resource recovery from Japanese municipal refuse are also reviewed and some problems regarding the technology encountered in the effort are described. In addition, an assessment of impacts of resource recovery on the municipality and the country as a whole are discussed.

In the second part the Resource Recovery Project of the Agency of Industrial Science and Technology (AIST) is described in detail: Firstly, the basic project concept with its objectives, the Agency's responsibilities, the R&D organization, and the financing is presented. Secondly, the R&D program areas are reviewed with the specific aim for each research theme. Thirdly, as the project is in its second year of Phase I term, current progress and some important results obtained from the feasibility studies on the selected research topics are stated and an interim evaluation is made. Finally, the currently proposed Phase II term of the project, which will start with FY 1976 and last for three to five years, is summarized to give some idea of what the Agency expects before the resource recovery system is transferred to the municipality and implemented in this country.

Phase II of the Project is essentially a demonstration of alternative prototype resource recovery systems under the Japanese socioeconomical circumstances for effective future implementation.

Some concluding remarks based on our AIST's project management are also presented.

CONTENTS

THE PHASE II PLAN
- The Need for Phase II of the Project
- Outline of Phase II Plan

CONCLUSIONS

I. GENERAL OVERVIEW OF RESOURCE RECOVERY IN JAPAN

BACKGROUND

As in the United States, resource recovery, or recycling, in Japan has taken various forms in the past. Let us call this stagewise change in the recycling form "a level of recycling." The lowest level of recycling, by which we mean, for example, returning bottles to the food or liquor store, or selling bundles of old newsprint, clothes, bottles, or the like to a ragman, has long been and is now practiced in every city or town. At this level, one does not need any special systematized effort, instead one simply follows the tradition of the society with little effort. To some extent, however, it could be argued that this depends on the life style or more general value concept of those days. In Japan, the idea of using things effectively and repeatedly was once considered a virtue and public awareness of the scarcity of natural resources in this island country enhanced the idea. At least, this was very true until the end of World War II. And for another decade or so in the postwar society before Japan emerged as an industrial country in the world, this life style was still considered a virtue.

For the past 10 to 15 years, however, this level of recycling has been diminishing gradually, almost without being noticed. This period of time turns out to have been the time when mass production and mass consumption in Japan started and were actually taking shape, and concurrently the per capita GNP or income, or labor cost was sharply increasing. This general circumstance and change in public awareness acted against the recycling and, because of higher costs of repairing or storing, one started discarding such things as once unthinkable; refrigerators, TV sets, relatively new furniture, and others.

Table VIII.1 shows an increase in the daily per capita production of municipal solid waste (national average) as compared with changes in the total population and net GNP values. It is known that the per capita generation is strongly related to the net GNP, whose linear relationship was confirmed. Along with this large growth rate of per capita waste generation during this period, a sharp change in the waste composition, both physical and chemical, was observed. This change was due to the fact that the collected waste contained more and more plastics, bulky wastes, mingled industrial wastes, and newer (and normally hard-to-treat and dispose) materials.

With all this historical background, little attention has been paid, until recently, to much higher levels of recycling or re-

TABLE VIII. 1

YEARLY CHANGE IN AVERAGE PER CAPITA WASTE GENERATION

Year	National Population (10^4)	Average Per Capita Generation (g)	GNP (Net) (billion yen)
1960	9,388	514	20,348
1961	9,473	491	24,275
1962	9,561	498	24,610
1963	9,654	613	27,783
1964	9,748	660	30,788
1965	9,840	695	32,451
1966	9,932	712	36,286
1967	10,018	755	41,140
1968	10,131	815	46,734
1969	10,257	870	52,522
1970	10,372	910	57,441
1971	10,454	960	60,728

Source: Ministry of Health and Welfare Data clamation, such as heat reuse and electric generation out of waste, materials extraction (paper fibers, ferrous and nonferrous metals) from mixed collected waste stream, or incinerator residues processing.

The only exception for this level of recycling is high-speed mechanical composting, which is a conversion-type resource reclamation from mixed municipal waste. As early as 1956, and for the following 10 years, more than 30 plants for composting had been constructed and operated successfully in Japan. However, by the end of 1971, the number of plants was only 28, of which most suffered from economical problems. As of now, barely seven plants remain in the whole country.

Although it is anticipated by many people that composting will come into the light again, this past failure appears to be predominantly economical; especially in contrast with chemical fertilizers. Farmers complained about contamination of compost with such noncompostables as glass or plastics.

Nevertheless, the need for resource recovery at various levels is increasingly emphasized, as the newer value concept based essentially on such ideas as "the Spaceship Earth" is becoming accepted in this country. To illustrate one aspect of this need, a macroscopic material balance is given in Table VIII.2. This shows that, in 1971, Japan imported (raw) materials of various kinds including foods and oils with an amount of 500 million tons, and exports of products totalled about 45 million tons; which, in turn, means the difference of about 400 million tons were being deposited in various forms of material or waste in this country.

Waste Disposal and Public Cleansing Law

When discussing resource recovery from municipal waste, one has to refer to this law as the sole national law on waste handling in Japan. The law passed in the National Diet (Japanese Parliament) in December 1970 and was enacted in September 1971 with the accompanying working rules of related governmental agencies. The waste, according to the law, is legally divided into two categories; industrial and general waste. Further, responsibilities for treatment of the former are assumed for the entrepreneur in charge of the emission, while the latter is for the muncipal authority. However, in practice, some amount of industrial waste is mingled with the normal general waste and is hauled by the municipality. Thus the term "municipal waste" or simply "urban refuse," although it is not defined in any form in the law, is commonly used and understood as the waste which is actually hauled and disposed of by the municipality.

The law, as its title partially indicates, is a revision of the formerly known "Public Cleansing Law." With this revision, an important point is that the law now clarifies the wastes and assumes the responsibility for their disposal, although there are no specific instructions or incentives for resource recovery

TABLE VIII. 2

MATERIAL TRADE BALANCE

(Import)	10^8 tons
Foods	0.2
Iron Ore	1.2
Other Metal Ores	0.2
Other Minerals	0.4
Crude Oil	2.3
Coal	0.5
Others	0.2
Total	5.0

(Export)	10^8 tons
Steel	0.24
Fertilizer	0.04
Cement	0.02
Foods	0.02
Textiles	0.02
Ships	0.06
Other Products	0.05
Total	0.45

involved. For the municipality, the law authorizes exemption from the direct disposal of the industrial waste, which is generally considered a new development in a legal sense.

From Disposal to Resource Recovery

Traditional handling of municipal refuse, as indicated in the disposal law, has never intended a higher level recycling until recently. However, the need for resource recovery observed for the last couple of years, arose first from the municipality sector, then from consumers and now is positively supported by the industry sector. At a recent meeting of the National Federation of Municipal Authorities for Public Cleansing (whose member municipalities are 498 in number), a resolution for promoting technology development of resource recovery was made formally.

The reasons that the municipality first supported resource recovery appear to be as follows: firstly, the municipality with the traditional disposal of incineration or landfilling became simply unmanageable with the increasing amount of complex-in-composition refuse, both financially and technologically. Secondly, the citizen's awareness of resource recovery instead of disposing the waste has been giving constant pressures to the municipality. These two reasons have together formed the following trends:

(1) Consumers' and citizens' increasing desire for higher quality of environment, has made the municipality aware that any simple disposal method which is even environmentally acceptable will no longer be practical.

(2) The municipality has thus realized that any such processing is expensive: with incineration, the facilities for air pollution control, water treatment and residues disposal needed to satisfy ever severer emission standards are costly. Similarly, with landfilling, costs for abatement of odor, soil pollution, vibrations, noise, traffic jams of hauling vehicles and other adverse effects are staggering.

(3) Land purchasing for disposal or processing has become increasingly difficult for the municipality because of neighborhood opposition and the increase of the price of land.

(4) Public awareness of scarcity of natural resources in this country has increased recently, especially after the Arab oil embargo last autumn.

(5) Industries who have been concerned mainly with recycling of industrial wastes alone, have now turned their attention to resource recovery from municipal refuse.

(6) Government, through various agencies, has started diversified efforts for resource recovery, stemming from the national interest in protection of resources and from foreign threats of foreign countries on the diplomatic stage.

CURRENT STATUS AND TRENDS

Japanese Municipal Waste for Resource Recovery

As in Europe and the United States, the composition and other characteristics of the Japanese waste are subject to greater change with seasons and locality. It is important to grasp those variations no matter what type of recycling is intended.

A typical example of a yearly average composition of Japanese municipal refuse is shown in Table VIII.3. This is the average composition of the waste collected in Tokyo metropolitan area in 1972 with the average moisture content (percent) for each entry. Compared with the composition of American refuse, the following differences for Japanese waste are noteworthy:

(1) overall moisture content is approximately twice as high;
(2) plastic content is 2 to 3 times more;
(3) food waste which is normally very wet, occupies relatively higher content;
(4) metals fraction is about half that of the American refuse; and
(5) paper fraction is also relatively lower.

Because of these relative features, Japanese waste has, on the average, a heating value of 1,300 Kcal/kg; generally ranging from 1,000 to 1,500 Kcal/kg. Although the caloric value tends to increase, this relatively lower heating value is considered a disadvantage especially for energy recovery from the Japanese municipal waste.

The combustible fraction which can be the raw material for the "back-end system" like pyrolysis has, however, a comparable chemical composition. An ultimate analysis is illustrated in Table VIII.4. The heating value of this combustible for this example was 4,755 Kcal/kg (dry base), which is, together with its chemical composition, approximately equal to those of the combustible fractions of European and American refuse. This indicates that a large part of the combustibles is cellulosic no matter where the refuse comes from.

In conclusion, Japanese waste is handicapped in that the pretreatment of separating the organics from inorganics requires more complicated, thus more costly, processing.

Almost all present consumer goods or products are considered the potential input to municipal waste processing. Thus whatever type of resource recovery may be intended, the current statistics on those materials and products are relevant. Furthermore, data may become important for predicting change in future refuse composition and the possibility of success for present source separation for facilitating the recycling. At present, source separation practiced in the Tokyo Metropolitan (Special District) areas, for example, requires the housewife to separate the waste into three categories; normal waste, hard-for-disposal waste such

TABLE VIII. 3

REFUSE COMPOSITION AND ITS AVERAGE MOISTURE CONTENT - TOKYO METROPOLITAN AREA IN 1972

	Composition	Weight Percent (Wet Base)	Av. Moisture Content, Percent
Combustible	Paper Products	38.2	51.8
	Plastic	7.3	36.6
	Textiles	3.6	44.6
	Wood, Bamboo	4.2	41.7
	Rubber, Leather	0.5	13.0
	Garbage (Food Waste)	22.7	76.3
	Other Organics	5.7	55.5
Non-combustible	Metal	4.1	5.7
	Glass, Ceramics	7.1	1.2
	Other Inorganics	6.6	-

TABLE VIII. 4

ULTIMATE ANALYSIS AND HEATING VALUE OF THE COMBUSTIBLE

Carbon (C)	Hydrogen (H)	Oxygen (O)	Sulfur (S)	Nitrogen (N)	Heating Value Kcal/Kg
51.8%	26%	38%	0.1%	2.6%	4,753

Source: Kotai Haibutsu (Solid Waste), September 1973.

as plastics or noncombustibles, and bulky matter. The first two types of waste are picked up daily or every other day, while the bulky wastes are hauled less frequently; usually once every two weeks.

In Table VIII.5, six important materials or products were selected, that might have effects on the municipal waste composition. They are: (1) automobiles, (2) paper, (3) plastics, (4) home electric appliances, (5) metal cans, and (6) glass bottles. For all the products except metal cans yearly statistical figures on both production and disposal are listed.

The automobiles abandoned on the street, for example, now draw public attention, and who is actually responsible and who should pay for taking care of them is a central controversy among the municipal authorities, automobile manufacturers, and the residents. Considering the fact that the municipal sanitation department is not capable of disposing or recycling of those cars, the future of this problem is hardly predictable.

For papers, the recycle ratio (recycled amount/production) instead of waste paper amount is listed. The figure of 38 percent recycle ratio already observed in 1972 is almost twice the corresponding American figure of 19 percent in 1967, which was reported last year at the First Conference. As predicted in this table, the ratio is expected to still increase at least nearly by 5 percent two years from now. Further we are optimistic for this reason: recent technological development by the AIST, which will be described later, has made it possible to recover the reusable paper fraction out of the mixed refuse mechanically in the most efficient and effective manner. When the equipment is installed in the near future on an extensive scale, the paper recycle ratio is expected to increase further, perhaps reaching about 55 percent or more.

As for plastics, only the waste fraction is indicated. Recent MITI data show, however, that in 1973, 163,000 tons out of 1,862,000 tons of waste plastics (approximately 9 percent) were recycled in one form or another. Current estimates for plastic recycling based on the data gives 523,000 tons of 2,589,000 waste tons in 1976, which corresponds to about 20 percent.

Municipality's Trends for Resource Recovery

As stated before, no specific effort for resource recovery by the municipality has been observed except high-speed composting.

Future trends, however, include many possibilities for the Japanese municipality. The most promising one for early realization is heat recovery by incineration. This possibility may be especially high for large cities, where large-scale incineration is actually in practice. On a national basis, transfer from landfilling to incineration in refuse disposal has been encouraged by the Ministry of Health and Welfare through its First (FY 1963 - FY 1967) and Second (FY 1967 - FY 1971) Five-Year

TABLE VIII. 5

MAJOR WASTE PRODUCTS

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(1) Junk Cars (Unit: 10^3 cars)

FY	1972	'73 (E)	'74 (E)	'75 (E)	'76 (E)
Number of Cars Owned A	22,930	25,299	27,502	29,530	31,377
Abandoned Cars B	1,980	2,610	3,000	3,360	3,680
B/A (%)	8.6	10.32	10.91	11.38	11.73

E: Estimated

(2) Paper Stock (Unit: 10^3 tons)

FY	1972	'73 (E)	'74 (E)	'75 (E)	'76 (E)
Production A	13,648	15,800	16,700	17,000	18,000
Recycled W. Paper B	5,131	6,000	6,600	7,200	7,600
City Source C	3,591	4,200	4,600	5,000	5,300
Industry Source	1,540	1,800	2,000	2,200	2,300
B/A (%)	37.60	37.98	39.52	42.35	42.22
C/B (%)	69.99	70.00	69.70	69.44	69.74

E: Estimated

TABLE VIII. 5 CONTINUED

(3) Plastics (Unit: 10^4 tons)

FY	1972	'73(E)	'74(E)	'75(E)	'76(E)
Production A	565.7	58.51	628.7	677.6	731.8
Waste Plastics B	166.6	186.2	209.7	235.1	258.9
Household Source C	84.0	94.2	105.9	119.0	131.4
B/A (%)	29.45	31.82	33.36	34.70	35.38
C/B (%)	50.42	50.59	50.50	50.62	50.75

E: Estimated

(4) Waste Home Electric Appliances (Unit: 10^4 tons)

FY	1972	'73(E)	1974 (E)		'75(E)	'76(E)
			Production	Waste		
Refrigerator	164	188	330	209	228	248
Washing Machine	245	266	415	283	303	326
Vacuum Cleaner	115	135	320	153	175	196
Air Conditioner	13	19	280	27	38	54
TV Set (B&W)	347	333	115	314	290	258
TV Set (Color)	76	132	600	204	280	373
Stereo Equipment	81	91	175	102	114	125
Electronic Heating Range	1	2	110	4	6	10

E: Estimated

TABLE VIII. 5 CONTINUED

(5) Cans (Production)

FY	1972	'73 (E)	'74 (E)	'75 (E)	'76 (E)
Steel Can (10^3 tons)	83	176	289	390	450
Aluminum Can (10^6 cans)	160	617	1,651	1,853	2,000

E: Estimated

(6) Glass Container (Unit: tons)

FY	1972	'73 (E)	'74 (E)	'75 (E)	'76 (E)
Production A	1,843,970	1,900,000	2,000,000	2,100,000	2,200,000
Waste Bottles B	553,191	570,000	600,000	630,000	660,000
Household Source C	331,915	342,000	360,000	378,000	396,000
B/A (%)	30.00	30.00	30.00	30.00	30.00
C/B (%)	60.00	60.00	60.00	60.00	60.00

Source: Each Table based on the MITI statistics.

Plans for Incineration. During the period, a large number of quality incineration facilities had been constructed mainly in large cities, with grants-in-aid from the government.

As a result, by the end of 1971 in the seven largest cities, 40.5 percent (weight) of the total refuse went to the incinerator, and the rest to landfilling, with a trace percentage for composting. Figure VIII.1 shows the percentage of incineration in Tokyo, Yokohama, Nagoya, Kyoto, Osaka, Kobe, and Kita-Kyushu, which together collected 9 million tons of refuse in 1971. This amount of waste is approximately one quarter of the total municipal refuse that was collected in Japan in that year.

With this increase in incineration as a means of disposal, relatively newer incinerators have some kind of heat recovery facilities. Among them, the waste heat boiler is most common for providing hot water or low quality steam to the nearby utilities or public buildings like nursing homes. Some boilers are capable of generating electricity of a few thousand kilowatts, which usually is only for in-plant power use for conserving the normal utilities. Table VIII.6 illustrates examples practiced or planned in the Tokyo and suburban cities.

Since Japan is located in the temperate climate region, except in Hokkaido, district heating is not practiced as in Europe and/or in a part of America. This in turn means that waste heat recovery by incineration for district heating purposes is not practical without any piping facilities. For electrical power generation, out-plant supply is, in principle, quite possible, although it is not performed because of non-technological reasons. Current boilers are mostly of the waste heat type and the waterwall furnaces are not used extensively. Major non-technical barriers to electricity are that most electric utility companies are skeptical about this idea, because of low quality electricity with fluctuations both in time and quantity. In addition, most coal burning power plants had been long before modified to oil or gas-fired furnaces in Japan.

In this respect, the only exception is the Nishiyodo Incineration Plant of Osaka City. The plant has a processing capacity of 400 tons of refuse per day, and is equipped with two 2,700 KW generators, with output voltage of 6,600 V. Normal power output is 1,600 KW per generator. Of this 3,200 KW, 700 KW is consumed for in-plant use, the remaining 2,500 KW is for selling. Kansai Electric is purchasing this electricity with an average price of 2.46 yen per KWH or about 8.2 mils/KWH. (Incidentally, current end-use average price of electricity in Japan is somewhere around 7 yens/KWH, or 23 mils/KWH.)

In Tokyo, Katsushika Incineration Plant which is now under construction and shall be operated from March 1977, will generate electricity of 12,000 KW, with a refuse amount of 1,200 tons/day. Of this, 5,000 KW is agreed with Tokyo Electric to be bought. This trend for energy recovery by selling electricity is expected to be fostered in the future by the initiative taken by the municipality sector.

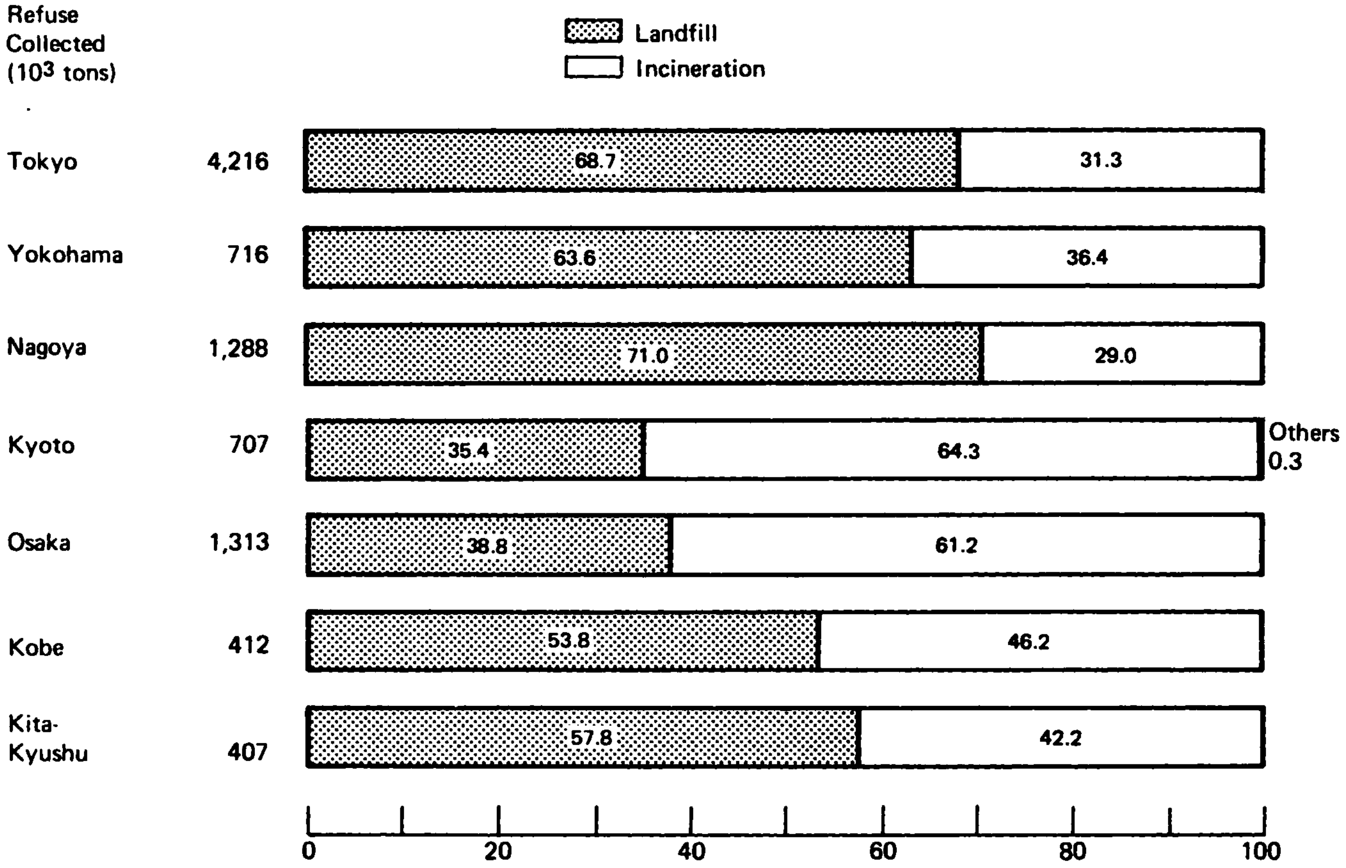


Figure VIII.1 Ultimate Disposal of Waste in Seven Largest Cities

Source: Large City Statistics Assoc. (Ed.): "Comparable Statistical Tables of Large Cities - FY 1971." (1973)

TABLE VIII.6 ENERGY RECOVERY AT TOKYO AND SUBURBAN INCINERATORS

Plant Location	Capacity (Refuse tons/day	Generator Capacity (KW)	Electricity Supply (KW)	Hot Water Supply to	Completion Date
(Tokyo)					
Setagaya	900	2,500	In-plant Power	Nursing Home	March, 1969
Shakujii	600	1,500	"	-	March, 1969
Chitose	600	1,700	"	Civic Center	January, 1971
Chi	1,200	2,500	"	Youth Center	September, 1973
Tamagava	600	2,000	"	Swimming Pool (Civic Center)	October, 1973
Koutou	1,800	3,000	"	Nursing Home	February, 1974
Itabashi	1,200	3,200	"	Ward's Public Facility	June 1974
Katsushika	1,200	12,000	5,000 (Planned)	nd	March, 1977
Adachi	1,000	nd	In-plant Power	nd	March, 1977
(Kawasaki)					
Rinkou	600	1,300	"	-	April, 1971
Tachibana	600	2,000	"	Nursing Home	December, 1974
(Yokohama)					
Kounan	900	3,000	"	Nursing Home Swimming Pool	March, 1974
Minami-Totsuka	1,500	4,500	"	"	March, 1976
(Chiba)					
Shinkou	450	1,200	"	nd	March, 1974
(Reference)					
Nishiyodo, Osaka	400	5,400	In-plant Power 700 Contract Sale 2,500	-	June, 1965

nd: not determined

For the past few years, community (civic) groups in cooperation with city sanitation authorities have been increasingly engaged in an active recycling movement, in many cities. Of these, the best known is the recycling in Toshima Special Ward of Tokyo, which often is referred to as "the Toshima Project." The principal idea for this Project is as follows: block community societies, which have long been in existence traditionally in Japan known as "cho-kais," or communal organs, take the initiative on the Project. A participating cho-kai asks its member families to bring whatever recyclable things they can to a nearby specified lot on a specific date by a certain time. (The cho-kai previously requests its Ward's Sanitation Office to send truck(s) of recycling firm(s) to the lot to pick the materials up.) The Ward Sanitation Office which belongs to the Tokyo Metropolitan Government, normally gives the permit for this activity, arranges the hauling schedule for the secondary material dealers, and refunds the profit to the cho-kai.

Recently a variation of this scheme has been seen: instead of the dealer's truck pick-up, the Ward's sanitation collection trucks haul all materials gathered and transport them to the dealer's plant. This variation has an advantage that the lot is kept always clean without any left-over, which is often seen in the Toshima Project.

The results of these recycling activities are summarized in Table VIII.7.

Trends Observed in (Central) Government's Efforts

Various efforts of the central government through its agencies and ministries have been made for resource recovery. Among these, the Ministry of International Trade and Industry (MITI), which has been playing a supervisory role for all the production industry, has been mainly concerned with recovery and reuse of industrial wastes to increase production efficiency.

However, for municipal refuse, little attention had been paid to resource recovery until two to three years ago, except that some investigations on the state-of-the-art were performed. The Agency of Science and Technology, an independent governmental agency, through its Resources Investigation Office, was the earliest to perform these kinds of surveys and studies on both general and industrial waste since 1965 or 1967.

The Agency of Industrial Science & Technology (AIST) of the MITI, as shall be described later, planned an R&D project for resource recovery from municipal waste back in 1971 and one year study program budget was appropriated for FY 1972. The R&D for resource recovery technology and systems formally started in FY 1973, as one of the national projects conducted at the AIST.

The Ministry of Health and Welfare, which is traditionally concerned with solid wastes from the disposal viewpoint, has not been much involved with resource recovery until very recently.

TABLE VIII.7 WASTE RECYCLING MOVEMENT IN METROPOLITAN TOKYO

FY	Participation		Recycled Materials								Revenue	Averaged on each household	
	Groups	Household	Paper (Kg)	Rag (Kg)	Metals (Kg)	Rubber (Kg)	Glass (Kg)	Others (Kg)	Bottles	Total (Kg)	(yen)	Quantity (Kg)	Refund (yen)
1969	3,604	1,562,272	4,191,881	210,623	494,542	16,285	575,520	388,669	125,532	5,877,520	23,786,195	3.8	15.2
1970	3,683	1,399,941	3,990,499	210,536	416,326	14,051	453,450	363,545	83,290	5,448,407	24,072,398	3.9	17.2
1971	2,771	931,319	3,427,261	194,131	327,208	9,826	599,398	422,654	51,411	4,980,478	14,388,231	5.3	15.4
1972	2,979	978,564	4,333,455	258,959	418,646	12,927	848,994	422,388	38,565	6,302,005	23,637,196	6.4	24.2

Note: Total amount does not include the number of bottles.

It is generally well known that an inter-institutional project for utility-oriented resource recovery on a gigantic raft afloat or held in the coastal ocean is in its planning stage. The program had been studied by the Research Institute for Ocean Economics, a non-profit organization, for two years and the program concept has been employed as a governmental project since the beginning of FY 1974 (April 1, 1974). An amount of approximately 50 million yen (about 170,000 dollars) was appropriated for this study. The participating agencies include the Environment Agency, the MITI through its Office of Ocean Development, the Ministry of Health and Welfare, and the Ministry of Transportation. The feasibility of this marine utility plant is considered very high because this type of resource recovery plant is normally for large cities and most large cities in Japan are located in the coastal region. If, for example, such a marine plant is planned for Tokyo Bay, the plant could serve not only Tokyo Metropolis but also its surrounding suburbs in an organized manner.

At present, the plant facilities will include technologies and processes mostly developed by the AIST, and the transportation of refuge from the coast to the floating plant will be conducted by pipeline. The plant is planned to have a pyrolysis process, desalination process, and possibly materials recovery section.

Current central Government's efforts for resource recovery from municipal waste, briefly described above, involve a wide variety of agencies. There is an observable trend, however, that these scattered efforts will be coordinated to increase efficiency. This means an intensive inter-institutional cooperation which is normally hindered by "unseen" barriers. Nevertheless, it is predicted that the Environment Agency, created in 1971, will play an important role as the leading agency in this organization of effort.

Trends in Industry

Industry as a private firm or group has been traditionally concerned with recycling only of industrial wastes. This is known as in-plant recycling. In this respect, pyrolytic liquefaction of by-products or waste plastics at the polymer manufacturing plant, for example, has been done for resource conservation purposes. The government (MITI) has taken an incentive policy, encouraging the industry to adopt this kind of plant by means of grants-in-aid, low interest loans, special amortization plans for the facilities, and tax exemptions.

The in-plant recycling (known in Japan often as "closedization" of the plant) has been increasingly enhanced recently because of the decreasing number of contractors who take care of plant wastes for disposal or reuse and the increase in disposal cost as the environmental restrictions get severer.

Industry, for the most part, has shown no interest in resource recovery from municipal refuse, with the exception of plant manufacturers. However, when the municipality, faced with increasing amounts of industrial waste mingled with normal waste (termed the "hard-to-dispose waste" by the municipality), started declaring that industrial circles should somehow assume the responsibility for this, the industry producing these materials or products responded with some action. For example, manufacturers of home electric appliances, automobiles, plastic products, and packaging materials, have shown recycling plans or programs that prevent those materials from coming into the municipal waste stream and have given some technological solutions.

The normal industry approach to this problem is exemplified by first establishing functional organization with concerned firms and performing various activities ranging from establishing the data base to operating some demonstration plants, which are usually supported or funded in part by the Government. The Plastic Waste Management Institute, for example, was established in 1972 by 34 polymer manufacturing companies. The MITI has been cooperative with the Institute since its formation, providing various assistance including subsidies, information, and authorization on conducting resource recovery projects. The Institute is also instrumental in providing government's grants-in-aid for individual plastic reutilization programs. It has two recycling plants running; one in Funabashi City and another in Koshigaya City, in both of which the source separation of plastic materials or products is practiced by the municipal authorities.

Another example of an industry-Government joint project was the establishment of the Waste Paper Recycling Promotion Center. The Center was erected in June 1974. Its primary concern is the storage of waste paper for providing a stable supply and thus for higher profits from recycled paper.

Furthermore, in July 1974, the Japan Electrical Manufacturers Association, which is representative of essentially all manufacturers of electrical appliances, established, with governmental assistance, the Recycling Association from Used Electric Appliances. The latter Association is setting many plans to recover resources from municipal bulky wastes, a large fraction of which is used electric appliances. The automotive industry and container manufacturing industry have shown interest in establishing similar organizations that will be involved with recycling.

In response to these movements in various industrial circles, the Bureau of Industrial Location and Environmental Protection, MITI, planned an incentive legislation for resource recovery early this summer. However, the legislation did not succeed because of disagreement on practical details among various industrial sectors, and was temporarily postponed. Instead, the Bureau is planning establishing an organization called the Clean Japan Center in FY 1975. The Center is intended to couple the resource recovery effort with the "Keep Japan Beautiful" movement fostered currently by the local Chambers of Commerce. In the future, the Center is expected to merge with other centers or institutions to organize its own and related activities and will have close contact with the municipality by exchanging information and holdings seminars or meetings for training municipal employees in resource recovery. In FY 1975 the Center, as one of the resource recovery efforts, will have two model plants at selected cities, where the demonstration of materials recovery from bulky wastes is to be conducted.

The Japan Resources Technical Institute, with its member companies of more than 100, was established in 1968 by permission of the Agency of Science and Technology and has been playing a pioneering role in the resource recovery field of both industrial and municipal wastes in Japan. The Institute is the oldest of this kind and represented by various industries. Recently, as of September 9, 1974, the Institute and the National Center for Resource Recovery signed an agreement on the joint cooperative program of exchanging information on resource recovery in both Japan and the United States.

RESOURCE RECOVERY TECHNOLOGY

Characteristics of Resource Recovery Systems

Resource recovery systems may be divided into two broad categories, i.e., materials and energy recovery. And each has two distinguishing subdivisions. These four resource recovery schemes are summarized in Table VIII.8.

Materials recovery (MRS) systems that fall into (1) Extraction MRS, of the table, are called usually the front end system (FES) in the terminology proposed by Abert & Zusman of the NCRR. The rest that is classified into (2) to (4) inclusive, is the back end system (BES) in the same sense.

For each subdivision numbered in the table, many unit operations or processes are considered. Under (1), the Extraction MRS, two types of processes are identified. The first type is the process in which products or parts such as bottles, cans, or usable refrigerator motors are reclaimed and the recovered products can easily be fed back to the nearest production line without much processing. The difficulty with this process is to identify the material to be reclaimed out of the mixed waste stream and select it effectively. Hand picking is the typical means for recovery.

The second type of process for the Extraction MRS includes the reclamation of such raw materials as glass cullet, pulp fibre, aluminum powder, and so forth. The basic idea is to extract the marketable raw materials out of the refuse. The process normally consists of crushing and sorting operations. Since the value of the reclaimed materials depends largely on the purity or

TABLE VIII. 8

RESOURCE RECOVERY SCHEME

Materials Recovery	(1)	Extraction Material Recovery (separation/refining)	FES
	(2)	Conversion Material Recovery (chemical, biological, etc.)	BES
Energy Recovery (thermal, electrical, etc.)	(3)	Storable/Transportable Energy Recovery (pyrolysis, hydrogenation, etc.)	BES
	(4)	Direct Energy Recovery (incineration power generation, etc.)	BES

FES: Front-End-System; BES: Back-End-System separation efficiency, the processing is usually done in the multi-stage and/or multi-pass fashion.

Under the (2) category, or Conversion MRS, are composting, anaerobic methanation, single-cell protein synthesis, alcohol synthesis and catalytic hydrogenation to form oils, utilizing organic fraction of the waste, and calcination to form building materials or ceramics of the inorganics of the refuse.

The first type of energy recovery, termed here (3) Storable and Transportable Energy (Source) Recovery System (ERS), includes pyrolytic conversion processes to fuel gases and oils, and sometimes to chars. It may be pointed out that the processes classified under (2) and (3) share the same process principle as pyrolysis, although the products from (2) are considered raw materials, while those from (3) are energy sources. This means that the process operating conditions usually differ. The products from (2) and (3) are, in most instances, subject to refining process for comparable quality with the corresponding virgin materials.

Electric power generation is a typical example of (4) Direct ERS. The process systems in the (4) category are mainly concerned with the matching of the energy supply/demand relationship both in quantity and timing. Most modern incinerators with power generating facilities are known to have an unexpected lower thermal efficiency simply because of "steaming off," most of the time.

Two major difficulties are identified in the resource recovery technology system: the first one is based on the fact that no formal effective technique is known so far for process synthesis, which is of vital importance when formulating a resource recovery system with known components satisfying a set of specific regional conditions. The second difficulty is normally found in designing a resource recovery process network that is functional and flexible enough to accept all possible variations in such input/output material and energy flows as:

1. input refuse flow is constantly obtainable in the steady-state manner,
2. input variations expected both in composition and quantity can be easily absorbed,
3. output energy and materials including not only the products but also all by-products must satisfy the local (environmental) emission standards,
4. recovered output resources of energy and materials must be in some form to maximize marketability with comparatively higher production efficiency.

Problems Identified in Resource Recovery R&D

No matter how high level and efficient a resource recovery system is intended, fundamental principles observed in conventional solid waste management and the environmental acceptability of the system must first be satisfied. Then comes the economic principle. Table VIII.9 summarizes the solid waste processing principles observed under Japanese circumstances.

In view of these general process principles, the following problems have been identified in the course of R&D, intended for the Japanese environment.

The first problem is concerned with the hazardous materials coming into the normal municipal waste. PCB and its related chemicals, explosives, mercury vapor, and several heavy metals are examples of these hazardous materials. The presence of these materials is due to careless and/or illegal dumping, more frequently in districts where the residential and industrial sectors are mingled. The trouble is that the material is hazardous enough for normal handling of the waste and too little in quantity to be recovered.

The second problem is based on the general characteristics of Japanese refuse; higher water and food waste content. In addition to these characteristics, the temperate climate has made it difficult to design a system which has a reasonable process efficiency and is satisfactory for hygienic conditions.

The third problem may be somehow related to the first. In many municipalities of this country, bulky wastes and the hard-to-process refuse whose content may vary from one municipality to another are collected separately and with different frequency at the source. And no suitable technology for these types of waste is available for disposal and/or resource recovery processing. For example, source separation of plastic-rich products and the non-combustibles into one container is conducted currently in the Tokyo Metropolitan Areas, because of the adverse effects on the incineration facilities. No workable technology aimed at disposal or resource recovery to pick PVC materials selectively out of this mixture has yet been developed.

NON-TECHNOLOGICAL PROBLEMS

It may be said that, for higher levels of recycling than "the ragman recycling," no general consensus on the methodology for the implementation of resource recovery systems has yet been reached in this country, although increasing awareness of resource recovery is confirmed. This means that the non-technological factors, i.e., societal, economical, and institutional factors, are yet to become mature before resource recovery can be implemented effectively in Japan.

The real problem appears to be the lack of proper information on resource recovery: dissemination of technical information and administrative policies, training, and education have not been generally conducted in a satisfactory manner. An expert technologist in this field and a friend of one of the authors, for example, once told me that a mayor of a town with population of

TABLE VIII. 9

PRINCIPLES OF DISPOSAL AND RESOURCE RECOVERY PROCESSING

Principle	Content
1 Volume Reduction	. Higher efficiency in collection, transportation, disposal and other handling.
2 Chemical Stability	. Effective in land-filling and reduction operations to air, water and land.
3 Harmlessness	. Harmless and innocuous to man and other organisms during the course from generation to ultimate disposal.
4 Environmental Acceptability	. Minimum secondary pollutions of the processing facility. . Lesser impacts on the existing socio-economical and environmental systems.
5. Higher Economics	. Lower net processing cost with revenues from the recycled products. . Higher marketability of the recycled products.

about 50,000 came to him to say, "My citizens are all for resource recovery. I consider power generation the most promising. Introduce me to the professionals, please." However, no one could blame the mayor.

Similar examples of ignorance may be cited of the consumer. Consumers, who are well aware of the need for resource recovery and often very anxious for it, buy the products that are not favorable for recycling simply because they lack the proper information.

Recovered resources compared with virgin materials are generally lower grade in quality. The reasons for this are partly that the raw material of resource recovery, i.e., municipal refuse, is far poorer material, and partly that there is an economic disadvantage in refining or upgrading in order to compete with the virgin materials.

In some instances, a disadvantage of this kind may become no problem at all: recycled pulp per se, for instance, is usually lower in grade compared with the virgin pulp. It has, nevertheless, its own proper usage and, in addition, can be mixed with virgin pulp in any proportion.

However, recovered plastic pellets, for example, are usually lower grade because of contamination of pigments and plasticizers, and thus have a narrower range of re-application. In this connection, it is hoped that another different system of industrial material standards for recycled materials will be established along with the existing standards. The latter, known in Japan as the JIS (Japan Industrial Standards), appears to be better-suited for the virgin material and its products. (Incidentally, the JIS has been handled traditionally at the AIST, to which both authors belong.)

Current government incentives are concerned primarily with the development of technological processes for resource recovery or disposal, and not for the recovered (secondary) materials. One of the reasons is that the recycled materials are yet to be produced on any large scale whose economic assessment is possible.

Recent awareness among Governmental agencies that, since secondary material is manufactured on a smaller scale in a scattered manner, the market opportunities will be much fewer and the price will be unstable, has made it possible to employ a central storage policy for certain materials like paper stock. The action taken by the Government (the MITI), in this connection, was the foundation and funding of the Waste Paper Recycling Promotion Center, in June 1974, which was mentioned earlier in this paper. It is predicted that, in the near future, similar facilities or centers for plastics, ferrous and nonferrous metals, will be established with Government incentives.

The MITI is, at present, considering some form of subsidy for filling the price gap between virgin and secondary materials, in its plant (at the Bureau of Industrial Location and Environmental Protection). Nevertheless, this and similar plans like depletion allowances, have not yet been implemented.

Other economic incentives to encourage consumers to accept recycled materials or products are also discussed at different administrative levels. One way of doing this is the economic disincentive of taxing those materials or products that pose particular recycling problems. But again, this has not yet been done.

Social Factors

There are many social factors involved that hinder the progress of effective resource recovery. We have to admit, in our efforts on this aspect of the problem, that we are behind the United States. The reason for this is mainly the greater social inertia in favor of the existing system in this country. Another is the fact that the Japanese have a special psychological reluctance to utilize things once used by others in that form. Those psychological and social barriers to resource recovery can only be lessened by constant education or enlightenment.

From the municipality's side, the lack of employee education and training in resource recovery implementation is identified as the major problem.

Another is the institutional problem. This includes not only local governments but also the Central Government, and is considered more serious than generally thought. Priority setting and consistent policy planning among the public sector is naturally of vital importance for effective and efficient realization of resource recovery.

Finally, legislative reorganization of both existing and future laws, acts, codes, or ordinances for resource recovery must be cited here with special emphasis. The current situation in this aspect of the resource recovery effort urgently needs attention.

II. THE AIST R&D PROJECT ON RESOURCE RECOVERY

OUTLINE OF THE PROJECT

The project was initiated to provide a technological solution to the municipal solid waste problem which has various social, economical, and technological impacts. The primary aim was to recover resources from refuse. The current Waste Disposal and Public Cleansing Law states, in Section 3 of Article 4, that the Government shall promote the development of processing technology and provide technical as well as financial aid to the local autonomous public agency. With this legal justification, the Agency of Industrial Science and Technology, MITI, in FY 1972, conducted a year-long state-of-the-art survey on resource recovery from municipal refuse and studied the possibility of starting a national R&D project on the subject from FY 1973. The project, entitled "R&D on Resource Recovery and Reuse Technological System," was then formally launched as Phase I and will last for three years. (Initial budget appropriation plan was 1.6 billion yen or about 5.3 million United States dollars, for this period.)

Unlike the conventional production technology R&D projects, the emphasis was placed on the technology "system," not on any specific technology alone.

Resource recovery, needless to say, can only become realistic when it satisfies environmental requirements. In this respect, the AIST's project, from the beginning, needed to have close contact and cooperation with local government circles and the Ministry of Health and Welfare who had been traditionally in charge of solid waste management.

The aims of the project may be summarized as follows:

(1) To recycle the values at the optimal conditions--
Resources Conservation

(2) To establish the resource recovery technology sytem--
Feasibility Study of Elemental Technologies

(3) To establish a total system for resource recovery--
Conceptual Systems Design and Incentives

(4) To propose a solution to environmental problems associated with municipal waste--
Impacts Assessment and Pollution Control

The project plan, in its first phase (Phase I), thus includes the feasibility study of selected elemental technologies and the conceptual design of a total system. Phase II, based on the results of Phase I, proposes a demonstration of the total system with particular emphasis on the technological aspect.

The basic project concept and plan are summarized in Figure VIII.2.

R&D PROGRAMS

Selection of the Program Fields

Elemental Technology

In a resource recovery system, the subsystems may be identified as the basic processes that should be termed here elemental technologies. The concept of an elemental technology is somewhat similar to that of a unit operation or unit process in the chemical industry. Elemental technologies, in the development stage, may be divided broadly into two categories; peripheral or interfacial elemental technology and critical elemental technology.

The former is elemental technology like the magnetic separator or mechanical composting technology, that has been already applied to resource recovery from municipal refuse, proved to be an established technology, and has no further need for R&D. The facility or equipment of this type of elemental technology is already on the market and can be procured with specifications.

The critical elemental technology, on the other hand, is an important technology and considered critical in the R&D. One kind under this elemental technology is technology based on a totally new concept or principle. Another kind under this category is technology, such as pyrolysis, that has been practiced in other fields of technology but has not been applied to resource recovery. And this newer application to resource recovery may require a feasibility study.

The present R&D is thus mainly concerned with critical elemental technology.

Within a process network for resource recovery, various fields of elemental technologies may be identified along the stream of the waste from its source to the ultimate disposal point. For the present R&D program purpose, four elemental technology fields were identified: (1) collection/transportation, (2) size reduction/extraction, (3) decomposition, and (4) reutilization.

Prior to the project initiation, critical technologies for each program field were first listed and a dozen program topics for R&D were selected. They are listed in Table VIII.10.

Goals:

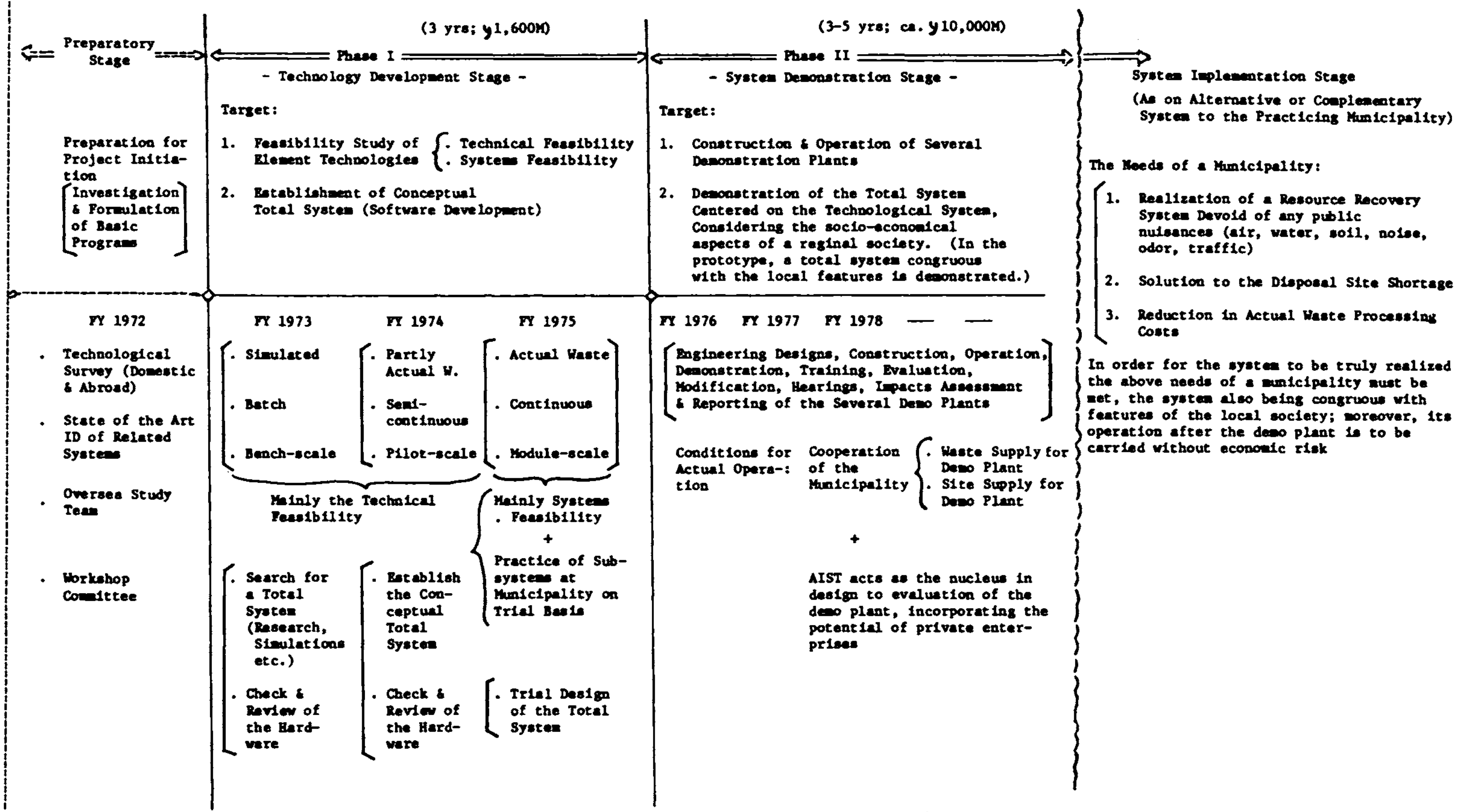
1. Conservation of Energy & Materials
2. Reduction in Net Processing Cost
3. Better Environmental Technology System

⟹ Proposal of a Prototype Refuse Alternative System and its Demonstration

Application:

Unlike other industrial single-purposed technology system, the potential user of the current system for the near future is the government or municipality.

Outline of R & D Programs:



Preparatory Stage

Preparation for Project Initiation
[Investigation & Formulation of Basic Programs]

FY 1972

- Technological Survey (Domestic & Abroad)
- State of the Art ID of Related Systems
- Oversea Study Team
- Workshop Committee

(3 yrs; ¥1,600M)

Phase I

- Technology Development Stage -

Target:

1. Feasibility Study of Element Technologies
   - . Technical Feasibility
   - . Systems Feasibility
2. Establishment of Conceptual Total System (Software Development)

FY 1973

- . Simulated
- . Batch
- . Bench-scale

FY 1974

- . Partly Actual W.
- . Semi-continuous
- . Pilot-scale

FY 1975

- . Actual Waste
- . Continuous
- . Module-scale

Mainly the Technical Feasibility (FY 1973, FY 1974)

Mainly Systems . Feasibility + Practice of Sub-systems at Municipality on Trial Basis (FY 1975)

FY 1973

- . Search for a Total System (Research, Simulations etc.)
- . Check & Review of the Hardware

FY 1974

- . Establish the Conceptual Total System
- . Check & Review of the Hardware

FY 1975

- . Trial Design of the Total System

(3-5 yrs; ca. ¥10,000M)

Phase II

- System Demonstration Stage -

Target:

1. Construction & Operation of Several Demonstration Plants
2. Demonstration of the Total System Centered on the Technological System, Considering the socio-economical aspects of a reginal society. (In the prototype, a total system congruous with the local features is demonstrated.)

FY 1976 FY 1977 FY 1978 —— ——

[Engineering Designs, Construction, Operation, Demonstration, Training, Evaluation, Modification, Hearings, Impacts Assessment & Reporting of the Several Demo Plants]

Conditions for Actual Opera-: tion

Cooperation of the Municipality
- . Waste Supply for Demo Plant
- . Site Supply for Demo Plant

+

AIST acts as the nucleus in design to evaluation of the demo plant, incorporating the potential of private enterprises

System Implementation Stage

(As on Alternative or Complementary System to the Practicing Municipality)

The Needs of a Municipality:

1. Realization of a Resource Recovery System Devoid of any public nuisances (air, water, soil, noise, odor, traffic)
2. Solution to the Disposal Site Shortage
3. Reduction in Actual Waste Processing Costs

In order for the system to be truly realized the above needs of a municipality must be met, the system also being congruous with features of the local society; moreover, its operation after the demo plant is to be carried without economic risk

⟨Office of Research & Development Programs
Agency of Industrial Science & Technology, MITI.⟩

Figure VIII.2 Summary of R&D Project Concept of Resource Recovery Systems

TABLE VIII. 10

R & D PROGRAMS AND SYSTEMS STUDY OF THE AIST - FY 1973 AND 1974 -

Study Field	Performed at the AIST's National Laboratory	Conducted at Contracted Private Corporation
Collection & Transportation	. Slurried Waste Pipeline Transportation Technology (NRIPR)	—
Shredding	—	. Low Temperature Shredding and Separation of Plastic Wastes (Hitachi, Ltd.) . Cryogenic Shredding Technology of Bulky Wastes (Kurimoto Iron Works, Ltd.)
Sorting and Classification	—	. Air Classification and Related Sorting Systems (Mitsubishi Heavy Industries, Ltd.) . Semi-wet Shredding and Sorting Process (Ebara Manufacturing Co., Ltd.) . Magnetic Fluid Sorting Technology for Non-ferrous Metals (Hitachi, Ltd.)
Chemical Decomposition	. Hydrogenation and Catalytic Pyrolysis Technology (GIDL, Hokkaido) . Fixed-bed Pyrolysis Technology of Cubitted Waste for Fuel Cases (NRIPR) . Combined Reactor Pyrolysis System (NCLI)	. Fluidized-bed Pyrolysis Process for oil Recovery (Hitachi, Ltd.) . Combined Fluidized-bed Pyrolysis/Combustion Reactor System for Fuel Gas Recovery (Ebara Manufacturing Co., Ltd.)
Reuse	. Incinerator Residues Utilization Technology (NCLI)	—
Systems	—	. Conceptual Design of a Total System for Resource Recovery and Reuse (Japan Industrial Technology Association)

NRIPR: National Research Institute for Pollution and Resources, Kawaguchi
GIDL, H: Government Industrial Development Laboratory, Sapporo, Hokkaido
NCLI: National Chemical Laboratory for Industry, Tokyo

One kind of selected program, which needed rather basic research, however, was assigned to be conducted at the National Research Laboratories under AIST, and the other that needed more advanced technological development was contracted with private firms that had the potential to carry out the R&D in this field of technology.

Systems Studies

Because of the complexity of the resource recovery problems, the importance of a systems approach was emphasized during the preparation stage of the project in FY 1972.

Comprehensive study and assessment on the state-of-the-art, and the subsequent systems analysis and, hopefully, a proposal of the total system with emphasis on technology, were identified to be necessary, along with the other "hardware"" study programs. A systems study under the title of "Conceptual Design of a Total System for Resource Recovery and Reuse," that is listed in Table VIII.10 was contracted with the Japan Industrial Technology Association, a quasi-governmental agency.

The JITA, being aware of the need for the interdisciplinary (and, perhaps, multi-disciplinary) study for this project, had formed, within it, an organization called "Committee on the Systems Study of Resource Recovery and Reuse." The Committee, chaired by Prof. Dr. Yoshitoshi Oyama, currently director of the National Research Institute of Environmental Sciences, of the Environment Agency, and the former President of the Tokyo Institute of Technology, is composed of professionals with various disciplines ranging from engineering to social psychology. The Committee also had at first six and has now three workshops under it.

The first subcommittee, or Workshop on Elemental Technology is primarily concerned with the technological state-of-the-art in resource recovery. It reviews the existing and potential technologies and makes some evaluations on those technologies. One function of the Workshop is to check and review the progress status of the selected R&D programs conducted by the AIST.

The Workshop on Systems Analysis, which is the second subcommittee, is concerned with computer analysis of some problems identified critical to the project progress and making the necessary predictions. In FY 1973, the Systems Dynamics technique, that was first developed at the Massachusetts Institute of Technology and was written in Dynamo Statements of a computer language, was utilized to analyze and predict the role of PVC (polyvinylchloride polymer) mixed with Japanese municipal waste.

The third subcommittee, Workshop on Demonstration Project, aims at preparing and making assessments on the coming Phase II of the AIST Project, which is to start from FY 1976. Phase II of the Project, described briefly in Figure VIII.2, is essentially a demonstration of the total resource recovery system at selected municipalities, and can be comparable with the U.S. counterparts of EPA. Currently, members of the workshop are studying the social, economic, and other characteristics of candidate municipalities.

Brief Review of Elemental Technology Fields

Although the goal of a project is to establish a resource recovery system, a brief review for each elemental technology field may be appropriate here. However, before we proceed to the review, the total processing system that we have in our plan in its generalized form can be depicted in contrast with the existing disposal systems, as in Figure VIII.3. The resource recovery system which is intended here is a conceptual alternative of the next generation that would be a substitute for conventional incinerators or sanitary landfilling.

Collection/Transportation

(Collection and transportation may be dealt with separately. But, because of the close relation between them, no attempt was made here to separate them.) Elemental technologies in this part of the whole process are not directly related to resource recovery itself. However, current importance of this technology field and the relation to subsequent processing may need a brief description.

Other than the conventional (packer) truck method, rails, ships, and pipelines are under consideration for application of refuse collection and transportation in Japan. Among these, the pipeline collection and transportation is considered most promising. The pipeline has many variations; vacuum, capsule, train, pressure, and slurry.

The facilities of pipeline transportation are usually costly and not economical for less densely populated areas. But once installed, the operation requires less manpower and can easily be automated, which is considered a great advantage over the conventional truck collection and transportation.

Most technologies regarding the pipeline collection and transportation have already developed on a commercial scale, and it appears to be unnecessary to initiate new R&D programs except that of slurry pipeline transferring.

Slurry transportation of the waste or other materials like coal may be very important, particularly for the wet processing that follows. Municipal waste slurry, because of the largest content of paper, behaves, in the pipe, in a way somewhat similar to cellulosic slurry. The waste slurry contaminated with dirt, and other inorganics, is a complex Non-Newtonian flue and its flow characteristics are not known well. The basic engineering data

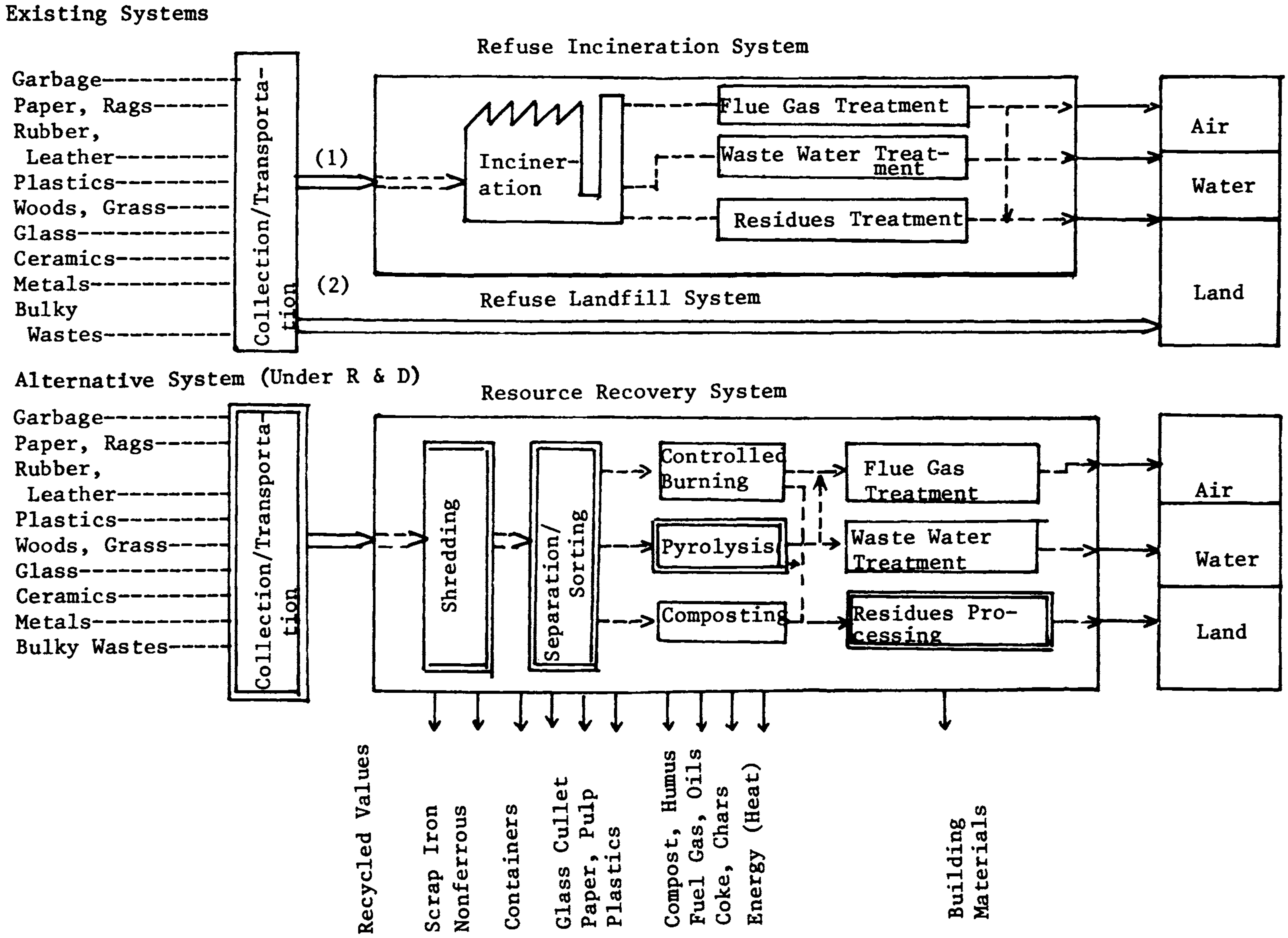


Figure VIII.3 Existing Disposal Systems and Compatible Resource Recovery System

▭ Existing System ▣ Under R & D

for designing such pipeline transportation are considered to be of extreme importance.

Size Reduction/Extraction

For size reduction, shredding is most commonly employed for the municipal refuse handling, in which a combination of shearing, compression, and impact forces is utilized effectively. Hence the shredding technology is considered to be a peripheral elemental technology and not for any further R&D. However, shredders that operate at room temperature have such environmentally adverse effects as noise, vibration, and dust, and are often not acceptable for aesthetic and hygienic reasons. In addition to these demerits, shredders require normally greater power consumption and rather frequent maintenance and the shreds coming from this type of equipment are not normally suitable for subsequent effective materials extraction operations for resource recovery because of their size distribution and lumping.

Cryogenic shredding, in contrast with ordinary temperature shredding, is becoming known to compensate for some of the latter's disadvantages. The basic principle of cryogenic shredding is as follows: any solid material when exposed under the cryogenic (low temperature) conditions shows a marked brittleness for a certain temperature range. This physical property may be utilized effectively for size reduction and the subsequent selective extraction of certain material(s).

Various coolants may be possible for waste processing. For both economical and safety reasons, liquid nitrogen (b.p. = -195.8 C) is most promising. Liquid nitrogen is normally produced as a by-product for oxygen production from air and is a totally inert gas. The latent heat (of vaporization) of imported LNG is often suggested for another source of cooling energy; nevertheless, direct utilization of this (cooling) heat seems impossible because of LNG plant location and its need for special handling.

First hand estimates favor the application of cryogenic shredding to the resource recovery processing, because most adverse environmental effects accompanied by the ordinary temperature shredding would be removed. However, this newer technology application needs further research and development. Economic disadvantages of using considerable amount of liquid nitrogen (the normal liquid N_2/refuse ratio ranges from 0.3 to nearly 1, on the weight basis) may or may not be offset by many advantages.

Technologies associated with materials extraction, in general, are based on a wide variety of principles: gravity (or density), air or hydro-dynamics, particle size or shape (screening), electrical conductivity, magneticity, electrostatic force, optical property, and so on.

Thus the selection of critical technologies for R&D purposes is usually very difficult. For the AIST programs, importance was placed on the fact that the technology as a component of a total processing system should perform most effectively with respect to upstream size reduction and downstream back end components of technology. And the feasibility for Japanese waste was also emphasized.

Air classification technology was selected because the technology had never been properly applied to the wet Japanese refuse, though the air classifier is operated on a commercial scale abroad. Plastics extraction in purified forms of pellets or powder by means of organic solvent (xylene) was also studied for its applicability to the plastics-rich Japanese waste. The semi-wet selective pulverizing system, already very successful with the completion of the first year of R&D, is considered best fitted to Japanese waste separation.

For separation of the inorganic fraction, most of the conventional processing technologies may be applicable that have been in practice in minerals processing. However, newer technology may also be worthy of study. A technology for separating various nonferrous metals by means of magnetic fluid (ferrofluidics, for example) is an R&D program currently underway. This involves processing with a heavy medium with variable but controllable apparent density to separate selectively the metals, one kind at a time.

Decomposition

Solid wastes may be decomposed thermally, chemically, and biologically. In view of its importance, let us restrict our discussion here to the thermal decomposition of organic matter. Pyrolysis, in its strict sense, is thermal decomposition in an oxygen-free environment. However, known "pyrolytic" processes often include partial oxidation (or combustion) and may not strictly be called pyrolysis. Because of this, the term "thermal decomposition" is used here in a much broader sense than pyrolysis, and it is distinguished from incineration or combustion in that the latter is thermal decomposition with an excess amount of air or oxygen.

As stated earlier, thermal decomposition is one of the most promising technologies for resource recovery, because it can be used for conversion materials recovery as well as energy recovery in a storable and transportable form. More than a dozen processes are being proposed for this purpose both in Japan and abroad. Nevertheless, it may be agreed that none has been proven yet to be completely workable on a commercial scale with the products being recovered in an acceptable manner.

General conditions for success of these thermal decomposition processes are considered more stringent in Japan, simply because of the higher moisture content of the Japanese refuse. The organic fraction of the Japanese waste, however, is still considered essentially cellulosic with some amount of hydrocarbons from plastics.

In analyzing a thermal decomposition process of the solid organic material, two distinct reaction stages should be clearly identified; endothermic and exothermic. In order that the solid organic matter be decomposed, heat must be supplied to increase first the enthalpy of the material to a decomposition temperature and then enable the decomposition reaction to occur, which, in most instances, is endothermic. As the decomposition to a lower molecular state of the matter proceeds, the second stage reaction(s) between the products and the surrounding gases will take place, which is (or are) usually exothermic. Partial oxidation, hydrogenation utilizing superheated steam, or carbon monoxide, and certain condensation reactions are such examples. First and second stage reactions could occur in a series or almost simultaneously, depending on the reaction scheme and the reaction conditions.

In any event, the reactor(s) is so designed that the selected reactions effectively and efficiently take place. Thus the various classifications of the thermal decomposition processes are possible.

The way of supplying the heat of the first endothermic stage may divide the processes into (1) external heating, (2) internal heating, and (3) partial oxidation processes. Or, according to the major final product state, another way of subdividing the processes is by (1) gasification, (2) liquefaction, and (3) carbonization. One has to know, however, that in either one of these processes, three phases of the final products do exist; for example, in a gasification process, a small amount of liquids and solids (chars or inorganic residue) is obtainable as by-products.

Equipmental features often become the name of the processes: (1) single and (2) combined, or dual reactor pyrolytic systems, or (1)-fluidized-bed, (2) fixed, or packed-bed, and (3) rotary kiln reactor processes. Furthermore, operational characterstics divide the equipment types into (1) batch, (2) continuous, and (3) semi-continuous processes.

With these diversified modes of thermal decomposition processes, one may easily imagine, by the combination of these subdivisions, how many processes could be possible. The point is, however, that a pyrolytic process must first satisfy the basic disposal and resource recovery principles cited earlier (see Table VIII.9) and be efficiently operable, without causing any environmentally adverse effects.

For the AIST R&D programs in this elemental technology field, three fundamental research projects and two more advanced, practical development projects were selected (refer to Table VIII.10).

Basic studies include: (1) fixed-bed gasification of molded waste, (2) catalytic and hydrogenation fluidized-bed reaction for liquid products, and (3) combined reactor system for gasification.

Fluidized-bed gasification and liquefaction are two contracted (but 100 percent supported by the AIST) R&D programs in this technology field.

We believe, with these five research programs of thermal decomposition, that, by the end of the Phase I term, we will be able to tell which would be the best pyrolytic process for Japanese solid waste under a certain set of conditions.

Reutilization

Elemental technologies under this category range from incinerator residue reutilization to wall board manufacturing from compost humus. They cover a wide range of technologies and cannot be classified in any specific manner.

This process is important, however, because the final product(s) should have greater marketability. In other words, the products already have an established market value, and the usually lower grade of the products from waste should not be disadvantageous in the market.

One basic research program of this project is being conducted at one of the AIST's laboratories, aimed at the reutilization of incineration and pyrolysis residues. Because of the relatively smaller fraction of metals contained in them, tiles, bricks, and certain ceramics, along with application of chars, are the major concern.

Target of Major Selected R&D Programs

1 Low Temperature Shredding and Separation of Plastic Wastes

To separate the PVC plastic fraction selectively out of the source separated plastic wastes by means of refrigeration.

2 Cryogenic Shredding Technology for Bulky Wastes

To perform an effective size reduction and separation of complex products or materials that occupy major fractions of bulky wastes and are not suitable for regular shredding.

3 Air Classification and Related Sorting System

For the first year program, to classify the humid Japanese waste effectively into the organic and inorganic fractions by means of air classification technology.

4 Semi-wet Shredding and Classification Process

To classify the damped or moisturized waste into easily processible fractions and separate the values, like pulp stock, with higher purity.

5 Magnetic Fluid Sorting Technology for Nonferrous Metals

To separate valuable nonferrous metals, such as aluminum, copper, and zinc out of the nonmagnetic inorganic mixture of the waste.

6 Fluidized-bed Thermal Decomposition Process for Oil Recovery

To obtain oils or liquid fuel products effectively by the thermal decomposition of the organic fraction of refuse.

7 Fluidized-bed Pyrolysis/Combustion Dual Reactor System for Fuel Gas Recovery

To apply the dual reactor pyrolysis technology to obtain high caloric fuel gas out of the organic component of solid waste.

DEVELOPMENT STATUS OF MAJOR R&D PROGRAMS

Low Temperature Shredding and Separation of Plastic Wastes

First year work (FY 1973) includes basic study on low temperature physical properties, like brittleness, of plastic materials, heat transmission tests of plastic wastes in the low temperature range, and the feasibility of shredding operations at lower temperatures. Those studies proved that the low temperature shredding and the subsequent separation of PVC polymers from other plastic wastes was feasible.

The second year study develops an optimal process for this purpose and provides the equipment design and operational specifications for the whole process, including the cooling duct and the shredders.

Construction and operations of a pilot plant with a processing capacity of 50 Kg/hr should be completed by the autumn of 1975, and the final continuous operation using the source-separated plastics (in Tokyo) in order to accumulate the performance data, should be followed until March 31, 1976.

Cryogenic Shredding Technology for Bulky Wastes

This R&D program will be completed within this fiscal year, i.e., by March 31, 1975. In its first year, batchwise operated equipment was constructed to test such non-crushables as washing machine motors, steel coded tires, and the like, to recover copper, steel, hard plastics, rubber, and other materials. Shredding characteristics, particle size distribution, and cryogenic properties of the constituent materials were studied, and an optimal set of operational conditions was sought to minimize the amount of liquid N_2 to be consumed. Also an engineering design of continuously operated equipment was completed and patented.

At present, the continuous process equipment with 1 ton/hr capacity has been constructed and soon the data collection operations should start. Economic feasibility should be studied concurrently.

Air Classification and Related Sorting System

A 1 ton/hr (dry basis) pilot plant having three major units of horizontal, vertical zig-zag air classifiers and a vibrating screen, was designed, constructed, and operated to separate the organic and inorganic fractions effectively from Japanese refuse. First, prepared wastes with different compostions and moisture contents, and then actual wastes were used to test the process. With an "as-received" refuse with moisture content of 42 percent, the data showed a better than expected result for the separated organics with more than 99 percent priority, while the separated inorganic fraction was contaminated with the organics and resulted in a purity less than expected.

Currently in its second year program, a process for recovering plastic materials in refined form from the separated organic stream by air classification is being developed. A pilot plant, based on a bench-scale laboratory test for this solvent (xylene) refining process, was designed and is being assembled now. The test operations will soon begin to collect the performance data.

The third and final year program includes materials extraction from the inorganic fraction obtained from air classification. A process consisting essentially of froth flotation and heavy media separation methods is planned to recover ferrous metal, aluminum, and glass. The latter half of the third year will be devoted to organizing all processes developed during the three years as a total sorting (materials recovery) system.

Semi-wet Pulverizing and Classification Process

The technology based on a totally new concept is substantiated in trommel-like equipment. The municipal waste with as-received moisture or damped, if necessary, is fed to one end of the rotating drum with screen holes and equipped with hammers inside and rotating at a different speed. Homogenization of the waste through the diffusion of the moisture and size reduction by tumbling and hammering actions take place almost simultaneously as the waste moves in the horizontal, longitudinal direction. During this process, selected materials while being pulverized will be screened out and classified automatically. Three-stage classification of the refuse has proved most practical and efficient.

Tests done by a model and module units (both operated batchwise) in the first year of research showed that one of the classifications was essentially all high quality recyclable waste paper. A waste paper processor recovered paper sheets from this fraction on a trial basis, and guaranteed the quality of the recovered material. This is probably the simplest process to separate the paper from the mixed refuse without any known environmental disadvantages. (No air, water, and possibly soil pollution is expected; in addition, there is less power consumption than in the conventional processes.)

This year is devoted mainly to modification of the test module equipment to a larger mode unit to check the scale-up factor. The designing of 2 tons/hr single drum continuous equipment is being done concurrently and the equipment will be assembled by the end of this fiscal year.

In the next year, a demonstration plant of this process will be constructed at a landfilling site of a suburban city of Tokyo, and further performance data will be accumulated before commercialization.

Magnetic Fluid Sorting Technology for Nonferrous Metals

The magnetic fluid, which consists of magnetite (Fe_3O_4) particles of about 100 A average diameter coated with a surface-active reagent and suspended in a base medium, usually water or kerosene, plays a central role in this separation technology. The fluid once placed in a magnetic field, possesses an apparent density corresponding to the field force. A particle of any nonferrous metal submerged in this fluid, therefore, may either float or sink, depending on its specific gravity. And this is the principle of this technology.

A batchwise equipment was built in the first year program and the same basic research was conducted for the feasibility of the process for waste. The process input must be an inorganic residue remaining after the ferrous metals have been extracted completely by a magnetic separator and a mixture of nonferrous metals and glass, ceramics, or the like. The first year study concluded that both floating and sinking units were necessary for effective separation of aluminum and copper. Also, some means to recover the valuable fluid that would be carried over along with the separated metals must be developed. Otherwise economics of the process using the very expensive magnetic medium seem unrealistic. (Current price per gallon of this liquid for research use is about 100,000 yen, or 350 United States dollars. We expect the price will drop to 1,000 yen or $2 per gallon by the time of commercialization.)

The second year program includes the development of a continuous process equipment with capacity of 100 Kg/hr. A unit of pretreatment by means of eddy current separation of non-metals and an additional medium recovery unity will be attached to the main part of the process. The performance data are to be obtainable within this year. Some make-up experimental runs may be necessary before commercialization in the next fiscal year of 1975.

Fluidized-bed Thermal Decomposition Process for Oil Recovery

First year experimental study was performed utilizing a pilot plant with reactor of 160 mm Ø. Simulated wastes with varying plastic composition were used to investigate the yield of liquid fuel product. Also process heat balance was studied in order to determine the way to supply heat to decomposition reaction in the fluidized-bed reactor. The result seemed favorable for the partial oxidation taking place in the reactor for oil recovery without much changing the heating value of the liquid product.

The first few months of the second year (FY 1974) are being devoted to investigating the process performance with an actual waste. A scale-up reactor with diameter of 500 mm Ø is in its designing stage and soon will be constructed. In the third year, a nearby commercial scale plant will be constructed and operated for the actual waste on a continuous basis.

Fluidized-bed Pyrolysis/Combustion Dual Reactor System for Fuel Gas Recovery

The basic idea of this process is as follows: the sand, fluidization medium, mixed with chars produced in the pyrolytic reactor flows to the second combustion reactor where the air is being blown from the bottom and the burning of the chars takes place. The heated sand in the combustion reactor, now free of chars, travels back to the first pyrolytic reactor through a pipe to provide the heating and reaction energy to the shredded waste. Thus the sand, through circulating between the two reactors, acts as an energy carrier and the two reactors are normally in a thermally equilibrated state with a certain feed rate.

This dual reactor system has been employed in petroleum cracking process and is not totally new. The advantages of this system are that the process is suitable for higher caloric gases and the operation can easily be automated because of its inherent stability.

The first year study was mainly concerned with the pyrolytic reactor section. (A combustion reactor that could be combined with it is in widespread use already.) Thus a single reactor with diameter 300 mm Ø system was designed and the feasibility of the pyrolysis process for Japanese waste was checked. Waste paper stock being pulverized was used to test the equipment. A fuel gas with the lower heating value of nearly 4,000 Kcal/Nm^3 was obtained at about 830 C. Moisture content was a testing parameter and an interesting result was obtained.

Currently, the sand circulation is tested on a model unit of the same geometry as the reactor system at the room temperature. The design of a reactor system with 500 mm Ø for each reactor is also being performed.

In the final year, a module size plant will be constructed and tested for feasibility on actual waste.

Conceptual Design of a Total System for Resource Recovery and Reuse

A partial description of the activities being done under this contracted study was made earlier (see systems studies, above).

The current major activity of the Systems Study Committee is preparation for the coming Phase II demonstration programs that will start in FY 1976.

THE PHASE II PLAN

The Need for Phase II of the Project

We are now (FY 1974) in the middle year of the three-year term of Phase I of the AIST Resource Recovery and Reuse Project. As stated earlier, the objectives of Phase I are: (1) technical and systems feasibility of selected elemental technologies to apply under the Japanese physical and social conditions and (2) conceptual design of a total system for effective resource recovery systems implementation. At the end of Phase I, we could not estimate, however, that all elemental technologies developed under the Project and/or the total system proposed should be implemented shortly thereafter on a "commercial" scale.

The reasons for this may be as follows. Firstly, those technologies, unlike the conventional production technologies, for lack of economic interest, should not be implemented without any economic aids or incentives of any form. Secondly, municipalities are considered as still not ready to accept the resource recovery concept in a more realistic manner. Thirdly, and most important of all, the system demonstration, which is most needed by the municipality instead of single technology demonstration, would have not yet been performed.

For these reasons, most municipalities being still within the amortization period of current disposal (mostly incineration) facilities may find the resource recovery systems implementation too risky to take both in economical and technical terms. Therefore, we have to conclude that we need the systems demonstration for a certain period of time before municipalities would start implementing the systems safely.

Outline of Phase II Plan

Based on the need justified above, the AIST is now planning a demonstration project for Phase II that should directly follow the current Phase I. The system we would pursue will include as many results of the Phase I term as possible.

The outline of the Phase II plan may be summarized as follows:

Period Three to five years starting with FY 1976.

Total Budget Appropriation Planned Approximately 10 billion yen, or 33 million United States dollars.

Method Construction, operation, and evaluation of several demonstration plants in selected municipalities.

Demonstration Plant Prototype systems that match the local conditions to be demonstrated. Plant processing capacity varies according to the locality and demonstration purpose. However, generally more than 100 tons of refuse per day may be necessary to demonstrate the economical factors. Prototypes include total systems, each including the existing facilities, like incinerator, as the subsystems. Others may include systems centered on materials recovery and/or energy recovery.

For the demonstration plants, municipalities should provide the refuse and the site on which the plant construction would be made. The AIST, or the Government, on the other hand, should guarantee plant hardware, construction, operation, and maintenance during the demonstration period.

Training of employees of the municipalities, operation of the plant under extreme conditions of incoming refuse, assessments of market opportunities for recovered materials or energy, and assessment of the environmental impacts, are planned with the consultation of the selected municipality.

At the end of the demonstration, should the municipality so desire, the whole plant might be acquired by the municipality based on the general disposal rules of Government properties; or the municipality could ask the AIST to remove the plant.

CONCLUSIONS

From the discussions in the first half of the paper, the following concluding remarks may be summarized.

A. The old style "ragman recycling" is currently seldom seen in Japan.

B. Increased public awareness of resource recovery from the municipal refuse has been observed especially over the last two years.

C. For processing (disposal or resource recovery) purposes, approximately 20 percent industrial waste normally mixed with the regular waste causes various problems to the municipality.

D. Source separation is widespread among Japanese municipalities, not for recycling for the most part, but for more effective disposal processing. (Separation of plastic products because of expected damage to the incinerator, for example.)

E. The main features of Japanese municipal refuse, compared with U.S. refuse, are higher average moisture content (more than 50 percent) and a higher fraction of plastics (reaching nearly 10 percent).

F. The Japanese paper recycle ratio is much higher than the figure of the U.S. counterpart, and anticipated to increase still further.

G. Incinerators are in widespread use among the Japanese municipalities. But heat recovery is not performed as much as in Europe.

H. Industrial and public (including the Central Government) sectors show a great deal of interest in resource recovery from the municipal refuse. Various efforts are beginning in this area.

I. Technological problems identified here include processing of waste contaminated with hazardous materials, storing of putrescible refuse or recovered materials, and resource recovery processing of source separated materials.

J. Non-technological problems identified here include economics of recycling processing and recycled resources and social acceptability of the resource recovery concept and recycled resources. The solution of these problems will require more time than the technological ones.

Conclusions, based on the AIST Project description in the latter half of the paper, are as follows:

A. R&D programs are being conducted on selected "critical" elemental technologies. The problems encountered involved not so much technical feasibility as systems feasibility.

B. One of the difficulties in designing the resource recovery process is to synthesize a processing system that absorbs the variations in composition and quantity of the input refuse.

C. System design or process synthesis techniques for resource recovery systems that must satisfy the diversified local conditions have not been satisfactorily developed. The need for this kind of study should be emphasized.

D. R&D programs performed during the Phase I period alone may not be sufficient for the municipality to implement as a resource recovery system. Phase II of the Project may be necessary for system demonstration before the municipality employs the system shown by the AIST, to preclude technological as well as economic risks.

E. The currently planned Phase II includes construction, operation, maintenance, and assessment of the demonstration plant of several selected cities.

The MITI, with its conservation of energy and materials policy, has been promoting and will promote through the AIST R&D programs on resource recovery systems and its other Bureaus various economic and administrative incentive programs to conserve the resources from various wastes, including industrial waste, with the cooperation of civic and industrial sectors.

APPENDIX B: TECHNICAL

B. I: TECHNICAL PROBLEMS AND RESEARCH OPPORTUNITIES IN RESOURCE RECOVERY

Booker Morey

In seeking a perspective on the technical problems that face resource recovery today, it has been helpful to briefly review the state-of-the-art of resource recovery that our forebears had. At the turn of the century, contractors paid the City of New York 57¢ per ton of raw rubbish for the privilege of picking out the following marketable commodities:

TABLE I.1

Component Recovered	Weight/% of Raw Refuse	
Rags	15	
Leather	2	
Wood	1.5	
Paper		
Newsprint	11	
Manila	2	
Pasteboard	10	
Metal	3.3	9
Glass	3.0	13

From the metals, tin was recovered and the iron cast into sash weights. The bottles were recovered and washed. The residue was burned, the ashes screened, and the fines used as shrubbery fertilizer. On the average, 30 percent of the rubbish was recovered by hand picking as marketable products.

Garbage was separately collected and rendered for grease and oil recovery. The products were used for hair preparations and for wagon grease while the tankage was used as a fertilizer base or as fuel. Rendering was expensive, and a dump fee of $.50 to $2.50 per ton had to be charged.

To approach in the 1970s the extent of resource recovery that was accomplished in the 1900s, at an economical cost and with a mechanized process, is a useful objective and reasonable expectation.

A number of factors are different today--the ore has changed in composition, as well as the relative value of an hourly wage and the value of the recovered resources. Garbage, which was source segregated then, is becoming increasingly source segregated now, and more garbage is appearing in the sanitary sewer system.

Concurrently, the market for the products of rendering such as hair oil has collapsed with the advent of the "dry look."

Source segregation and separate collection was practiced in 1900 on four classes of waste:

Street sweepings - primarily manure
Ashes
Garbage
Rubbish (boxes, rags, leather, furniture)

Source separation apparently met with less than total enthusiasm:

> The tenement-house districts, especially those inhabited by the least educated, often produce a careless and filthy class of waste. Such districts could be inspected rigidly with advantage, to educate and force the people to deposit their wastes in proper receptacles, rather than to throw them into the streets and other public places. Unfortunately, this educational process is most difficult, due to the ignorance of the people, their lack of order and reverence for things clean, and the political advantage of non-interference (Parsons 1906).

Landfill presented difficulties, even then:

> This method is practiced in some places, but the result is most untidy and unsightly. In those climates where the carrion buzzard is prevalent, the surface garbage is eaten by these natural scavengers. The birds beget, however, as indecorous a reminder of the waste-heaps as the garbage itself.

> When the garbage in the mixture is in sufficient quantity, the putrefaction may become a decided cause for annoyance, and possibly of an unsanitary state, especially in cases of contagious epidemic. Covered garbage remains in a putrefactive condition for long periods, as light and air are essential for rapid decomposition. Land thus filled is not safe for improvement until many years have passed (Parsons 1966).

Incineration and reduction required higher capital outlay than did other disposal methods. Many of the incinerators worked poorly, belching large quantities of smoke, and:

> had setbacks and recorded failures from bad advice, poor inception and faulty design. This is especially true of the early efforts to incinerate garbage in the United States, where civic committees were often appointed, incompetent to grasp the technical questions involved, who placed too much reliance on the theories and statements of astute promoters and inventors. Many communities have spent large sums of money to produce little else but failure, owing to a lack of suitable engineering advice, and have, therefore, been led to condemn all means for treatment.
>
> The types of furnace so far adopted in America have been of cheaper form of construction than those of the latest and best pattern in Europe, and the municipalities have given too much consideration to first cost and too little to efficient working and results to be achieved.
>
> The failures have been chiefly due to incorrect designs of furnaces, large grates, slow combustion, low temperatures, too much reliance on stoking, and inexperienced firemen. Unless high temperatures are generated in the furnace-cell, the garbage mass will be subjected to frying rather than to cremation, and odors are sure to be discharged from the stack (Parsons 1906).

Reflected here are two of the problems of the 1970s. Most municipalities have recognized that civic committees responsible for choosing a system need technical help, and seek the advice of a consulting engineering firm that is not in the business of building resource recovery plants to give unbiased evaluation of such plants. Most of the consulting engineering companies offering such a service are ill-equipped to do so, being unfamiliar with the processes, economics, marketing, and acceptability of proposals. Worse yet, in most cases, the poor choice made for one community (before the effects of such a choice can be assessed) becomes an asset to that company in soliciting for the same job in another community.

In examining municipal trash as a raw material for resource recovery there are two basic approaches. The first is to recover materials in a form of quality that will meet existing markets.

The second way is to develop markets for products that result from certain processing steps.

At this time, there appears to me to be no technical problems that should prevent a prudent man from risking the capital required on new resource recovery plants, with the objective of making them work reliably and economically. Accordingly, the problems discussed here are relatively short-range opportunities for improvement in the economical operation and for improved recovery of commodities in this and the next generation of plants.

Perhaps the easiest approach to these problems is to discuss the commodities most likely to be produced from the plants.

The most easily recoverable product from municipal waste by a mechanical device is the magnetic ferrous metals. The metal can be recovered before or after a pyrolysis or incineration step.

The U.S. Bureau of Mines, in developing processes to clean the ferrous fraction from incinerator residue, typically find about .005 percent of copper and .001 percent of tin to be alloyed on or in the recovered steel. National Steel has had extensive work in this type of steel and find it of limited substitutability in their blast furnace because the copper and tin impurities pass through into the pig and make the iron of no value to steelmaking.

For these reasons incinerator ferrous had a very difficult time finding a home. It took six years in Tampa, Florida, to have it accepted next door for use in reinforcing bars.

In Harrisburg last year the city fathers watched the price of #1 dealer bundle steel rising over $125 per ton and felt upset at the $5 per ton contract that they had for their incinerator residue metal. The contract was reopened for bidding but there was no response; not even a tender of the same $5 per ton offer previously held. The same experience has been true in Chicago where, even with no market for the steel for use in cementation or to the nearby Gary works, steel was separated from the residue and separately trucked to a different landfill (Oberman 1974). The reasons for this have nothing to do with resource recovery.

There are two ways to view this market response to the product. The first is to identify it as an area where research into slag, tin, and copper removal would pay off. Certainly for existing incinerators this is justified. To me, in view of the alternative which I will describe, it clearly states that there is no economic or socially acceptable reason to build new large-scale plants to incinerate or pyrolyze things that will not burn.

By far the best market in both size and value for ferrous metals recoverable from municipal waste is to upgrade the metal to #1 dealer bundle (Meyer 1975). This grade has tight specifications on purity and on form. Detinning usually provides such a product and, in addition, recovers tin and lead (Meyer 1975b, Hill 1973). Detinning does also remove aluminum which can cause slag problems in a basic open hearth and pinhole problems in casting if not removed prior to melting.

The cost of detinning rises with the aluminum content of the steel because the aluminum dissolves in the caustic bath, consumes reagent, raises the viscosity, eventually affects current efficiency in the electrowinning of the tin, and finally requires disposal of the contaminated caustic solution.

In assuming that detinning is the best treatment for the steel fraction recovered from municipal waste, profitable opportunities exist for research into the removal and recovery of aluminum from bimetal cans. The aluminum that is contained on the tops of bimetal cans represents 30 to 35 percent of the aluminum that is found in the trash, and if these tops could be removed and recovered would represent a real value. Such removal could conceivably raise the value paid by a detinner for the steel. Alcoa has begun some studies on scoring the aluminum tops so they would pop off nearly in their entirety during shredding. Other problems in the secondary separation of these tops have led to a temporary suspension of these efforts. Alternatively, but of decidedly less total value, would be development of a chemical method to remove aluminum and regenerate caustic from the bath.

Detinning cannot remove copper. The removal of tin, however, does reduce the effect of copper on hot shortness and does allow higher contaminant levels of copper when used for steelmaking. Too much copper reduces the value of the steel, and at some point the metal has application in the manufacture of reinforcing bars or in the cementation market.

To date the best method of separating copper from steel, which usually occurs as parts of motors, is by source segregation of the steel scrap most likely to contain motors, such as whiteware. The concept and use of a light and heavy ferrous separation as developed by the Bureau of Mines appears to be another effective way of keeping copper out of a class of ferrous that would then become #1 dealer bundle. Mechanized ways for the separation or identification of copper on steel represent at this point a more defensive research opportunity than one that could offer a large profit in the value of the recovered copper.

NONFERROUS METAL RECOVERY

Of all the commodities of value in refuse that will be recovered by the first and second generation resource recovery plants, nonferrous metals have the highest unit value. At this time we really have no good data on the amounts of nonferrous metals contained in municipal refuse. Figures for aluminum are the most common and clearly indicate that the aluminum is by far the most important of the nonferrous metals contained in trash. However, estimates as shown in Table I.2 for other nonferrous metals easily indicate that their recovery can have more value to the resource recovery plant than aluminum, in some geographic areas.

Recovering a mixture of nonferrous metals which is primarily aluminum and selling this mixture to be reused in aluminum has the advantage that further processing costs are not incurred at the

TABLE I. 2 NONFERROUS METAL CONTENT OF MUNICIPAL TRASH

	Aluminum	Copper	Zinc	Other	Al/Cu+Zn
1)	0.5%	0.5%	0.5%		
2)		0.7%	0.7%	0.7%	
3)	0.4%		0.3%		.4/.3=1.33
4)	0.5%		0.3%		
5)					5/1
6)			Cu/Zn=1		2/1
7)					1/1
8)					4/1
9)			Cu/Zn=1/3		
10)	0.1-0.7	0.1-0.2	0.05-0.01	0.01-0.1	
11)					9/1
12)		Cu/Zn 1/1-3/1			8/1

Source: 1) Meyer (1975b); Bourcier (1972)
2) Hill (1973); Stanczyk (1970)
3) Sullivan (1973)
4) Connecticut Resource Recovery Authority
5) Morey (1974)
6) Meyer (1975a)
7) Meyer (1975c)
8) Michaels (1974)
9) Morey (1975)
10) ASTM (1974)
11) Cummings (1974)
12) Bourcier (1974)

resource recovery plant. The disadvantage includes the lower value of pure individual components. Some of the impurities that could be picked up in the nonferrous metal recovery section are very serious. A complication of such impurities along with their effects is a valid list of opportunities to increase or protect the value and usefulness of the aluminum.

Lead, tin, and bismuth, as solder components are introduced into aluminum either as contaminent steel cans or as part of electronic equipment mounted on an aluminum chassis. Each of the three contaminant elements is about equally bad, segregating at grain boundaries during cooling and weakening the metal. These appear to be the most troublesome of the commonly encountered metals (Bourcier 1975).

Iron, although used at about .005 percent as a dispersion hardener, will cause problems above 1 percent, especially during casting. The metal will slowly dissolve in molten aluminum. Surprisingly, stainless steel will dissolve at a much more rapid rate and contribute both iron and chrome to the melt. When heavy media is used for aluminum recovery, the entrained media, whether magnetite or ferrosilicon, apparently appears in the slag and is not the contaminant it was once claimed to be.

Glass, with virtually the same density as solid aluminum, sinks in the molten aluminum bath and eventually requires removal. There is a slow reaction at 1400 F that reduces the silicon, and contributes to contamination over a long residence time. This then reacts with magnesium, reducing the effectiveness of the magnesium as a hardener.

Zinc forms a solid solution with aluminum, and such an alloy has limited uses in aircraft and auto bumpers. It becomes a difficult alloy to cast.

Copper limits the usefulness of aluminum to casting alloys, but at the moment is a desirable contaminant.

Once melted together, the effect of these impurities is immediate and unremitting. Right now, aluminum of almost any grade has value. It finds use by suitable dilution with new aluminum. The low recycle rate has kept this situation stable. With the advent of resource recovery and auto shredder nonferrous metal recovery, these same secondary metals can be recovered again and again, each time increasing in impurities and requiring more and more dilution for reuse. Other than magnesium removal with chlorine, there are very few metals that can be removed from a molten aluminum alloy. The major refining process uses an expensive Hoopes cell. Such refining certainly may increase in importance as recovery of nonferrous metals increases.

Chemical refining of physical mixtures by leaching in aqueous media represents an opportunity whose time will come. Dissolution of aluminum for refinement into bauxite is not felt promising because of the very large losses in energy stored in the metal.

The physical separation of the different alloys and alloy types will become more and more important to prevent the formation of a low grade alloy. This represents one of the greater opportunities for profitable research.

The total recovery of nonferrous metals from resource recovery plants is quite low, averaging 50 percent of the aluminum in the refuse. The major losses, not including aluminum bimetal cans, derive from foil and can stock losses in the over head fraction of an air classifier. Additional losses occur in the portion of underflow that is not treated in the nonferrous recovery system. Finally, the devices that are proposed for the recovery of nonferrous metals have approximately an 80 percent recovery of the nonferrous metals that are fed to the separator itself.

Of these losses the most serious are in the air classifier and the efficiency of the nonferrous metal recovery device. Improvement in recoveries by the devices can be expected and new and more efficient designs can be confidently predicted. Losses in the fines will decrease in total resource recovery systems as a consequence of recovering clean glass.

The most difficult problem will be to lower the losses of aluminum in air classifier overheads or in the organic fraction, even as it is derived in hydropulping. In this regard, alternatives to air classifier and hydropulping for separation of organics from inorganics is a fruitful area of consideration and is not yet one where an obvious alternative is apparent.

GLASS RECOVERY

Of the inorganic substances of significant quantity in raw refuse, glass has the lowest unit value and one of the widest ranges of values.

Secondary alternatives for the use of impure glass include asphalt, slurry seal, or as an additive to bricks, masonry, or concrete blocks. In all of these applications glass displaces sand or aggregate, and has a value of $1 to $3 per ton. Delivery charges must be deducted from the revenue, but so would transportation and landfill cost, if no use was found.

There are other construction uses for somewhat purified glass. These include rockwool, foam glass, tile, uses as filler in plastics, and use in chemically bonded bricks (by Certainteed). In these applications the value of the glass can approach the value of cullet ($21 to $26 per ton). It is hard to believe that a significant market for recycle glass can exist at a price higher than that paid for cullet, because cullet would simply be diverted from glass furnaces to these other uses as such a market developed. Only a unique size or size distribution for recycled cullet could maintain its value over factory cullet.

In the past, the major reason for developing secondary uses for glass was the reluctance to recycle the glass into glassmaking furnaces. The major reason now is the transportation cost involved in moving the glass to glass manufacturing facilities.

To recover glass of cullet quality requires extensive and relatively expensive processing. There appears to be only two processes capable of recovering cullet quality glass. The most tested process is by optical sorting which can give a clean and color sorted glass product, and the other is froth flotation, which gives a mixture of colors. The concept in the aluminum scrap field of "value by dilution" applies to a limited extent in glass. There are severe limits which if exceeded cause even reject bottles from a glass plant to be landfilled rather than recycled. The major problems involving quality center around refractories, seed, cord, and color. Even greater problems at this point are caused by unfamiliarity and consequent lack of confidence that glass container manufacturers and batch house operators have in using cullet derived from municipal refuse. Glassmaking is an art. Even though science has invaded the practice and improved productivity, it rarely has significantly dented the batch house foreman. These gentlemen, skilled in their art, know from experience what works and what does not. New and different things usually does not work.

Refractories are particles that do not dissolve in the molten glass. A certain amount of refractories are always found in the glass as furnace linings or tapping holes degrade or spall off. Small size refractories contained in the raw sand cause an additional amount of opaque particles to be found in the product ware. Both of these imperfections in the glass are esthetically undesirable, but more significantly, they cause points of stress which are especially undesirable in pressurized bottles.

The specifications and the tolerance levels of refractories are very dependent on the size of the refractory. Refractories such as sillimanite, kyanite, ceramics (especially high alumina ceramics), corundum, zircon, and andalusite in size larger than 20 mesh are tolerated at a rate of only one particle in forty pounds of cullet. This is a very tight specification and purity is a problem. In the smaller size ranges such as 40 by 60 mesh, 20 particles per pound are accepted. The reason is that most of the cited refractories dissolve in a glass melt at a very slow rate and the smaller ones will disappear in the 8 to 24 hours holding times found in the glass tanks. Larger stones cause defective bottles that are removed on the inspection line and remelted. A large stone can recirculate through the system up to 15 times, causing 15 bottles to be rejected and increasing the probability of missing and shipping a bad bottle in direct proportion to the number of passes that the ceramic makes through the system.

One of the problems that requires a significant amount of attention at this point in recycling glass from municipal waste is the identification of the foreign materials that are associated in municipal waste and identifying which among them actually do form stones under glassmaking conditions. The identification of these types would be a help in improving processes aimed at their elimination.

Metals cause problems in many ways. Copper remains undissolved, aluminum can tint a flint furnace amber and cause silicon metal stones in an amber tank by reducing silica (Cummings 1975). Iron will slowly dissolve, and is one of the major colorants in green and amber furnaces.

Seeds are small bubbles that do not "fine out" and are caused by large concentrations of air-entraining dust-sized cullet or sand or by certain decomposition reactions, for example the reactions of sulfate with sulfide giving SO_2. Mixtures of oxidizing and reducing glasses in large quantities also cause seeds. Many other factors as yet unknown appear to affect seed formation. A maker of plastic coated bottles reports that the plastic is good in his furnace and that it acts as a firing agent. This result is obtained even at rates that violate the tentative GCMI standards for organics by approximately tenfold (Arrandale 1974). Other manufacturers claim that the plastic is indeed a detriment.

Cord, a distinguishable second phase in the glass, also results in stress and weakness, and can be caused by inhomogeneous melting or inhomogeneous feed to the furnace, or by a reaction occurring in the forehearth. The control of cord is a much more difficult problem and is not well worked out.

The final major problem in recovering glass from municipal refuse is the fact that the colors that are obtained in the final glass product represent the buying habits--more literally the drinking habits--of the geographic area in which the refuse is collected. Glass container manufacturers have come a long way in their tolerance for mixed color cullet and recognize now that large substitutions can be made of mixed color cullet into green and amber tanks. The tolerance for mixed color cullet in flint is minimal and will remain at approximately 10 percent. Hope for undiscovered, new and highly powerful decolorizers is I believe unfounded.

Since flint accounts for 60 to 70 percent of the bottle shipments, areas with extensive resource recovery facilities and relatively few glass manufacturing plants can truly exceed the capability of a glass plant to accept mixed color cullet. There are a number of alternative solutions to the problem. These include finding other high-value outlets for the mixed colored glass, testing consumer acceptance of green bottles (when legal, and where flint has been generally used), and to test market reaction to bottles that do not remain the same shade throughout the year. This would be an "Eco green" (TM) bottle. A most reasonable alternative is color sorting. To date the only successful color sorting technique that can come close to meeting glass container manufacturing industry specifications is optical sorting. This work has been done both by the U.S. Bureau of Mines and on a larger scale by Sortex, GCMI, and the EPA at Franklin, Ohio. Forty tons of flint glass was optically sorted and blended as 20 percent of a new batch of flint glass. The bottles that were made from this mixture looked good but did not quite meet the specifications. Hopefully, there will be improvement in both sides by lowering of the standards and raising of the quality of the recovered glass.

Since optical sorting works in the size range of about 3/16 by about 3/4 of an inch, and this is the area of the tightest refractory and metal contamination specifications, the GCMI guidelines are probably impossible to meet economically with commercially available equipment. At this time there are no test procedures to find one particle in forty pounds of glass, and this may truly be a blessing.

Another alternative is to take the color sorted large flint particles and grind them to less than 20 mesh, where the tolerance for the refractories is much higher. This is not a desirable alternative.

The relatively limited size range that can be economically processed by optical sorters sets limitations on the total recovery of glass that can be achieved by optical sorting. In a study of size distribution of glass from a number of primary shredder installations, between 54 percent and 86 percent of the glass was broken to less than 3/16 inch. The median was 70 percent finer than 3/16 inch (Woodruff 1973). No matter what primary processing is used, breakage distributions will apply and recovery of glass above 75 percent in this narrow size range will be very difficult.

The objective of color sorting is to recover a clean, pure flint fraction. The remaining mixture, including some flint, will be used in green and amber furnaces. Although other optical sorters are under development, an alternative color sorting procedure would be desirable. The parameters for such a process would include less cost and the capability of treating finer sizes, and possibly more sensitivity than the optical sorting techniques now available.

Such a device would probably be based on physical properties of the glass that are related in some way to the color within the glass. There is little published data on comparison of physical properties of container glasses as a function of their color. The spectral curves are well known and the chemical durability or the corrosion resistance of the different colored containers has been studied. Many of the fundamental properties are not available in the literature. These include conductivity, surface chemistry, thermal properties, magnetic, and electromagnetic properties.

Suggestions to improve the ability of color sorting have included tagging the flint or the colored glass or to consistently make the flint glass or the other colors heavier in density by the addition of zinc oxide. Extensive calculations have apparently shown this to be an uneconomical alternative.

FUEL

Because of the large quantities of fuel involved from resource recovery plants, the most likely outlets are utilities and cement kilns with back end clean up systems for the solid fuel. If there are not large quantities, then the conversion costs to the utility or the cement plant are not justified and the fuel cannot be used. More rarely, large quantity steam users may be found and low quality steam can be sold as generated from waterwall incinerators, grate fired burners, or bark firing facilities in paper mills. When industrial user contracts are signed, the need for back up facilities in the steam generation plant usually becomes mandatory to assure a steady supply of steam. This is a significant added expense. Newer incinerators, generally of European design, can supply steam at 1200 F, 1000 psi which approaches the quality of steam used by utilities, and if the expense of generators is added, electricity can be sold into the power network. Since this power is only a small fraction of the total power in the system, high reliability is not necessary.

There must, in any case, be an economic incentive to use a new and unfamiliar fuel. Utilities are in the business of making and selling electricity, not in the business of waste disposal. Although resource recovery plants are in an economically justifiable position to discount the fuel on a BTU basis by about 10 percent below competitive fuels, a new factor has developed. Most regulatory agencies allow utilities to have a fuel adjustment clause. These utilities have far less incentive to seek less expensive fuels or to make the concessions necessary for the substitution.

It is felt that primary shredded material of 3 inches or less can only be used in grate-fired furnaces. These furnaces are now relatively rare and quite inefficient. For suspension firing, sizes on the order of about 1/2 inch are needed, and of a shape that will combust nearly completely in the 1/2 second (or so) residence time available in suspension. Union Electric has proven that there is no appreciable adverse effect in firing refuse on the life of a Combustion Engineering tangentially fired boiler deriving 10 percent to 20 percent of its heat or using 20 percent refuse (by weight) as fuel. Continued studies on the corrosion and erosion effects will undoubtedly take place. Union Electric also feels confident that refuse can be fired in other boiler designs such as a front wall fired boiler (like those made by Babcock and Wilcox, Foster Wheeler, or Riley). Increased emissions are expected from firing refuse but are not expected to be a significant problem. Nitrogen oxides apparently will also increase as a result of firing refuse, but this is a consideration primarily in the Chicago area and Southern California. The chlorine appears to be diluted enough to not affect corrosion rates.

The need for alternative forms of fuel made from the organic fraction of refuse is very important, and in some cases critical to the success of a resource recovery project. This research program would include the manufacture of other forms of refuse into specific compounds like glucose, methanol, methane, and ammonia. Since these have been adequately discussed, I will not repeat these programs here.

PLASTICS RECOVERY

Plastics recovery represents a desirable objective and a difficult goal. The economic separation of plastics into a clean form from the remaining refuse has not yet been accomplished. An assessment of the economic potential of a plastic separation needs to be made. Since plastics range from very filmy material to large chunks, they will be very difficult to isolate into a single fraction. The U.S. Bureau of Mines has been working on the problem, and the U.S. Forest Products Laboratory has reported a thermal method for separating plastic from paper. Should just "plastics" be isolated, then the mixture apparently has little value. Thermosets must be removed from thermoplastics. Even the thermoplastics must be separated into groups before a new plastic of value can be extruded.

To aid in the bonding of the plastics development of new coupling agents is worth considering. There are a few possible uses for the plastics in the mixed condition. If the plastics are ground to small enough size, they can be used as fillers in the molding of other plastics, where their chemical inertness is more important than the chemical reactivity. The ground plastics then would compete with clay, ground glass, carbon black, and other fillers. Mitsui Mining has reported separation of ground plastics by type using froth flotation. There are studies on depolymerization of the plastic to its constituent monomer for reuse.

Plastics are excellent high energy fuel sources. The concept of using the plastics as fuel is not a totally unacceptable alternative.

PAPER RECOVERY

The economical recovery of paper from municipal refuse in a form clean enough for reuse is an important goal. Inhibiting this objective are two problems. The first is the highly cyclic and limited market for secondary products made from paper. The capital cost of constructing a new secondary paper mill is very large and there is great reluctance to invest the capital in a new plant unless there is a good chance of acquiring the needed feed at an economical rate. Extensive paper recovery systems such as the mechanized ones of Black Clawson cannot be justified without a sure market for the fiber. A promise to create such a market in the future is not enough. Apparently because of this, two recent

Black Clawson proposals did not include fiber recovery. In the foreseeable future, paper will be recovered by the least capital-intensive methods even though they may be highly inefficient. These processes will be of the type that can be started and stopped economically, depending on the market fluctuations and conditions. Hand-picking or perhaps a light air classification would be the probable operation.

Opportunities for research for the recovery of paper include the studies of effective dry recovery techniques for paper, and increasing the secondary market for mixed paper in applications in the construction field rather than in making more paperboard. Lower cost repulping and manufacture processes should more properly be advocated and studied by paper producers.

MARKET DEVELOPMENT

The development of alternative markets for many of the products and by-products of resource recovery plants is a wide open area. It is hard to believe that a fraction of refuse that is easily isolated can have unique properties which make the value of that fraction very high. Should such an application be found, substitutes for refuse would quickly bring the price down. The products from more extensive processing of refuse can easily have much higher value and the greatest hope lies in processing the organics to a degree, or partially cleaning the glass-rock mixtures. Although fairly high grade construction applications are possible, the organics should continue to become a valuable chemical feedstock.

PROCESSING PROBLEMS

Most of the problems discussed in this section relate to the operation of a typical resource recovery plant.

1. Protection of shredders from explosives. Enough experience has shown that high explosives beyond the normal gas cons, propane tanks, and cases of aerosols enter shredders to make hazardous conditions. Apparently, some are dumped in refuse as a response to the proud statement by an official that the new shredder can take anything. Some arrive in an effort at anonymous disposal of contraband or war souvenirs.
2. Alternative disposal systems are needed that could be used for large household quantities of insecticides, poisons, or irritants to help protect the working environment of the plant. Incineration of the air used in the shredding and air classifier operations is important.
3. Partial resource recovery systems are needed for use in smaller towns and municipalities. Ultimately, partial resource recovery will be included in large systems if fewer and fewer recoverable items are found in the refuse as a result of

legislation. Total recovery may drop as an inevitable consequence.

SUMMARY

The first generation of full-scale resource recovery plants are ready to be implemented. These plants will only recover the major components of the municipal trash, and of COMRATE's list of imported metals that are especially recommended for recycling, (NAS 1975) only tin has a high probability of being recovered. There is too little gold and silver (as jewelry) or mercury (as batteries), for example, to justify the processing cost of recovery for these plants.

Recovery of a major portion of the municipal solid waste as fuel or useful energy is the economic and technical key to low cost or profitable resource recovery. Without that value, the cost of shredding and air classifying must be justified in terms of savings in landfill costs. There is insufficient revenue in the value of the inorganics to support the cost of shredding.

There is need to improve both the recovery and the purity of the products of a resource recovery plant. The markets for these products must be confirmed by large-scale production, and alternative high values markets must be established. Some specific needs and opportunities for research follow.

1. Processes for the separation of aluminum and copper from magnetic metals.
2. Improved recovery of nonferrous metals.
3. Physical sorting and chemical purification of mixtures on nonferrous metals.
4. Improved low cost separation of organics from inorganics.
5. Lower cost recovery processes for cullet quality glass. Improved color sorting and refractory removal.
6. Development of alternative forms of fuel derived from the organic fraction of municipal trash.
7. Derivation of chemicals of commerce from the organics in municipal trash.
8. Evaluation of the value and development of plastics recovery and sorting processes.
9. Continued efforts to recover a recyclable grade of paper.
10. Improvement in protection systems for equipment and personnel in resource recovery plants.
11. Evaluation and development of regional systems for economically serving small communities and maintaining resource recovery at central processing points.

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B.II: RECLAMATION OF MATERIAL AND ENERGY VALUES FROM MUNICIPAL WASTES

J. J. Cordiano

Municipal solid waste (MSW) is the mixed refuse and garbage which is collected from residential, commercial, institutional, and some industrial sources. Disposal of this mixed waste has become an increasingly formidable problem--over 125 million tons are generated annually. In March 1973, a report issued by the National League of Cities and the U.S. Conference of Mayors disclosed that 46.5 percent of the cities responding to a questionnaire expect to run out of landfill capacity for current and anticipated MSW in one to five years.

The predominant method of waste disposal involves hauling to a central site where it is discarded--in some areas carelessly to form smouldering dumps--but increasingly in a "sanitary" landfill where untreated waste is buried daily in layers, each covered with several inches of compacted earth. While landfill has transformed thousands of acres of "low-value" property into parks and playgrounds, the possible detrimental side effects, such as pollution of underground water and the uncontrolled generation of methane gas, may eventually outweigh the economic and social benefits derived from this means of disposal.

In coastal areas, ocean dumping has been practiced for many years. Until recently, the ocean was considered a safe dumping ground because it had remarkable abilities to dilute, disperse, and degrade wastes. However, with the growth of population and industry along our coastlines, the sheer bulk of MSW generated, coupled with the development of non-degradable waste products, is concentrating pollutants in coastal waters at an alarming rate.

In urban areas, incineration is used to dispose of 10 percent of the MSW collected. Incinerators, however, are becoming more costly to operate because of air and water pollution controls and operating difficulties from handling glass, rubber, and some plastics. Incineration systems with heat recovery are few and utilize less than 1 percent of the energy value in MSW. More recently, additional heat recovery incinerators, based on European experience and design, have been introduced into the U.S. and Canada, but there are still significant technical problems with these systems which adversely affect the energy conversion efficiency and reliable deliverability of the product.

A solid waste management concept which has received a great deal of attention in recent years involves the processing of solid waste for resource recovery--to economically compete with existing waste disposal systems, to provide a positive contribution to a clean environment, and to offer a small but significant contribution to our supplies of energy and other natural resources. The resource recovery process and systems designed to recover the components in refuse and convert them to usable products generally fall into the following four classifications:

1. Energy Recovery - waste heat recovery from incineration; pyrolysis for gas, char, and oil products; and use of processed refuse as a fuel supplement.
2. Product Recovery - ferrous metal for detinning, steelmaking, and copper cementation; paper for recycling in newprint; glass for use as cullet, paving, mineral wool; fiber for use in roofing, coarse paper, and textiles for rags.
3. Compost Production
4. Chemical Conversion - For protein, cattle feed, alcohol, and acids.

The current resurgence of interest in resource recovery stems from the increasing efforts to solve the growing problems of solid wastes augmented by the energy crisis which became apparent to the world in the fall of 1973. Developing shortages and increasing prices of raw materials are shipping market forces in large urban areas with the result that recycling is becoming competitive with other means of waste disposal.

A number of processes have been developed for recovering the thermal energy available from solid waste. Depending on their composition and morphology, municipal solid wastes will vary between 4000 and 9000 BTU/pound. The utilization of solid waste as a fuel has been the most effective means to date for recovering this thermal energy. Municipal solid waste can be processed into many different fuel forms and used in a variety of furnaces. The refuse can be used "as-received" or processed into a solid fuel, a liquid fuel, or a fuel gas. The most commonly used process for the recovery of the thermal energy in municipal solid waste is steam generation by incineration of the refuse "as-received." These steam recovery municipal incinerators are quite common in Europe, Japan, and Canada, and have been used to a limited extent in the United States.

The "as-received" refuse can be processed to produce a fuel fraction for use in boilers and industrial furnaces. The refuse can be shredded and most of the noncombustibles removed. The refuse can also be dried to improve its heating value and ease of handling. Combustion Equipment Associates (CEA) and Raytheon have reported the development of processes for removing most of the inert fillers from the wastes and comminution of the wastes to a fine powder. Liquid fuels can be produced from the refuse by pyrolysis or hydrogenation or a combination of these processes.

The liquid fuel is usually comparable to a heavy fuel oil. Gasification can be accomplished by a number of thermochemical and anaerobic digestive processes.

Although the refuse represents an energy source at a time when energy is in high demand, there are a number of problems associated with its use. The major problem is the day to day (if not minute to minute) variation of the waste composition. Moisture content will fluctuate from 15 to 50 percent by weight of the refuse, greatly affecting the BTU content and the processibility of the material. Compared with other fuels, the fuels from wastes are more difficult to transport, store, and process and have very low energy densities. Even when shredded refuse is briquetted its energy density is only one fourth that of coal. Most of the waste fuels are in a dilute or partly oxidized form and as a result have relatively low energy levels and produce lower maximum flame temperatures. The lower flame temperatures result in lower heat transfer rates and increased total gas volumes. The greater gas volumes necessitate larger combustion zones.

Two other problems associated with the use of waste fuels are ash generation and corrosion. High temperature liquid phase corrosion (above 900 F) and low temperature dew point corrosion are the two main problems reported from the use of waste fuels. Although the low-alloy steels are more susceptible to corrosion by the alkalies and chlorides in the refuse, the stainless alloys are also attacked at the higher temperatures. Most of the waste derived solid fuels have relatively high ash content (about 20 percent by weight on a BTU replacement basis) and have to be fired in furnaces with ash handling systems. However, CEA reports only 2 percent ash (by weight) in its new "Eco-Fuel II." Higher ash content will increase the soot blowing and air pollution control equipment requirements. Also the ash builds up in the boiler tubes which reduces heat transfer rates and limits operating capacities.

Because of these problems with waste fuels and the associated economic considerations, using the refuse as a supplemental fuel may be more desirable than using it as the primary fuel in boiler units. The solid waste fuel can effectively be used as a 10 to 20 percent BTU replacement for coal, and the compositional variations, corrosion, and ash handling problems would be minimized.

Several pilot studies using refuse as a supplemental fuel with coal or oil in boilers have now been initiated. The most extensive of these has been at the Union Electric Company of St. Louis where a 125 MW pulverized coal firing unit has been modified to fire shredded refuse from which the ferrous metal has been removed. At Commonwealth Edison of Chicago, bags of shredded refuse, with the ferrous metal removed, were manually fed into a cyclone unit at 10 percent BTU replacement rate with very encouraging results. At the General Motors Corporation plant in Pontiac, Michigan, a spreader stoker unit was built with two separate, air-swept chute feeders, using bark burners for firing shredded refuse and coal simultaneously. Cubetted, shredded refuse has been used as a supplemental fuel in an underfed stoker-fired boiler at the Fort Wayne municipal electric plant.

To date, the results from the pilot studies using the refuse as a supplemental fuel have been very promising. It burned well in the boiler units tested and did not appear to accelerate boiler corrosion in the short term. However, it is felt that boiler corrosion could be a problem if the refuse exceeds 30 percent BTU replacement of the coal. In a review of a study of European boilers firing 40 percent or more refuse, it was found that corrosion was reported as a problem. Preliminary results from these pilot studies further showed that the refuse does not have a detrimental effect on the fly ash or gas emissions from the boiler. However, increased loading of the electrostatic precipitators was reported. The report also noted that the use of refuse as a supplemental fuel results in the formation of boiler tube slag which can be more easily removed than the slag formed on boiler tubes in all-coal-fired units.

A number of material recovery processes have been developed for recovering the metal, glass, paper, and cellulose fiber from municipal solid waste. The Black-Clawson Company has developed the Hydroposal/Fiberclaim process for recovering cellulose fiber. A demonstration plant for evaluating this wet process has been built in Franklin, Ohio. The received refuse is mixed with water and pulped into a slurry. The heavy fraction of the refuse is ejected from the bottom of the pulper. Equipment for receiving the ferrous metal, aluminum, and glass from this heavy fraction has been installed and is being evaluated. The cellulose fibers are recovered from the pulped slurry by subsequent processes. If the fibers are not removed and the slurry is dewatered, the filter cake product can be used for fuel in stoker boilers similar to those using bark or bagasse as a fuel.

Several dry processes have been developed for recovering the paper fraction from refuse. Franklin Institute has developed a ballistic separator which extracts the paper fraction from the mixed refuse. The refuse is shredded in a hammermill and then fed into a double-deck vibrating screen having both 1 inch and 3/8 inch meshes. The plus 1 inch material is fed into the ballistic separator which separates the light paper fraction from the other refuse. The minus 1 inch plus 3/8 inch material is air classified in order to recover the rest of the light paper fraction. The soft plastics are separated from the paper by subsequent processing steps. The minus 3/8 inch material is not recovered.

The Forest Products Laboratory (USDA) has also developed a dry system for recovering the paper fraction from milled refuse. In this system, the milled refuse is subjected to successive air classification steps. In the initial classification the glass, metal, and heavy organics are dropped out. Prior to the final classification, the lights are fed through a rotary dryer which causes the soft plastics to ball up and separate from the paper in the final classification.

Recovery of the ferrous metal in the refuse is common to most of the resource recovery processes developed because of the ease by which it can be achieved. The magnetic systems developed have been relatively successful in recovering an acceptable ferrous product for detinning, for use in the copper industry, or as blast furnace charge. Recovery of the nonferrous metal fractions in refuse has not been widespread. This is primarily due to the low percentage of nonferrous metal in refuse, the high cost of the recovery equipment, and remaining questions about the effectiveness of the processes developed. Two basic systems have been developed for nonferrous metal recovery: high energy electromagnetic separation (eddy current techniques) and heavy liquid separation. The National Center for Resource Recovery has developed a system for nonferrous metal recovery for the air classified heavies incorporating a rising current separator, a multiple screen deck, and a series of heavy media separators. The rising current separator floats off most of the organics and washes the sink fraction. The screening process divides the sink fraction into manageable groupings for processing in the heavy liquid tanks. Utilizing liquids of appropriate specific gravity, the different nonferrous metals can be separated and recovered from the glass, and heavy organic fractions. Nonferrous metal recovery has also been effectively achieved by eddy current techniques. Both Combustion Power and Vanderbilt University have developed high energy electromagnetic separators.

Recovery of the glass in municipal waste is of such interest that several processes have been developed for recovering the glass for use as cullet or as a raw material in structural block, mineral wool, aggregate, terrazzo, or in Glasphalt. Heavy liquid separation, froth flotation, wet and dry vibrating tables, and size reduction processes have been used for glass recovery. Techniques for color sorting of glass have also been developed. However, the economics for glass recovery have not been very promising to date.

In 1974, the University of Dayton Research Institute developed a design for a resource recovery facility that would be applicable to many communities utilizing reliable equipment proven in other industrial applications.

The objective of the study was to provide a resource recovery plant for a community of 600,000 people to initially process 350,000 tons of MSW per year with a design capacity of 560,000 tons per year (2150 TPD, on a 5-day week basis) and a comprehensive analysis of the total capital and operating costs for the proposed facility. The analysis is summarized below.

These costs are as of July 1, 1974, and do not include land costs.

TABLE II.1

TURNKEY CAPITAL COSTS

Buildings, site preparation, and equipment	$13,100,000
Additions	
Start up costs - 4 months payroll	300,000
Working capital - 3 months payroll	250,000
Total initial investment	$13,650,000

TABLE II.2

OPERATING COST USING 1974 RATES (EXCLUDES INTEREST ON INVESTMENT)

1.	Manpower Costs		$879,682
2.	Maintenance Material		681,741
3.	Other Plant Costs		720,620
4.	General & Administrative		41,960
	SUBTOTAL		2,324,003
5.	Depreciation and Start Up		1,438,865
	TOTAL		3,762,868
6.	Operating Cost Per Ton	6.64	
7.	Total Cost Per Ton	10.75	

B.III: RESOURCE RECOVERY FROM RAW URBAN REFUSE

P. M. Sullivan, M. H. Stanczyk, and M. J. Spendlove

(Abstract and Introduction from Bureau of Mines Report of Investigations 7760, U.S. Department of the Interior, 1973, presented by Charles Kenahan and Harry Makar.)

ABSTRACT

At its College Park Metallurgy Research Center in Maryland, the Bureau of Mines has installed and is operating a 5-ton-per-hour pilot plant for continuous mechanical separation of values contained in raw urban refuse. The entire system was assembled using commercially available equipment. The process relies on multi-stage processing including shredding, air classification, screening, gravity concentration, and electrostatic separation.

Compactor trucks deliver raw refuse collected along typical routes in metropolitan Washington, D.C., to the pilot plant. The loads are separated into concentrates of (1) light-gage iron, (2) massive metals, (3) glass, (4) putrescibles and waste combustibles, (5) paper, and (6) plastics.

While some refinements remain to be made in the processing system flowsheet, the data obtained to date have been highly encouraging, indicating favorable economics for commercial-size plants.

INTRODUCTION

Of the 160 million tons of refuse collected annually in the United States, it is estimated that about 30 million tons are incinerated, generating about 7 million tons of residues. In previous work, the Bureau of Mines developed a continuous mechanical process capable of converting 85 percent of municipal incinerator residues into potentially useful products (Henn and Peters 1972, Stanczyk and DeCesare 1972, Sullivan and Stanczyk 1971). That process is presently being scaled up in a demonstration-size plant with a capacity of 250 tons of residues per day at Lowell, Massachusetts.

The huge tonnage of refuse that is not incinerated is generally disposed of by sanitary landfill or open dumping. The potential value of materials contained in this portion is far greater than that of the materials contained in incinerator residues. Conceivably, the products that could be reclaimed might also be of higher quality. In addition, processing of the combustible portion could yield plastic and paper fractions that might be used to make new products. The combustibles, alternatively, could be utilized as a source of energy by burning to produce steam, by pyrolysis to produce combustible gases and oil, or by conversion to oil with carbon monoxide and steam (Anderson 1971, Appell et al. 1971, Sanner et al. 1970).

Development of a successful raw refuse recovery process would not only provide a means for municipalities to generate revenue from the sale of products, but a major financial gain could be realized by savings in costs of haulage and landfill operations. Widespread adoption of the process by major municipalities and densely populated regions would also contribute significantly to conservation of our natural resources.

Thus, even before the incinerator residue recovery process had been fully optimized, the Bureau of Mines began research to develop a companion process to recover materials of major value from raw refuse. At the same time, other researchers were well advanced in developing processes for recycling some of the components of raw refuse (Boettcher 1972, Herbert 1972). The approach taken by the Bureau was aimed at developing a complete system for separating the components of refuse into as many products as necessary to permit maximum recycling of all materials. Raw refuse was viewed as an ore, as was the case with incinerator residues. Therefore, mineral engineering analysis and mineral engineering principles were applied to separate the components of refuse into product concentrates which with a final cleaning could be converted into potentially useful materials. The present report describes the flowsheet and the pilot plant that resulted from these studies.

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B. IV: MARKETING ASPECTS OF MATERIALS RECOVERY

Peter J. Cambourelis

(Abstract of Presentation)

Raytheon's work in the resource recovery area is based on a close working relationship with the Bureau since 1971 on both the incinerator residue and raw refuse processes (see B.III., above). Raytheon provides funds and manpower to help the Bureau run and maintain both pilot plants, which are operated by the Bureau.

Work Done by Raytheon in the Solid Waste Area

Basic work on statewide solid waste disposal plan for Massachusetts;
transportation studies;
full-scale equipment evaluation, using pilot-plant produced materials;
market studies/evaluation, using pilot-plant produced materials;
four incinerator residue applications being studied; and
studying five 2000 ton per day plants to process raw waste.

Ongoing Programs

1. Lowell Funded by EPA, the city and the Massachusetts Department of Public Works. This is a scale up of the USBM Incinerator Residue Process. The plant will be able to process either incinerator residue or the heavy fraction remaining when fuel has been extracted by a raw refuse separation process.

It produces for sale ferrous scrap, aluminum-base alloys scrap, copper and zinc-base alloys scrap, cullet.

Status: design completed, equipment orders placed, construction bids open, could begin operations in about a year.

2. Rochester, New York Plant A 2000 ton per day plant to process raw solid waste. It extracts light dry fuel, metals and glass, and 100 to 200 tons per day heavy organics initially for landfill. Later these will either be dried and finely shredded for use as a suspension fuel, pelletized for use as a stoker fuel,

or pyrolized to produce gas. Eventually 70 to 100 tons per day relatively innocuous landfill is expected.

Initial work in marketing the residue plant output products was frustrating because, although the materials were commonplace, suspicion of the products because of their diverse mixed origins meant that they had to be treated as new materials with no background history. Use of the pilot plants to produce pilot plant products for trial testing by prospective users was found to be the only way to get realistic market information.

Uncertainty in the market about the products, some objectively and some subjectively based, predicated this empirical approach until more data and statistics can be obtained and adaptation and accommodations made in processes on both sides.

For this reason, there is real value and perhaps necessity for the EPA-type full-scale demonstrations in conjunction with the USBM pilot plant work. The technical monitoring of this sequence--pilot plant followed by full-scale demonstration--could be carried out by the USBM, should this be beyond the technical capability of EPA.

Generally, buildings are amortized over a 20 to 30 year period, whereas process equipment is amortized over a 5 to 10 year period. The feeling is that the equipment will be amortized before significant changes have been made.

Specific Materials

1. Ferrous Scrap Ferrous scrap from raw waste separation plants will be used by the detinners, who will want to do their own secondary shredding. The aluminum content in ferrous scrap to be supplied to the detinners will be minimized by solid waste processing plant operators because of the high sales value of recovered aluminum scrap. Detinners remove more (aluminum) after secondary shredding not so much for the value of aluminum recovered as because residual aluminum would kill the caustic solution used by the detinner to dissolve tin. The price varies from region to region; on the Pittsburgh market about 40 to 60 percent of #1 dealer bundle price is expected. Pittsburgh #1 dealer bundle prices were as high as $165/$175 per gross ton in 1974 but are now under $100. Incinerator-residue derived ferrous scrap from the Lowell plant will be sent to a mini mill in Rhode Island, which will pay 90 percent of the #2 dealer bundle prices for the closest (Boston) market. The tin and copper content of incinerator-derived ferrous scrap cannot be reduced enough for unlimited use by mini mills and others. Use of this incinerator-derived ferrous scrap will require dilution at perhaps 10:1 to keep copper and/or tin contents down to acceptable levels, i.e., minimizing the risk of hot shortness.

2. Nonferrous Scraps There is little question but that these can be sold.

Aluminum-base alloy scrap: the price for aluminum will be based on the closing prices in the American metal market. (The plants will deal directly with users such as Reynolds Metals, ALCOA, and secondary ingot manufacturers). The current (April 1975) price is $240 a ton--60 percent of the August 1974 price.

Copper-zinc base alloy scrap will be used by the refiners (AMAX, ASARCO). This is a small quantity, high value material with a copper content about 30 to 50 percent. The hope is to develop processes to extract the zinc. The current value for the mix is $303 to $325 per ton; July quotes were $600 to $800. Prices are loosely based on the London metal exchange, but there is no known published index which can be used as a basis for pricing long-term contracts.

3. Glass Clean mixed cullet will be bought by the glass manufacturers to replace silica and soda ash. This market is very locality specific, and there is a high saturation potential because mixed color cullet can only be used in any significant quantity for the manufacture of amber and green glass containers. Recent EPA regulations shutting down soda ash plants, together with the fuel saving derived from using cullet, have increased the market for waste-derived glass, but it is impossible to generalize about the value of this product. Optical sorting is not completely reliable, and is too expensive because it separates by examining each piece individually. The development of an economically feasible mass-process for color sorting would considerably improve the market.

To develop other markets, the specific characteristics of glass-based materials need to be examined and taken advantage of for uses such as expanded aggregate, flux in brick manufacture, and so on.

4. Fuel For the Rochester plant the County of Monroe has an agreement in principle with Rochester Gas & Electric, aiming at a target of 20 to 30 percent substitution for coal on a BTU basis. The value again is locality specific, depending on prices of the locally used fuel. At about 13 million BTUs per ton and a bulk contract price to Rochester Gas and Electric for coal of about $1 per million BTUs, the price for refuse-derived fuel would be $13 per ton, less a charge to operate and amortize the refuse-derived fuel (RDF) receiving facilities at the utility. The ideal situation, obviously, is for the plant to be adjacent to the utility, but this cannot always be managed. Incentives need to be devised to overcome the inherent conservatism of the utilities. Because of fuel adjustment clauses, utilities have no real "bottom-line" incentive to use RDF. Legislation is required providing such incentives through tax abatement or relief or any other measure which will provide the utilities with higher profits

when they replace some proportion of their normal fuel usage with RDF.

General Discussion

The point was emphasized that it is impossible to generalize about the value of these products, the market is very locality specific, and prices for materials fluctuate considerably. The suggestion of an "economic fly wheel" to provide artificial stability was regarded with disfavor.

The long-term value of the Bureau's work is that their experimental projects can meet the need for empirical data where the risk involved has deterred private enterprise. The lessons learned from successes and failures of trying out various approaches and processes will ultimately reduce the uncertainty and provide a data base for future private or state efforts.

The main institutional barrier is the failure of regulatory agencies to come up with firm regulations. Risks must be measurable in terms of a definite knowledge of regulatory requirements; in this way government can share the risk with private enterprise.

B.V: REVIEW OF ADVANCED SOLID WASTE PROCESSING TECHNOLOGY

David Gordon Wilson

(The following paper is reproduced as it appeared in the Proceedings of the A.I.ChE. Symposium on Solid Waste Management, June 4, 1974)

ABSTRACT

This paper briefly examines recent research into various alternatives for solid-waste processing - size reduction, compaction, incineration with and without heat recovery, and the production of fuels or secondary materials from wastes - from the viewpoint of the policy maker.

Some of these alternatives are traditional, such as incineration and separation for reclamation. However, changing economics and the changing character of solid wastes have made past methods largely unsuitable for present conditions. In some areas, detailed research has filled, or promises to fill, the apparent needs. In general, however, confirmation of the research findings into full-scale, long-term operation is still lacking.

In other areas, such as size reduction and heat recovery, sufficient research has been carried out to indicate desirable policies, and either the economics or the environmental impact have proved sufficiently advantageous for these alternatives to have been accepted quite recently as being better on a number of counts than their immediate alternatives. Despite this acceptance, problems have been encountered, and research needs to be carried out to give guidance to the policy maker. For instance, in both these areas (size reduction and heat recovery), equipment reliability has occasionally been low and maintenance costs have been high. The reasons for these situations should be identified and avoiding action recommended.

There remain a number of alternatives where the work which has been carried out so far is essentially of an advocacy nature. Some of the alternatives for the production of fuels from wastes are in this category. The policy maker may understandably be confused. On the one hand, claims for extremely favorable economics are made. On the other hand, these supposedly attractive possibilities are not being adopted. We shall endeavor to suggest the promising areas.

PAST REVIEWS OF PROCESSING ALTERNATIVES

The present paper is extracted from the report to N.S.F. of a team headed by Dr. David H. Marks of M.I.T. into recent policy-related research in solid-waste management. Earlier reviews of processing alternatives are available. The comprehensive studies of solid-waste management edited by Golueke and McGauhey[1,2] and the abstracts and excerpts from the literature[3] are excellent discussions of research underway in the late sixties. From the nature of the research team, the emphasis tends to be on biological processes, with less-thorough treatment given to the mechanical-, civil- and chemical-engineering aspects.

Current practice is discussed thoroughly in the American Public Works Association's "Municipal Refuse Disposal"[4]. A British handbook covering European practice is "Public Cleansing" by Flintoff and Millard.[5] Because European work has in the past been somewhat more advanced than U.S. practice, this last book has an up-to-date approach, and can quote operational experience from many areas.

Two more-recent reviews of solid-waste practice have been by Glysson,[6] beautifully illustrated and well presented, and Wilson,[7] involving members of the present team.

SIZE REDUCTION

Summary

Size reduction has become an accepted method of solid-waste processing. A wide variety of processing methods and manufacturers are available. There are few reliable data presently available to enable a policy maker to choose among the available methods and types of equipment. A fact-finding tour of existing users is recommended before selection of new plant.

When applied to solid-waste processing, size reduction implies that large pieces of solid waste are torn, sheared, cut, or fractured, to produce smaller pieces. Reduction in size by the application of pressure is not included in this general category, except insofar as glass-like materials will break into smaller pieces whether they are sheared or compacted. There are several synonyms for size reduction in solid-waste processing: comminution; crushing, pulverization; hammermilling; mastication; grinding; or shredding. All these terms are used more or less interchangeably. In addition, "rasping" is a method of size reduction which is reserved for slow-velocity abrasion and shearing; "chipping" is a high-velocity cutting process reserved for the size reduction of tree branches and other wood.

Size reduction has been available for solid-waste processing for many decades, particularly in Europe. Size reduction was regarded as desirable for bulky refuse such as furniture and "white goods" (ranges, refrigerators, washing machines and the like). However, size reduction was also used in Britain and Europe for regular household refuse because it enabled the comminuted refuse to be sold as a soil conditioner.[8] Shredding of solid wastes became widely practised with the development of composting processing, particularly in Europe after the second World War. Although composting has not generally been successful, the beneficial properties which size reduction gives to solid wastes became more generally recognized, and is now being frequently used as a preprocessing method for landfilling, encouraged by the changing character of municipal refuse. Refuse has changed from being predominantly ashes from coal fires to being principally newspapers, paper and plastic packaging materials, and bottles and cans. Size reduction reduces the overall volume of refuse, particularly with the application of a low compaction pressure after processing; size reduction is required for composting and stabilization; most newly developed methods of automatic sorting for reclamation require size reduction before various types of air classification are used; size reduction is needed before most pyrolysis processes: and some methods of incineration require prior size reduction.

In the last decade, size reduction by modern methods spread to this continent by way of Montreal. A commercial landfill was supplied from a transfer station where some reclamation was practised before the refuse was fed to Gondard hammermills (W. J. Johnson[9]). Johnson's report is excellent for the practical and financial details which are given. Some hand-picked separation and salvage was accomplished from the conveyor belt feeding the hammer mill. The milled refuse was trucked eleven miles to the company's own landfills. With Montreal wages and prices in the 1966-1970 period, cost averaged $2.12 per ton before salvage, and $1.57 per ton with credit for salvage. Subsequently, a demonstration size-reduction processing plant and landfill was started in Madison, Wisconsin, with the support of the Bureau of Solid-Waste Management of the Public Health Service.[10] This Madison work has been highly successful, and has been the catalyst for the surge in interest in and commitment to size reduction for U.S. solid waste. In the six years, 1968-1974, between 10 and 20 size-reduction processing plants, principally for landfill, have been commissioned or are being built in the United States.[11]

Recent research

An excellent review of alternative size-reduction methods and of some operational experience has been made by Patrick.[12] Very useful reports of tests of the characteristics of milled refuse in U.S. conditions have come from the Madison team.[13,14] Some of these are reviewed by Wilson.[7]

The advantages of size reduction for various purposes are offset to some extent by the high capital and running costs. The size reduction of solid wastes is not a process which can be regarded as trouble free, or which can be left to the operation of unskilled employees. Size-reduction equipment has considerable maintenance requirements. For instance, hammermills generally require that the impact edges of the hammers be retipped with hard-faced welding every 12 hours or so of operation. Stoppages are fairly frequent, particularly with equipment designed for low throughput. The higher the throughput, the larger is the required power level, so that with the largest hammermills currently in use, three-thousand-horsepower motors and large-inertia hammers and rotors give the potential of digesting a full-size automobile in 10 or 20 pounds and therefore the probability that such normally troublesome items as bedsprings, carpets, and coils of wire and rope will not cause a stoppage.

A study conducted at Battelle Memorial Institute[15] attempted to correlate costs of size-reduction equipment on the basis of the particle size of the product and the machine capacity in tons per hour. At the time of the study, insufficient hard data were available for close estimates to be given but trends were established. More recent work by Trezek[16] has had the aim of determining the minimum energy required to transform unified components into particles, with the aim of providing design data for new size-reduction equipment with lower maintenance costs. Many reports describing operating experience with recent size-reduction plants have recently been becoming available.[17, 18, 19] The National Center for Resource Recovery has conducted a study of the characteristics of the comminuted product of different types of equipment.[20]

This study is recommended for the careful documentation and analysis of all costs in connection with the NCRR proposal for a reclamation plant. Various size-reduction options and operations are reviewed. Costs of $2.00 per ton are anticipated.

COMPACTION AND BALING

Summary

Baling by high-pressure compaction is a viable process which can reduce the long-haul transportation costs of solid wastes and improve the properties of landfills. However, there is presently no known commercial baling operation which is profitable.

Review of past developments

The reduction of volume of solid wastes by the application of pressure has been a technique used at several stages of solid-waste handling and processing for many years. Refuse trucks have become generally fitted with compaction arrangements since the Second World War. In the same period, stationary compactors have been developed for use in apartment buildings, institutions, restaurants, hotels and commercial and industrial facilities. Domestic compactors have been introduced with considerable commercial success. All these applications of compaction use relatively low compaction pressures, generally below 50 pounds per square inch. Mean density produced by such pressures are generally less than 40 pounds per cubic foot or about 1,000 pounds per cubic yard.

Compaction for baling necessarily uses considerably higher pressures. At face pressures of the order of 1,000 pounds per square inch, typical municipal solid wastes begin to lock together when compacted so that the resulting bale can hold together without a container. Usually strapping is used as a safeguard.

The Japanese firm of Tezuka Kosan has probably received the most publicity for its compaction work.[21] Tezuka chose to experiment with a number of types of enclosure for its bales and to propose the use of the enclosed bales for various types of construction work. Bales have been enclosed in steel, concrete, and in chicken wire as a reinforcing for asphalt. However, since solid wastes contain a great deal of organic material which is not stable, such uses cannot in general rely on the mechanical properties of the bales. These uses therefore have not been found acceptable elsewhere.

The most detailed research into high-pressure compaction has been undertaken by Wolf and Sosnovsky [22,23] which is discussed below. The city of San Diego has also experimented with bales.[24]

The greatest volume of bales has probably been handled by Reclamation Systems Inc. of Cambridge, Ma., which installed two vertical Lombard presses, each of one-thousand-tons-per-day capacity, and which has been working at a low production level for the past three years.[25]

Baling research

The largest program of research into baling was sponsored by the American Public Works Association for the city of Chicago and the Bureau of Solid-Waste Management of the Public Health Service from 1967 to 1970.[22,23] The behavior of solid wastes during baling and the performance of the bales produced in subsequent handling were thoroughly investigated. Experiments were carried out with a scrap-metal baler having three rams producing bales 16 inches by 20 inches by a variable length. The face pressures were 94 psi for the first ram; 573 psi for the second ram; and up to 3,500 psi for the third ram. The comparatively small size of these bales would presumably make the results conservative, because solid waste has a characteristic size which is significant in these dimensions. It is possible, for instance, for a wad composed of a single newspaper to form a separation surface in a bale of this size, and the pressures required to penetrate this wad to form locking junctions would be very high. In a press having a cross section of 4 feet by 4 feet, as is used in the Reclamation Systems plant in Cambridge, Ma., components normally found in refuse would not be able to form such a separation surface.

In the APWA study, stable bales were found to be achieved at pressures of 2,000 psi and above, although sometimes a stable bale could be formed at pressures of 1,000 psi. No improvement was found at above 3,500 psi face pressure. These findings apply to reasonably dry refuse. When the refuse was sodden, as after exposure to rain, stable bales could not be formed. The limit of moisture content of paper for bale stability was found to be about 40 percent.

Refuse which had been previously comminuted (subjected to size reduction) was found to give good bales at lower pressures, but at over 1,500 psi face pressure, improvement due to precomminution was insignificant.

Baling was found to be especially beneficial for oversize wastes such as bedsprings, refrigerators, ranges and so forth.

After compaction, bales exhibit a spring back if they are not strapped. The increase in volume can go as high as 95 percent of the minimum, compacted, volume during the following 24 hours.

Bales were also shipped by rail for 700 miles and dropped from a height of 9 or 10 feet. It was found that bales compacted at pressures from 2,000 to 3,500 psi were stable under these rather extreme conditions. Bales made at 1,500 psi face pressure were stable but required some care in stacking. Bales which had been compacted two weeks seemed to be as stable as just-compacted bales.

The Wolf and Sosnovsky work is thorough, valuable for the wealth of data supplied and of generally high quality.

Needed research

Although some work was done in the APWA study on the decomposition of bales, showing that aerobic decomposition took place at least in the first two weeks of storage, the conditions of this investigation were not extensive enough for firm conclusions to be drawn for all circumstances. Reports from visitors to the Tezuka Kosan plant in Japan claimed that bales stored in the open had become a breeding place for flies. Newly made bales at Reclamation Systems in Cambridge are sprayed with an insecticide, showing that the possibility of fly breeding is at least recognized. Knowledge of decomposition processes in bales in various conditions is required.

The flammability characteristics of baled refuse needs further examination. It was formerly maintained that baled refuse would be unlikely to support combustion once the loose outer layers had burned off. However, the burning during a 24-hour period of between two- and four-thousand tons of baled refuse stored in the yards of Reclamation Systems showed that complete combustion is possible.

CONVENTIONAL INCINERATION

Summary

Conventional incineration is facing a difficult period in which stricter air-quality limits, higher standards for ash disposal, increased labor costs, and increased capital costs, are all putting the overall cost for incineration to very high levels. Despite the increased sophistication of present-day incinerators in the U.S., none is working in a wholly satisfactory manner. Research reports tend to be written from either an advocacy or antagonist viewpoint.

A widely recognized problem is the unreliability and high maintenance costs, often associated with the use of operators with a low level of training. Automatic operation of incineration would be highly desirable to eliminate the effects of the low skill level of most incinerator operators.

Two approaches which offer the possibility of a greatly increased degree of automatic control are suspension burning, which requires prior size reduction of refuse; and slagging operation, in which either the wastes or the products of combustion are melted. Both of these approaches have seen advances in the last few years, but neither appears to offer any prospect of a reduction of costs.

Present position of conventional incineration

The present position of conventional incineration was very competently reviewed by a study for the National Air-Pollution-Control Administration and summarized by Sarofim and Niessen[7]. Conventional non-slagging incineration uses temperatures from 1600F to 2000F. Typical refuse has an adiabatic flame temperature of just under 2000F with 100 percent excess air. Combustion is relatively easy to control with this large a proportion of excess air. However, the size of air-cleaning equipment has to be increased as the amount of air added increases.

Slagging operation requires furnace temperatures of around 3000F. This temperature is reached by typical refuse with zero excess air for combustion. In practice, an attempt to operate with zero excess air would mean that many parts of the refuse would not in fact burn. Slagging incinerators require one or more of the three following steps to bring about higher temperatures with the use of reasonable quantities of excess air.

1. Supplementary fuel
2. Use of enriched air or pure oxygen
3. Preheating of the combustion air

All three approaches have been tried. None can yet be said to have achieved complete success, although pilot plants have operated for significant periods. Slagging operation requires special, and expensive, furnace linings, none of which appear yet to have proved themselves in extended service. However, the Dravo incinerator at Wolfsburg, Germany, (using heat regeneration to the combustion air) has operated for at least two years.

Fluidized-bed incineration

A pilot study of the incineration of municipal refuse in a fluidized bed has been reported at West Virginia University.

A fluidized-bed combuster for comminuted solid wastes has also been developed by the Combustion Power Company in California as part of its contract with the Environmental Protection Agency for the development of a gas turbine to produce power from the burning of refuse.[26] This gives good data about the combustion of fluidized refuse.

In a fluidized bed, combustion air is fed from beneath a perforated plate through a bed of, typically, sand, which at above a certain fluidizing velocity becomes airborne and behaves somewhat like a liquid with a definite liquid-like surface. When this bed is preheated, for instance by the combustion of methanol, or natural gas, to perhaps 1200F, and subsequently small pieces of combustible material are fed into the bed, combustion takes place within the bed and the sand particles cause very high heat-transfer rates to the newly arriving solids.

The absence of hot spots leads to low emissions of oxides of nitrogen, which is a positive feature. A very good burnout is usually achieved up to the maximum loading for the bed.

On the negative side, fluidized-bed incineration is a relatively large user of energy because of the need for size reduction and the requirement that the combustion air, and in addition a small quantity of fuel-feed air, be pressurized. Presently anticipated costs per ton are higher than for alternative forms of incineration.

Air-pollution-control equipment

Until the early 1970's, the main requirement for the stack-gas-cleaning equipment of incinerators was to remove the particles and the visible smoke. As a result of the Clean Air Act of 1967-1970 there has been movement towards restriction of other emission besides particulates, such as carbon monoxide, nitrogen oxides, hydrocarbons, and hydrogen chloride. Some of these are removed in a so-called wet-bottom gas-quenching system. Water in excess of that required to cool the gases is sprayed from coarse nozzles in the flue and in contacting the gases absorb nitrogen chloride, sulphur oxides, organic acids, and some particulates.[7]

Gas quenching with water in this way reduces the volume of gas to be treated by subsequent particulate-removal methods. The two methods which can be used to reach the low particulate loading allowed by present codes are electrostatic precipitators and bag-house filters. Most new incinerators in recent years have been fitted with electrostatic precipitators, but there are signs of a movement towards bag houses or other types of fabric filter because of problems which have occurred with electrostatic precipitators and because of the higher collection efficiencies which are reached by fabric filters at particle sizes of the order of one micron. The Niessen and Sarofim report is a good guide to recent work in this area.[7]

Boettner et al[27] gave a good review of the combustion products which are to be expected from the combustion of the principal plastic polymers. They point out that toxic products can be released by the incomplete combustion even of pure hydrocarbon plastics such as polyethylene. Complete combustion of hydrocarbon plastics causes no environmental damage, producing only carbon dioxide and water (and heat), but the halogen-containing plastics, such as the vinyl chlorides, produce hydrochloric acid even when completely burned. Other plastics are discussed, but it is emphasized that even a cursory review of all the thousands of variations on the principal formulations would be presently impossible. It appears, therefore, that we must rely on the public-spiritedness of the manufacturers of synthetic materials not to produce substances which might, in certain circumstances, result in dangerous conditions being produced during incineration.

The deaths which have reportedly resulted from smoldering furniture containing urethane-foam padding represent a clear danger signal to incinerator operators.

INCINERATION WITH HEAT RECOVERY

Summary

To use the heat generated in incineration of solid wastes would seem to be an obvious conservation measure which would lead to cash savings. However, the history of heat-recovery incinerators in the United States has, at least until the 1973 energy crisis, been marked by general failures to produce the expected results.

Introduction

Heat-recovery incinerators have been designed to raise steam. Some of this steam has been used for in-plant use, such as running auxiliary turbines or feed-water desalination plants as at Oceanside, Long Island.[28] The Oceanside plant was among those plagued by tube-corrosion problems, mentioned below. When attempts have been made to sell the steam, the market has been found to be resistant because the quality of the steam (the temperature and the pressure) is generally lower than is desired for process applications and sometimes higher than is needed for heating applications; and the supply is uncertain. Accordingly, standby equipment is always necessary, and therefore the only credit that can be taken for this steam supply is the possible saving of fuel.[7] With low fuel prices, this saving has seldom paid the extra costs of the double connection for standby equipment. With increasing fuel costs and a decreased supply of energy the prospects for future heat utilization from incineration are much brighter. Niessen and Sarofim give a very good discussion of the costs and operating factors of various types of incinerators.[7]

Alternative methods of construction

Heat can be recovered from the combustion products of an incinerator either by having the combustion take place in a conventional, well-insulated combustion chamber (lined with fire-brick material) and leading the gases past convection steam generators; or the combustion chamber can be lined with steel tubes, probably welded together to form a so-called "water-wall" construction. Over the past decade the practice in Europe and in North America has been predominantly to go to water-wall construction. The European units, in Rotterdam, Munich, Paris and Amsterdam, supply steam to power stations (or, as in Paris, the incinerator might actually be part of a power station).[29] In this country, this type of operation has recently been experimented with in St. Louis under a federal grant, and is described in the next sections.

Steam-raising incinerators have suffered tube failures in this country and in Europe. At least a contributory factor has been the condensation of hydrochloric acid, formed from the combustion of polyvinyl chlorides. It is not clear at the time of writing that this problem had been completely solved. It has been claimed that a close control of gas-side and water-side temperatures will avoid condensation in critical areas. But controls are a principal need and a remaining problem area for incineration, as mentioned above.

SOLID WASTE AS A SUPPLEMENTARY FUEL

Summary

If refuse is subjected to some degree of separation of noncombustibles and is reduced in size, it can be burned in suspension in a common combustion chamber with other solid fuels.

Introduction

It was mentioned above that the unreliability of supply of solid wastes and their varying combustion characteristics would normally require that standby equipment be used when heat recovered during incineration is used for some purpose external to the incinerator. This applies particularly to refuse when it is burned in the as-received condition. In electricity-generation plants in Germany, two separate water-wall combustion chambers, one for refuse and one for conventional fuel, discharge their gases to common superheaters, economizers, air-pollution-control system, and stack.[7] A slightly different system proposed by Pacific Gas and Electric Company in San Francisco was to have two separate furnaces, with the steam from the refuse furnace delivered to superheaters in an adjoining conventional utility boiler. This necessity for duplication of capital plant reduces the attractiveness of incineration heat recovery.

Suspension burning

At the Meramec station of Union Electric in St. Louis, refuse which has been reduced in size to a maximum of two inches and air classified to remove most of the inorganic fraction is burned in suspension in a modified combustion chamber with a small grate to burn out any chunks which form or pass through the system.[30,31] Conventional pulverized-coal burners supply most of the energy (90%) in the same combustion chambers. In this approach the additional capital cost required to convert an existing utility boiler to one burning refuse is small, and the risk to disruption of the normal boiler operation, which is normally an overriding concern, is also small.

Operating problems in St. Louis have been principally the erosion of the pulverized-fuel supply tubes. The basic plant operation and control with combined firing has been quite successful.

This method of burning the air-classified light fraction of municipal refuse would seem to be one with wide applications

As preliminary to the St. Louis experiment, Hornerand Shifrin, Inc. carried out a detailed study of the use of solid waste in coal-fired utility boilers.[32] They concluded that problems should be minimal if refuse is comminuted to a size of about one inch, and if the refuse constitutes no more than ten percent of the heat input. The value of the refuse as fuel was stated to be $2.50 to $4.00 per ton (1972 price levels) so that the process should be attractive. The capacity of suspension-fired boilers is much more than enough to take all U.S. municipal solid waste generated even at the recommended low proportion of firing. No deterioration in ambient air quality, and even an improvement in some areas, was foreseen.

These predictions seem to be borne out by the progress so far of the St. Louis experiments. However, a final report of the economics and of any operational difficulties has not yet been seen.

CONVERSION OF SOLID WASTES INTO A STORABLE TRANSPORTABLE FUEL

Summary

Conversion of the energy of solid waste into a fuel (rather than directly into heat) seems to offer considerable promise. There are several alternative approaches under active investigation. At the present time, none seems to face insuperable technical difficulties. On the other hand, none has yet been developed to the point where major use in commercial markets has been found.

The following sections describe the principal alternative approaches.

Air-classified light fraction as bulk fuel

As was described above, when solid waste is comminuted and subjected to air classification, most of the inorganic materials remain with the heavier fraction, and the organic, or combustible, components are found with the light fraction.

The average fuel composition of the air-classified light fraction, on a dry-weight basis, is about 30 percent ash, 35 percent carbon, and less than 0.25 percent sulphur; and it has a heating value of about 6,000 Btu per lbm. Its heating value is therefore higher than that of wood and peat; about equal to lignite; and lower than that of hard coal. Although the heat content by volume is, under conditions of little or no compression, lower than that for coal, the material is sufficiently dense for transfer trailers serving refuse shredders to be weight-limited rather than volume-limited. In other words, increased density would not bring large savings in highway transportation.

The burning behavior of the air-classified light fraction has been studied for suspension burning both with and without auxiliary fuel, as in the St. Louis power plant and the Combustion Power Co. tests mentioned above. However, the burning characteristics in grate-type combustion chambers is not known. The National Center for Resource Recovery is proposing experimental work in this area. The large quantity of ash produced is a disadvantage of using this fuel in comparison with oil and gas in particular. Nevertheless, with the end of the cheap-fuel era there are likely to be abundant applications for this lower-cost energy source.

The air-classified light fraction may also be compressed into cubes and used as a solid fuel. The National Research Corporation of Fort Wayne, Indiana has produced cubes of one-and-a-half inches approximately which has been successfully burned experimentally in solid-fuel boilers.[33] This approach has obvious attraction: it should be considered in any evaluation of alternatives for reclamation.

Fuel-gas production from solid wastes

When organic materials are allowed to decompose anaerobically (digestion), carbon dioxide and methane are produced in approximately equal volumes. The theoretical quantities are that one pound of convertible waste yields 6.65 cubic feet of methane, and a like volume of carbon dioxide, at standard conditions of temperature and pressure.

Research on the anaerobic digestion of solid wastes to produce methane has been carried out at the Universities of California and Illinois[34,35] and, more recently, at Dynatech Corporation in Cambridge, Ma.[36]

In a digestion process, initial separation of the inorganic fraction is required. The organic fraction is slurried with water, and nutrients are added. Raw refuse sludge may be used as a nutrient, thus saving the costs of purchased nutrients and of sludge disposal.

The digestors proposed by Dynatech[36] consist of large circular tanks with floating covers. The contents must be stirred continuously. The aqueous feed stream to the digestors has to be heated to about 95-100F.

The products from the digestors are the gases, which must be scrubbed to remove the carbon dioxide: waste water, which must be returned to a sewage-treatment plant; and a dewatered cake, which can be incinerated for landfill. (There is also the possibility that this cake could be composted for use as a dry fuel:see below).

Dynatech's estimates of the cost of production of methane by the anaerobic process are $1 per million Btu, if the credit for the treatment of solid wastes is $10.65 a ton. Competitive fuel costs are approaching this figure.

The University of Illinois reports[34,35] give valuable details of experimental data. [redacted] Methane-production costs of less than 25% of Dynatech's figures are predicted, [redacted]. *

Compost fuel

Solid wastes, sewage sludge, cattle-feed-lot wastes, agricultural and food-canning wastes may all be stabilized by composting. Compost is normally considered to have one use: as a soil conditioner. The material may also be used as a fuel.

This use for compost has been pioneered by Cobey Environmental Controls Company in a test program with the Department of Agriculture at Beltsville, Maryland and the General Motors Corporation, which produces the Cobey-Terex mobile composter.[37] This device can be driven to straddle a long pile of refuse, shredding, aerating, and turning it as it goes. The heat produced by aerobic action and the drying effect of the wind combine to produce a stabilized storable product, compost, which can be used as a soil conditioner or as a fuel. Its calorific value is about 5,000 Btu per pound, approximately equal to that of lignite. This material has been proposed particularly for agricultural purposes, such as crop drying. It is rather similar to the air-classified light fraction discussed above in that it has similar heat content, density, and ash content, and has not been fully evaluated as a potential fuel to be used on various grates.

Pyrolysis

When organic materials are heated in the total or partial absence of oxygen, they break down into combinations of gases, liquids, tars, and solids (ash). The relative proportions of these various constituents change as the temperature is varied between 500F and 1500F, with gas production increasing and liquid production decreasing as the temperature increases. Comminution to two- to four-inches maximum size, and separation out of the inorganic fraction, is required for all processes except for that developed by Union Carbide.[38] The wastes are introduced into a chamber (reactor) and either hot inert gas under pressure, or a fluid bed such as sand, is introduced to heat the wastes. The process is either run on a batch basis, in which case the reactor has to be periodically filled and emptied, or on a continuous basis with approximately steady-flow conditions prevailing throughout the system.

Pyrolysis has the very large advantage that, in comparison with incineration, there are no gases or liquid products which have to be treated before discharge to the environment. The solids which remain after pyrolysis are inert and can be landfilled without more than the usual precautions being necessary against leaching.

The liquid fuel produced from pyrolysis has an average heating value of about 12,000 Btu per lbm; the low-sulphur char has a heating value of about 9,000 Btu per lbm. A high-heating-value gas, 600 Btu per cu. ft., can also be produced. At least one of these streams is normally required as a heat input to the process.

Research and development into pyrolysis is being actively pursued by the Bureau of Mines,[39] by Garrett Research[40], by Monsanto Envirochem,[33] Pan American Resources,[41] Union Carbide,[38] the Universities of West Virginia,[42] Oklahoma and California.[43]

The early work by Pan American Resources culminated in the installation of continuous-operating "Lantz" convertor at a Ford Motor Co. plant in the late sixties. It was not economically successful and was taken out of service.

This failure was of particular significance because of the extremely favorable predictions which were made for pyrolysis costs and income in Pan American Resources proposals.[44] Economic predictions for present pyrolysis processes are almost equally favorable, indicating frequently a very low per-ton cost or even a net income. While

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* Deletions in author's original.

it is easy to identify costs which have not been considered, or the assumption of low interest rates and a tax-free status, for instance, a large proportion of the costs and income must simply be considered to be conjecture until a full-scale plant is operated.

Garrett Research has been operating a pilot pyrolysis plant of four tons per day, and is building a 150-ton-per-day demonstration plant in San Diego county, California. This plant will yield very valuable cost and operating data.

An approach to pyrolysis which avoids the expensive shredding process and some of the costs of transferring heat to the refuse in the externally heated systems is to confine solid waste with oxygen sufficient to burn some of the refuse and to produce melting temperatures; the remainder of the refuse is pyrolyzed; the steam and methane undergo a shift reaction to produce carbon monoxide and hydrogen.[38] This approach has been pioneered by Union Carbide which has a pilot plant operating at its plant in Tarrytown, New York. The slagging of the solids reduces the volume and the handling difficulty very greatly and produces a glass-like frit similar to that from the slagging incinerators. The system is potentially favorable and should be considered a serious contender in areas where disposal costs are high and where a market for high-Btu gas exists.

Production of ethyl alcohol by hydrolysis

The hydrolysis of the organic constituents of refuse to produce fermentable sugars and subsequently alcohol has been vigorously proposed by Andrew Porteous[45] In this process, wastes are to be comminuted and separated by, for instance, air classification. The organic fraction is pulped in water and fed to a reactor where sulfuric acid is added, and the mixture is heated to 230C. Maximum conversion to fermentable sugars is reckoned to take only a few minutes. Subsequently the mixture is cooled, neutralized with calcium carbonate and fermented for about 24 hours at 40C. An aqueous ethyl-alcohol solution is produced which can be distilled or rectified to give 95% ethanol. A high-BOD waste liquid stream is discharged and requires treatment.

With a refuse feed of 40-per-cent paper content and a treatment credit of only $3 per ton, Porteous predicts that this process would be profitable. No experimental work appears to be in progress on this approach, however.

An alternative approach to acid hydrolysis for the production of sugars from cellulose is enzymatic hydrolysis. The prospects for this process have been advanced by the research at the U.S. Army Natick Laboratories into mutants of enzymes which were found to attack clothing.[46] Enzymatic hydrolysis is slower than acid hydrolysis but has advantages in that the process is carried out at normal temperatures and pressures in reactors which can be made from less-expensive materials than the acid-resistant materials needed for acid hydrolysis. In addition, the byproducts, for instance the lignin, are in a relatively pure form and can be used for other processes or could be pyrolyzed, for instance.

The enzymes developed at Natick have been supplied to other laboratories, among them those at the University of California.

Careful experimental work in addition to some design studies are reported by Golueke.[1,2] Economic predictions under the conditions assumed were not highly favorable. However, as the authors stated, there were many unknowns which could change in favor of the process. One of these is the cost of energy. Under present conditions it is possible that biological fractionation would be an attractive process. How it would compare with the Porteous process seems to depend entirely on two sets of uncertain predictions for capital and operational costs, which in turn depend on predictions of rate processes occurring in large batches. Evaluation would seem to have to wait on demonstration-plant operation.

General survey

Freeman[45] gives voluminous and useful data on various alternatives for using the energy in solid wastes. The information is, however, limited. For instance, pyrolysis is treated as one process. He evaluates a process requiring very fine shredding. The economics of many processes evaluated can appear to be less favorable than may be the case for unconsidered variations.

SEPARATION PROCESSES

Summary

Reclamation by separation from solid wastes is likely to be economically viable if carried out in an area where the credit for solid-waste processing can be $8.00 per ton or more and where at least 500 tons per day can be processed for several years. In these circumstances, secondary-materials industries are likely to locate near a reclamation plant to take the products.

Introduction

Separation of solid wastes into more-or-less pure components is carried out in the belief that most of the individual waste components can find markets, or can at least be disposed of at very low costs, if these components are produced in fractions of sufficient purity. The markets for separated materials are discussed below. The technology for separation has to be aimed at producing the highest possible purity, or the least contaminants, because the per-ton prices obtainable for most secondary materials drop extremely rapidly with small mixtures of contaminants. For instance, steel with .02 percent copper is almost unsaleable; newspaper with plastic cups, asphaltic glues, or waxed cartons, for instance, is presently unsaleable, except possibly as a fuel. Even unadulterated glass can double its value if separated into primary colors.

Separation technology has followed three main approaches. The most popular approach is primary size reduction followed by air classification and subsequent processing of the light and heavy fractions. A second approach is to pulp the incoming solid waste in water and to carry out separation processes on the slurry so produced. A third approach is to separate the solid wastes insofar as possible in the as-received condition. These approaches are briefly reviewed below.

Methods based on air classification

Methods based on air classification can be described with reference to the proposals by the National Center for Resource Recovery[20] and the Bureau of Mines.[47] Both these are thorough proposals based on carefully obtained data and are recommended for consideration. Solid wastes are comminuted and fed to an air classifier. The light organic fraction is fed to a landfill, or an incinerator, or can be processed by any of the methods described above into a storable fuel, or may be sorted into plastic and paper fractions by a promising electrodynamic technique.[48] The ferrous component of the heavy fraction is magnetically separated, and the remainder is sorted by size. The smaller pieces tend to be glass, which can be fed to optical sorting machines produced by the Sortex Company to produce single-color, higher-value fractions. The larger pieces of the nonmagnetic heavy fraction tend to be nonferrous metals, which are sorted by heavy-media separators. Water elutriation is suggested by the Bureau of Mines to separate aluminum from the heavy organic fraction.

This approach is typical of a branched binary system,[7] in which a relatively large number of sorting devices are strung together, each device separating the flow into two streams. There are many choices to be made for the individual devices. None seems to be presently capable of yielding a high-purity product, although the contamination of most streams is sufficiently low for the products to be saleable. There are many directions being pursued to provide improved separation systems for various streams. A team at Vanderbilt University has developed apparently effective eddy-current separators for glass and nonferrous metals.[49] Avco Corporation and others are developing ferrofluids (suspensions of iron particles in kerosine, for instance, which vary in apparent density in strong magnetic fields) as alternatives to heavy-media separators.[50] Another alternative to heavy-media separators are fluidized beds,[51] which have been developed effectively at the Warren Spring Laboratory in Britain.

The National Center for Resource Recovery estimates that the breakeven credit for treating solid wastes with this type of system is about \$7.50 per ton, (1973 dollars) in a typical urban area. Presumably this figure, already below the cost of new incineration plants, will fall as the credits for materials and energy increase (assuming continued increases in raw-material prices) and as better separation systems become available.

The research studies by the NCRR and the Bureau of Mines are of high quality and have been backed up with detailed analyses of, and experiments with, refuse pulverized and air classified by various means. The initial cost of such a plant should be relatively small. The potential revenues are not high but are predicted as being sufficient to lower the overall costs of refuse treatment in many areas. The Bureau of Mines work is not as firmly developed, and the economic predictions may tend to be optimistic.

Water-based systems

The first automated central-station solid-waste separation plant is a water-based system at Franklin, Ohio using the Black-Clawson paper-making Hydrapulper as the fundamental treatment unit.[52] Wastes are fed to this pulper without pretreatment, and a variety of screens and cyclones, and a magnet, are used for separation of the useable fibers, the ferrous metals, and the nonferrous metals and glass. The nonferrous metals and glass are sorted optically and magnetically by a multi-branch binary system developed by the Sortex Company.

The proportion of solid wastes reclaimed was initially about 15 percent (into useable fibers) and is increasing to 30 percent as the glass- and metal-recovery sections come on stream. Most of the remaining portion is incinerated.

The cost of this first plant was comparable to that of an incinerator. The operating cost is apparently somewhat less than would be the case for an incinerator (ie, of the order of \$8 per ton). The figures are somewhat difficult to analyze because of the EPA demonstration grant and prior grants used for the development of the process. Presumably future larger plants with improved equipment would show favorable economics. Black Clawson has proposed a commercially financed plant for Hempstead, L.I., with, however, slightly higher operating costs being predicted.[53]

The Black Clawson system has been proved workable in the field. The economics in initial operation have not been as favorable as forecast, but continued development will lead to steadily improving figures. Because of the downgrading of the fibers, the revenues are unlikely to be as high as for an optimum dry-separation process.

Another system based on water separation is the John F. Tracy separation system, in which the key element is a water trough of the order of 60-feet long and 15-feet wide and 10-feet deep for a one-thousand-ton-per-day plant.[54] Wastes are dumped on an apron, where the larger bundles of paper and cardboard are removed manually. Oversized items such as automotive tires and white goods (refrigerators and so forth) can also be removed at this stage. The remainder is pushed into the tank and agitated, and the sink portion, almost entirely of inorganics, is removed by a drag conveyor onto a belt for magnetic separation of ferrous materials and for hand picking of the larger nonferrous fraction. The floating portion is chopped, pulped, screened, and digested.

The simplicity of this system has much to commend it. It is labor-intensive for high-value components and capital-intensive for the bulk, low-value components. Costs of about \$9.00 per ton are predicted for treatment with an allowance for salvage income.

Raw-refuse separation

Traditional reclamation plants separated solid wastes in the as-received condition. The wastes were loaded in some manner onto a so-called "picking" conveyor belt, which in most plants was arranged to take the wastes up an incline to a second-floor level. People would be positioned by hoppers next to the belt, and each person would have responsibility for extracting from the flow of refuse passing by a particular class of large,saleable items. One person would remove newspaper, a second cardboard, a third glass and a fourth nonferrous metals.

This type of operation is still carried out in Europe and was the basis of plants run by Lone Star Organics in Houston[55] and by Sanitary Refuse Collectors in Montreal[9] until about 1971. It was shown by Darnay and Franklin[56] that at present secondary-material prices and wage rates such plants could no longer be economically viable.

An attempt to automate a plant of this type has been made at M.I.T.[57] under an EPA grant. The principal features of the M.I.T. approach are that the larger pieces of refuse are first sorted out for treatment on an item-by-item basis; these larger items are examined by a number of sensors in series; a decision is made by a minicomputer as to which among perhaps 25 categories the large items should be switched; and subsequently switching is accomplished by means of bottom-opening carts which pass over a series of hoppers feeding balers.

Separation of the large items is accomplished by means of a two-deck vibrating screen of perhaps eight-inch- and four-inch-mesh sizes. Loose paper and plastic film is sucked off by an overhead fan operating on the inside of an open-mesh belt. Separation of this stream into paper and plastic may be accomplished by means of the electrostatic process developed by the Bureau of Mines[48]. A magnet removes ferrous materials. The fines passing through the vibrating screens join the large items which are rejected as inhomogeneous by the sensing system and are passed to a small hammermill for further size reduction and size classification. Subsequently the small items are to be classified in a multi-stream vortex classifier.

This development is not at the proof-of-concept stage at which it could be immediately developed by manufacturers. This might be the case in 1975. The economics look favorable because of the absence of the need to comminute the entire input stream; the small energy requirements per ton; and the potentially high purity of the output streams. This type of plant also has the advantage that the materials being separated, or the purity of the materials, can be changed from day to day as market conditions fluctuate.

Markets for separated materials

Both the immediate and long-term future for the sale of secondary materials look very promising. There are several reasons for this.

1. Increasing population and increasing standards of living are continuing to push up consumption rates in most materials.
2. Shortages in some materials are making policy makers believe that predicted shortages in other materials might in fact occur. Accordingly, there is a move to anticipate the problems by beginning to incorporate secondary materials wherever possible.
3. The environmental movement of the last decade has lead to a large number of developments of uses for secondary materials, some of which are beginning to appear in the market place.
4. The energy costs of secondary materials are usually lower than those of primary materials, so that there is an economic incentive to use secondary materials.

The market for separated materials depends on geographical location, and the quantity which can be sold on a steady, week-by-week basis. The market traditionally varies greatly in capacity from year to year and even from week to week. This situation has prevented investment in recycling plants in the past. The market is likely to improve in the future for the reasons given above. In addition, once some large-scale recycling plants producing high-quality (or at least, known-quality) product streams in large volume with high reliability are established, industries will begin to rely on these sources of supply and the market fluctuations will diminish.

Two excellent reviews of the secondary-materials market are that by the National Center for Resource Recovery[56] and by Darnay and Franklin.[56] Much other valuable information about alternative reclamation processes is given in the NCRR report, and useful data showing the effect of labor rates on hand-picking methods, for instance, are presented by Darney and Franklin.[56]

OTHER PROCESSES

Composting

The food and plant wastes and paper products in solid wastes can be broken down into a humus-like product when acted upon by air-loving microorganisms in a controlled environment. There must be: sufficient humidity; sufficient thermal insulation to conserve the heat given off so that the temperature in the composting mass may rise to the 140F - 170F range; sufficient air in all parts of the mass; and sufficient nitrogen in a form which can be taken up by the microorganisms. Sewage sludge may be added to provide the humidity and the nutrients. Modern compost plants differ from one another in the manner in which the air is either added by blowers or allowed to permeate by natural diffusion.

The first composting system was, and is, to chop the wastes and to pile it into "windrows". These rows must be turned over every few days to ensure that the central parts do not become taken over by anaerobic bacteria (which work at low temperature, therefore they do not kill pathogenic organisms, and are foul smelling) and that the outer parts of the piles are occasionally subjected to high temperatures. Such a system requires a great deal of land area.

Mechanical composting systems are attempts to reduce the plant area required by accelerating the process in more closely controlled conditions than is possible in windrows and possibly by carrying out the process over a height on a number of levels.

In either case, the production of compost requires a considerable capital investment. The cost of producing compost in the two U.S. plants still operating, in Altoona, Pennsylvania[59] and Brooklyn, N.Y.[60] ranges from $10 to $30 per ton. With the credits received for treating refuse the compost can be sold for between $5 and $20 per ton (bulk and packaged prices) in Altoona and $18 per ton in Brooklyn.[58] The market potential for a low-value material such as compost selling at these prices is small.

Composting has vigorous advocates and equally vigorous detractors, a situation leading to the possibility of confusion in policy makers.

Leaders in composting research are Golueke and his co-workers at the University of California.[61]

An independent review of composting is given by Lodman[7]. A somewhat negative, but not necessarily biased, survey is made by the National Center for Resource Recovery[58] in its excellent review of the reclamation field.

In summary, composting as a process for municipal wastes is feasibly operationally but has proven uneconomical in all but two of the approximately twenty plants started in the U.S. in the last two decades.

The prospects for composting may improve as fuel costs increase and with them the costs of fertilizers. (However, the production and distribution of compost from central plants use a certain amount of fuel). A boost would be given to composting also by a research finding that humus or compost-like materials are a necessary addition to productive soils over the long term. Occasional findings of this nature have not received widespread support or confirmation. So long as farmers and gardeners feel that they can achieve satisfactory results from the use of low-cost synthetic fertilizers the market for compost will remain small.

Protein production

The hydrolysis process described earlier yields fermentable sugars, and these may be used for a wide variety of products besides the alcohol production suggested previously. One use is as a feed for the growth of Torula yeast, which presently is used as a poultry-food supplement. Uses of this type have been investigated by the Forest Products Laboratory[62] and reviewed by the NCRR[59] which concluded that at late 1972 prices the process would be marginally uneconomic. With rapidly increasing prices for protein supplements, this process may become economically viable.

Wet oxidation

The contacting of organic wastes with air or oxygen under high pressures (500 to 1000 psi) and moderate temperatures (300 - 350F) causes breakdown into carbon dioxide, organic acids, water and a low-volume residue. Wet oxidation has been used to sterilize and stabilize sewage sludge, but its relatively high cost (Golueke reports $49 - $60 per ton)[1] is causing it to be phased out. However, as Golueke reports, organic acids have not been recovered and sold, and estimates for the value of these products range up to $90 per ton of incoming waste. He considers it vital to extend laboratory-scale experimental work to pilot-plant levels so that closer estimates of performance can be made.

ACKNOWLEDGEMENTS

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B. VI: UNION CARBIDE'S PUROX PROCESS

Daniel M. Gillies

(A 200 ton per day PUROX System is currently under test in Union Carbide's facility at South Charleston, West Virginia. Results are highly encouraging. The material presented below is based directly on a PUROX brochure issued about two years ago. Additional data, including up-to-date information on progress, can be obtained from Mr. Richard S. Paul, Environmental Systems Department, Union Carbide Corporation, 270 Park Avenue, New York, New York 10017.)

INTRODUCTION

The solid waste explosion has become a matter of imperative concern to environmentalists, legislators, and the public at large. More than 500,000 tons of mixed municipal refuse are generated in the United States every day. The disposal problems created by this avalanche of trash are becoming daily more serious:

- the volume of refuse is growing constantly as a result of increasing population concentrations in urban areas and the wider use of non-returnable containers and convenience packaging, and
- land required for disposal by present methods is becoming more scarce and costly even when these methods are environmentally acceptable.

Furthermore, recovery of the valuable resources contained in mixed municipal refuse is now recognized as a desirable economic and environmental objective.

The traditional, and cheapest, method of handling this refuse has been the municipal open dump--where unprocessed garbage produced severe problems of ground water pollution through leaching, loss of land value, fire dangers, and rodent infestation. A more acceptable sanitary landfill method reduces these threats to the environment by composting and covering the garbage with dirt. However, this practice is also being greatly restricted as acceptable sites, if available at all, must be located further and further from population centers.

Both of these methods may be supplemented by incinerating the waste before land filling. Conventional incineration provides significant volume reduction and some alleviation of the pollution caused by leaching at landfill sites but introduces new environmental and economic problems:

- with incineration, air pollution standards cannot be met without extremely costly stack gas cleaning systems;
- while volume reductions of 80 to 90 percent are possible, the residue is not biologically inactive and landfilling is still required; and
- resource recovery is minimal.

Faced with the high costs of environmentally acceptable incineration and the increasing scarcity of sites available for landfill, many local, regional, and state governments are in need of advanced disposal systems. To satisfy these needs, such a system must be:

- economically attractive,
- environmentally sound,
- capable of realistic resource recovery, and
- suitable for long-term operation.

These requirements are met by the PUROX System (covered by U.S. Patent No. 3,729,298 and corresponding foreign patents) developed by Union Carbide Corporation in response to the need for advanced solutions to the problems of solid waste disposal and resource recovery.

THE PUROX SYSTEM

The Union Carbide PUROX System utilizes oxygen, instead of air, to produce high-temperature incineration and pyrolysis of all types of refuse. The only products formed are a compact, sterile residue and a fuel gas valuable as a clean-burning source of energy.

"PUROX" System

Fuel Gas Composition

Constituents	Volume (%)
CO	47
H_2	33
CO_2	14
CH_4	4
C_2H_x	1
N_2	1
	100

Fuel Gas Quantity 7 Million BTU/ton Refuse

In summary, the key advantages of the PUROX System are as follows:

- production of a clean burning fuel gas and a sterile, compact solid residue;
- elimination of pollutant emissions to the atmosphere;
- flexibility to handle all forms and types of refuse; and
- economically attractive installation and operating costs.

Union Carbide has been able to achieve this unique combination of desirable features because of its broad experience in all of the complementary technologies required for such a system. These include: oxygen production methods and applications, high-temperature combustion and pyrolysis processes, furnace design and operation, hydrocarbon and fuel gas treatment, and abatement techniques for control of pollution from gaseous, liquid, and solid industrial wastes.

DESCRIPTION OF THE PUROX SYSTEM

Figure VI.1 is a schematic drawing of the basic PUROX System. The key element is the vertical shaft furnace into which refuse is fed through a charging lock at the top. Oxygen is injected into the combustion zone at the bottom of the furnace where it reacts with carbon char residue from the pyrolysis zone. The temperature generated in the hearth is sufficiently high to melt and fuse all noncombustible materials. The molten material continuously overflows from the hearth into a water quench tank where it forms a hard, sterile, granular product.

The hot gases formed by the reaction of oxygen and carbon char rise through the descending waste. In the middle portion of the

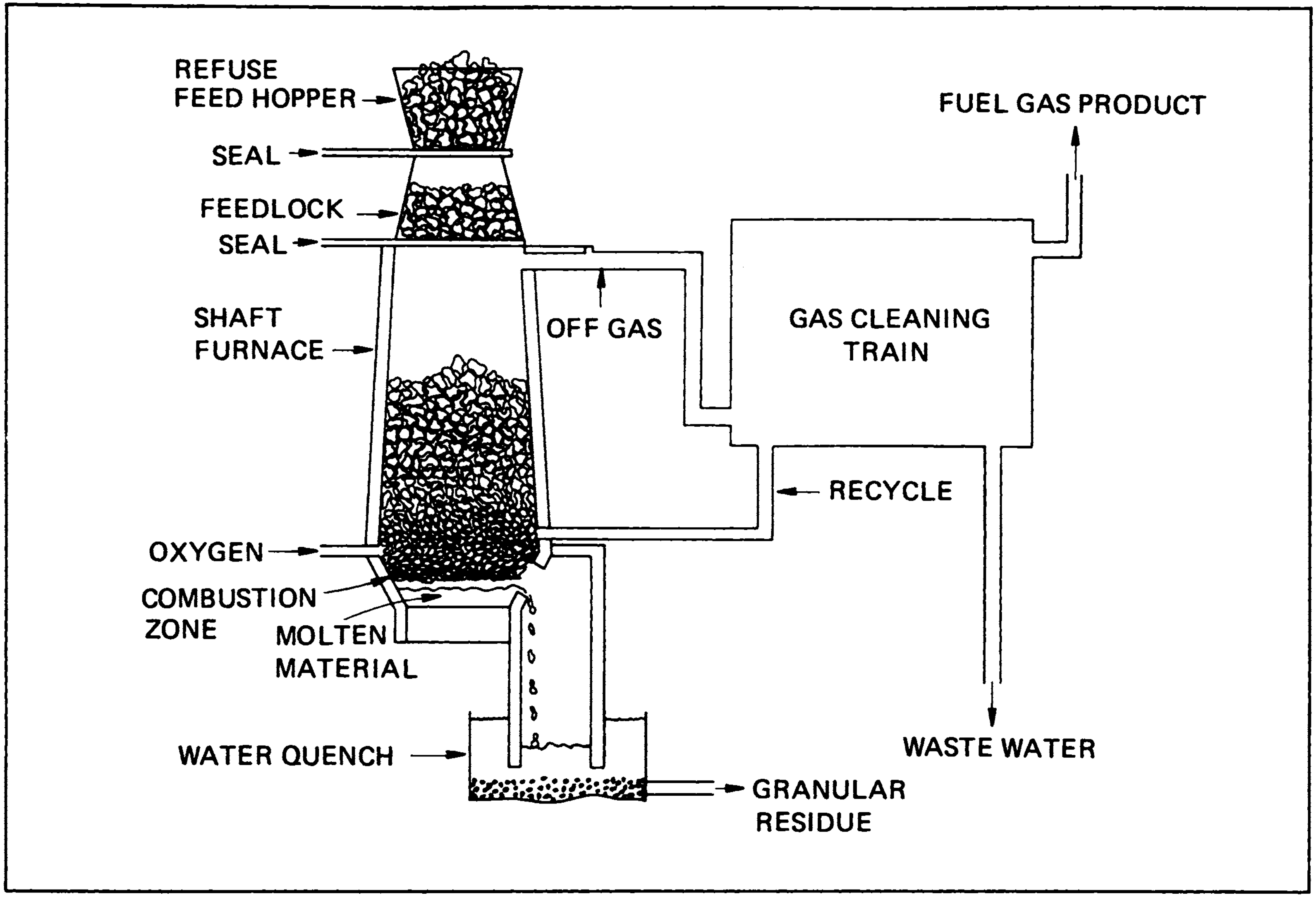

Figure VI.1 Oxygen Refuse Converter

vertical shaft furnace, organic materials are pyrolysed under an essentially reducing atmosphere to yield a gaseous mixture high in carbon monoxide and hydrogen (typically about 50 percent CO and 30 percent H_2 by volume on a dry basis). As the hot gaseous products continue to flow upward, they dry the entering refuse in the upper zone of the furnace. The high thermal efficiency of the PUROX System is indicated by the relatively low temperature (about 200 F) of the product gas exiting through a duct to the gas cleaning section of the system.

As it leaves the furnace, the gas mixture contains water vapor, some oil mist formed by the condensation of high-boiling organics, and minor amounts of fly ash. The oil mist and fly ash solids are removed by a gas cleaning system. After cleaning, the product gas is passed through a condenser. The resultant dry gas is a clean-burning fuel, comparable to natural gas in combustion characteristics (see Table VI.1). Its heating value is approximately 300 BTU/cubic foot. This recovered gas can be used effectively as a supplementary fuel in an existing utility boiler or other fuel-consuming operations without downrating of the boiler or making extensive and costly boiler modifications. Because the gas produced by the PUROX System is essentially sulfur-free and contains only about one-tenth the amount of fly ash allowable under federal air quality standards, it is an ideal fuel for all types of existing gas-fired furnaces.

The PUROX System produces four times as much energy as it consumes. Only 20 percent of the total energy recovered by the system is needed to meet all of its internal energy requirements, including that consumed to produce the oxygen used in the furnace. The remaining 80 percent is available for other fuel applications. This is an important recovered resource, particularly in view of the growing shortage of clean fuels.

The granular solid residue produced from the non-combustible portions of the refuse is free of any biologically active material. The volume of solid by-product is only about 2 to 3 percent of the volume of incoming refuse, depending upon the amount of noncombustible materials in the mixed wastes. By contrast, a well-designed and efficiently-operated conventional incinerator produces a solid residue volume of 10 percent or more of the volume of refuse burned. Importantly, the dense granular residue produced by the PUROX System is considered suitable as a construction fill material or for other potentially valuable uses.

The PUROX System is notable in another respect. It is designed to use only a small fraction of the oxidant gas required in conventional incineration. As shown by the comparison in Table VI.2, the PUROX System requires only one-fifth of a ton of oxygen per ton of refuse, while a conventional incinerator requires approximately seven tons of air per ton of solid waste burned. This 35-fold difference in oxidant gas flow means that the PUROX

TABLE VI. 1

COMPARISON OF FUELS

	Fuel Gas	Methane	Propane
Lower heating Value (BTU/SCF)(1)	286	910	2,312
Compression Power (KWH/MM BTU)(2)	5.7	1.8	0.6
Combustion Air Requirements (SCF/MM BTU)(3)	8,300	10,500	10,300
Volume of Combustion Products (SCF/MM BTU)	10,500	11,600	11,200
Heat Release/Volume of Combustion Products (BTU/SCF)	95	86	89

(1) Standard cubic foot dry, as measured at 60°F and 1 atmosphere pressure. Heating value calculated at 18°C.

(2) Gas compressed to 35 psig from 1 atm., 100°F with 75% efficiency.

(3) Based on the air needed to convert the fuel to CO_2 and H_2O - no excess air.

TABLE VI. 2

COMPARISON OF PUROX SYSTEM WITH CONVENTIONAL INCINERATOR

	"PUROX" SYSTEM	CONVENTIONAL INCINERATOR
OXIDANT (tons/ton refuse)		
oxygen	0.2	-
air	-	7.1
FURNACE VOLUME		
CF/daily ton	2-4	20
FURNACE GAS		
Tons/ton refuse	1	8
CFM/daily ton	30	620
Temperature, °F.	200	1700
FLY ASH IN CLEAN GAS		
lbs/ton refuse	0.2	2
RESIDUE - % of original volume	3	10

System will produce only one-twentieth as much gas volume to be cleaned. This factor, in turn, makes it possible to reduce fly ash content in the gaseous emissions to less than one-tenth of that attainable with a conventional incinerator. Combustion of the fuel gas from the PUROX System produces emissions far below the allowable maximum specified by federal air quality standards.

The use of oxygen enables the PUROX System to process effectively solid waste of widely varying composition. This flexibility is especially advantageous in adapting to operating variations which commonly result from seasonal, regional, and socioeconomic factors.

Another important feature of this system is its compatibility with other solid waste disposal facilities either new or existing. It can handle refuse in "as received" condition, or it can be used to treat refuse which has been pre-processed by shredding, separation, or resource recovery operations in existing equipment.

RESOURCE RECOVERY

Solid waste is looked upon more and more for its potential value as a "resource." Any resource recovery system must be evaluated according to the nature and economic value of its by-products. The inputs and products of the PUROX System are shown in Figure VI.2.

For each ton of solid refuse fed into the PUROX System, approximately one-fifth of a ton of oxygen is required for combustion and pyrolysis. The furnace produces approximately one-fifth of a ton of granular noncombustible solids from each ton of waste. The gas withdrawn from the furnace is cleaned and processed to yield a usable fuel gas. Waste water is removed for further treatment if required. Organics and fly ash, separated from the off-gas during the cleaning stage, are recycled to the furnace. As an alternative to recycling organics to the furnace for further cracking to fuel gas, it is possible to separate and recover them as a saleable fuel oil, similar to number 6 bunker oil.

As mentioned above, the PUROX System is a net energy producer. For example, the fuel gas produced by a 1,000 ton-per-day PUROX System will yield 30,000 KW of electric power when used as a supplementary fuel in an existing utility boiler. Approximately 5,000 KW of this energy is needed to meet the requirements of the PUROX facility, leaving 25,000 KW for use elsewhere.

In those situations where an existing utility boiler is not available, the PUROX System fuel gas may be combusted in an on-site gas turbine-generator. Under these conditions, the net energy production will be somewhat reduced. However, even the use of a gas turbine generating system will produce 21,000 KW of

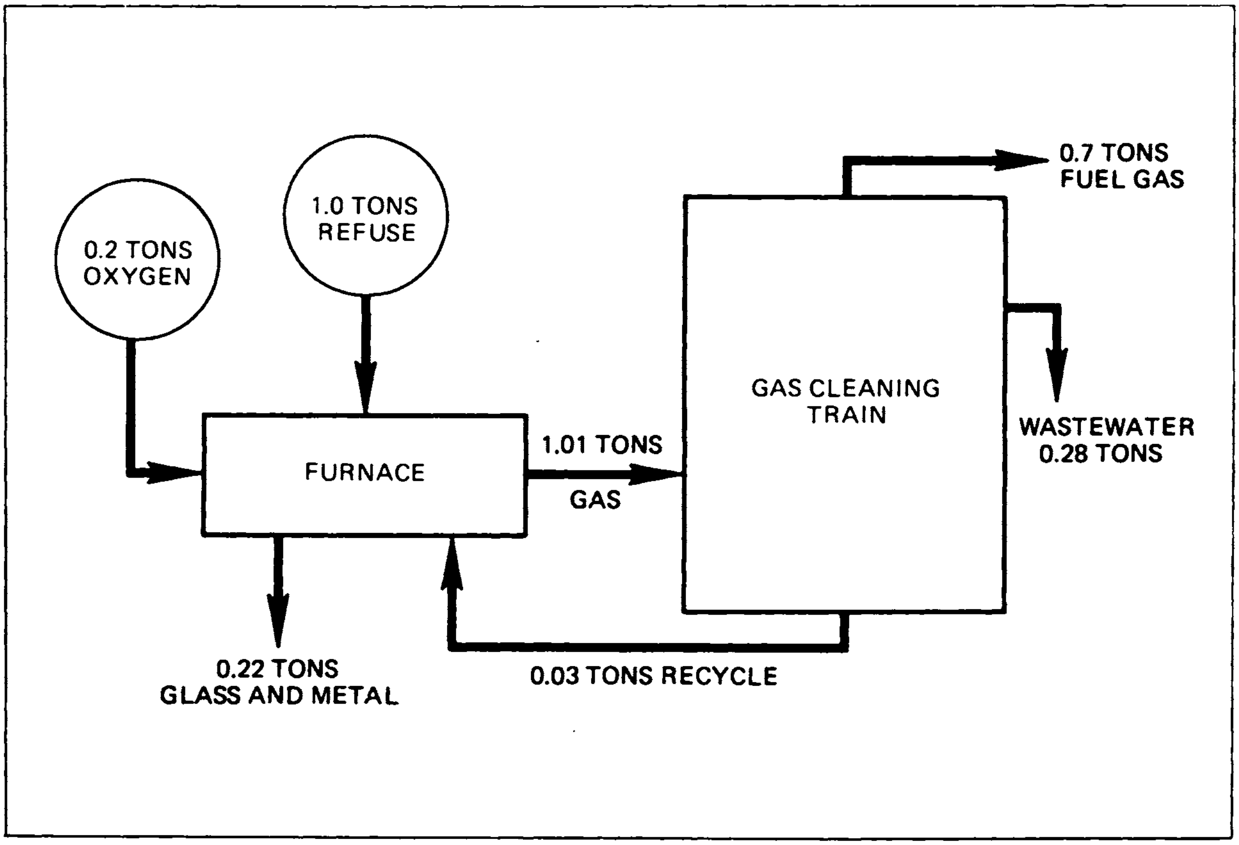

Figure VI.2 Inputs and Products of PUROX System power. Energy requirements for the PUROX facility would then be increased to approximately 7,000 KW and a net energy production of 14,000 KW would result.

PILOT OPERATION

The data presented here were obtained from the operation of a PUROX System pilot plant which has been in operation since 1970. (For a discussion of pilot plant results, see Anderson 1974.) This unit has the capacity to treat five tons per day of solid wastes and has been tested with refuse of varying composition from several different municipal sources. The successful operation of this pilot plant has provided the basic process information required to scale up the PUROX System design to large capacity units.

To obtain operating experience and performance data for these full-scale units, Union Carbide has installed a 200 ton per day PUROX System at South Charleston, West Virginia. This initial facility, which began operation in early 1974, is being used to confirm the technical and economic feasibility of commercial-size units. Results are highly encouraging. Another important objective of the South Charleston operation is to determine the optimum size for "modular" furnace units as shown in Figure VI.3. These modular units may then be installed in multiples as required to meet the solid waste disposal needs of large municipalities.

ECONOMICS

The "per-ton" cost of municipal solid waste disposal by the PUROX System is influenced to a considerable extent by the size and capacity of the facility. The usual economies of scale apply--the larger the facility, the lower the unit processing cost. Labor requirements, a principal factor in the operating costs, do not increase in direct proportion to plant size: a 1,000 ton per day installation would require far fewer than four times the number of operating personnel employed in a 250 ton per day plant.

In designing a large waste disposal plant, the increased cost of transporting refuse to the facility must be balanced against the economic advantages of increasing the size of the plant itself. The PUROX System may be adapted to large-capacity municipal waste disposal requirements by employing two or more furnaces of optimum modular size. Modular design also contributes to operating flexibility since it permits individual units to be shut down during periods of low demand, or for routine maintenance.

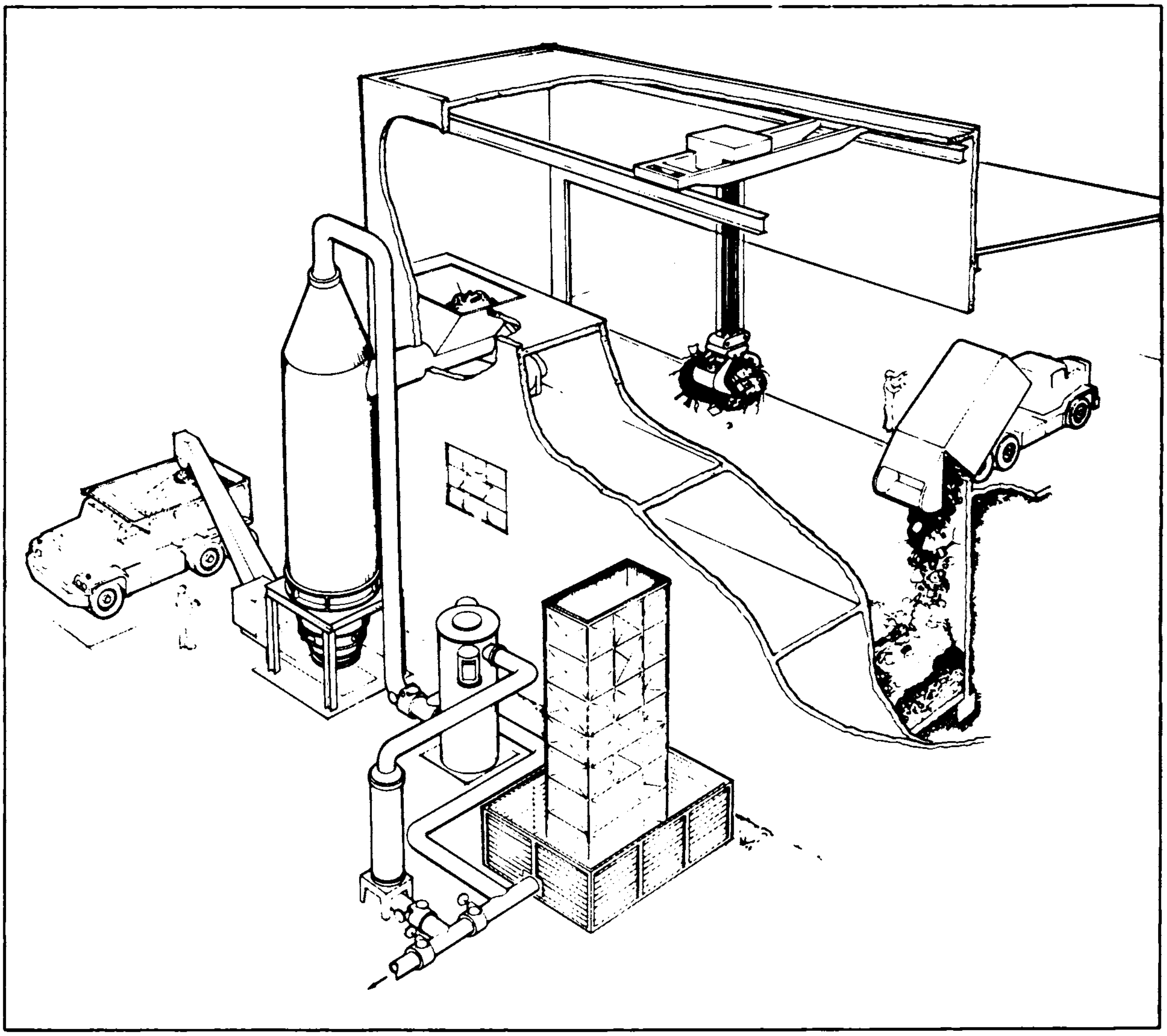

Figure VI.3 Drawing of a Modular PUROX Unit

The PUROX System affords the most favorable economics when employed in areas of high population density where landfill sites are scarce and expensive, and where a large amount of refuse is concentrated in a relatively small geographic area. With a resource recovery process like the PUROX System, the unit cost of disposal tends to decrease as population density increases. With the landfill method of waste disposal, the reverse is true--unit cost increases in proportion to population density.

The PUROX System encourages community acceptance of a large, centralized disposal facility serving several surrounding municipalities because its environmentally clean operation avoids the major objections commonly associated with landfill and incinerator sitings. In addition, markets for the recovered fuel gas and uses for the solid residues are more likely to be located in the more densely populated areas.

OXYGEN SUPPLY

A key requirement of the PUROX System is an economical supply of oxygen gas. Sources of this supply include: on-site air separation plants, employing either the conventional cryogenic process or the newer LINDOX pressure-swing adsorption (PSA) system; delivery of liquid oxygen by trailer tank trucks or railroad tankcars, for on-site storage and vaporization to gas on demand; and pipeline delivery of gaseous oxygen.

Oxygen pipeline systems afford many economic and operating advantages. However, pipeline complexes are concentrated in relatively few highly industrialized areas and are therefore not available to the majority of municipalities requiring the PUROX System. Trucked-in supplies of liquid oxygen are convenient as back-up for on-site production facilities and for handling peak demands. But the unit cost of liquid oxygen is too high to make this supply method economically attractive for continuous, large-volume applications.

On-site oxygen production facilities will probably be the most efficient source of supply for the majority of PUROX*System installations. Either the conventional cryogenic air separation process for large-capacity production, or the LINDOX*PSA System for small- to medium-size plants, can be custom-designed to meet any oxygen supply requirement. Union Carbide has more than 20 years of experience in building and operating highly automated oxygen plants for a variety of customers and applications.

Union Carbide oxygen plants are noted for their overall efficiency, reliability, and safety. As an integral part of a PUROX System, a dependable on-site oxygen supply will provide a

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* PUROX and LINDOX are trademarks of Union Carbide Corporation.

total solid waste disposal facility requiring a minimum of operator attention and no unusual or extensive safety precautions. Efficient operation of all units is assured by Union Carbide's maintenance service, on either a routine or as-required basis, whenever expert assistance is required.

REFERENCE

Anderson, J.E. (1974) The Oxygen Refuse Converter - A System for Producing Fuel Gas, Oil, Molten Metal and Slag from Refuse. Proceedings of 1974 National Incinerator Conference, ASME, New York.

B. VII: ENZYMATIC HYDROLYSIS OF CELLULOSIC WASTES TO GLUCOSE

L.A. Spano, J. Mendeiros, and M. Mandels

(Summary of a paper published by the United States Army Natick Laboratories, Pollution Abatement Division, January 7, 1975, presented by L.A. Spano at hearings of the House Committee on Science and Technology and the Joint Economic Committee of the Congress of the United States.)

Cellulose is the world's most abundant organic material which can be used as a source of food, fuel, and chemicals. The net worldwide production of cellulose is estimated at 100 billion tons per year. This is approximately 150 pounds of cellulose per day for each and every one of the earth's 3.7 billion people. The energy to produce this vast quantity of celluose ends up as waste such as municipal trash, animal feed lot wastes, wood wastes, and agricultural wastes.

Since this resource is the only organic material that is annually replenishable in very large quantity, it behooves us to explore it as a source of energy, food, and chemicals.

The utilization of cellulose is greatly simplified if it is first hydrolyzed to its monomer glucose. Once the glucose is formed, it can be used as a food consumable by man and animals, it can be used as a feed stock for chemicals, or it can be fermented to ethanol (a clean-burning fuel). It is estimated that from one ton of waste paper we can produce 1/2 ton of glucose or approximately 500 pounds of ethanol. In order to conserve time for discussion, I will not dwell on the reasons why Natick decided to explore enzymatic processes for the disposal of cellulosic wastes. Such details are covered in my written statement.

With your permission, Mr. Chairman, I will briefly cover the following:

(a) the enzymatic process itself and how it works,
(b) our accomplishments to date,
(c) our current status, and
(d) our future plans.

The process is based on the use of cellulose enzymes derived from mutant strains of the fungus Trichoderma viride isolated and developed at the Natick Development Center. The first step in the process is the production of the enzymes. This is accomplished by growing the fungus in a culture medium containing cellulose and various nutrient salts. Following its growth, the fungus culture is filtered and the solids dried for possible use as animal food. The clear straw-colored filtrate is the enzyme solution that is used in the hydrolysis vessel. The acidity and temperature of the enzyme solution are adjusted to a pH 4.8 and 50 C, respectively. Milled cellulose is then stirred into the enzyme broth and allowed to react and form the glucose sugar. The crude glucose syrup is harvested and used as desired. The residue is dried and can be used as fuel or as a source of chemicals.

The key to this process is the production of high quality cellulose from Trichoderma viride. To date we have defined the conditions needed to produce the enzyme in quantity. We have also developed mutant strains that produce 2 to 4 times as many cellulose enzyme as the wild strain. In this area we feel that we have yet to reach the upper limit. A tenfold increase over the wild strain is considered very probable. To date we have tested over 100 cellulosic waste materials covering a variety of (a) industrial, (b) agricultural, (c) food processing and municipal wastes. In 24 hours or less we have been able to convert the cellulose present in all wastes tested to glucose. This residence time of 24 hours is relatively short for biological systems.

Another important variable to be optimized is the preparation of the substrate. This variable will affect not only the degree of saccharification but also the economics of the process. We have found ball milling to be an effective pretreatment. However, the milling operation is an energy intensive and costly process. An intensive search for other physical, chemical, or combinations of both treatments is now underway to improve the economics of the overall process.

A potential approach to reducing the cost of substrate pretreatment may be the substitution of hydropulping for the ball mining operation. Recent studies with hydropulped materials show encouraging trends. Having proven that this process is technically feasible, we have scaled up our laboratory equipment to prepilot size in order to optimize the process variables and obtain the engineering and economic data needed for the design of a demonstration pilot plant. The capacity of the prepilot equipment ranges between 1,000 to 4,000 pounds of waste per month. This equipment is now operational at Natick. The demonstration pilot plant when designed will have a processing capacity of 6,000 pounds of waste per day.

Upon completion of these studies it will be possible to engineer larger pilot demonstration plants and possibly full-scale plants. The potential worldwide impact of this process on the energy, food, and ecology problems has been recognized both nationally and internationally. Requests for information, process data or for the opportunity to visit and observe the process have come from all parts of the world. In conclusion, we at Natick are convinced that:

1. the vast quantity of cellulose produced annually should be exploited as a source of energy, food and chemicals; and
2. the enzymatic hydrolysis of such energy-rich material as cellulose is technically feasible and practically achievable on a large scale by 1980, provided exploitation of this new technology is fully supported and pursued without delay.

B. VIII: RESOURCE RECOVERY OF PULP FIBER FROM URBAN WASTE

Charles P. West

INTRODUCTION

In the flurry of "environmental" activity that has taken place in the past decade, a wealth of information has been gathered as to ways and means of resolving the solid waste problem. These solutions ranged from power generation to island building in local bays and lakes to packing the waste and shooting it into space.

The problem revolves around people, their social establishment, political behavior, life styles, and economic philosophy. In this particular instance, technology is not the problem; there exists enough know-how to enable us to establish the best technical methodology for solid waste management, bearing in mind a flexible approach as new technologies evolve.

This methodology is commensurate with the best return to society, the people and their institutions, and the environment.

It is impossible to isolate municipal solid waste as the sole problem if one is to deal with overall solid waste exclusive of sewage and not include industrial wastes and agricultural wastes. One must also include its effect of water pollution as well as air pollution. A generalist's view is that all four classes of waste are related and that a proper investigation and exploitation is required for society, both present and future.

This paper will deal with the fiber fraction, namely, the waste paper only.

U.S. PAPER INDUSTRY--RECENT TRENDS

Although there are over 3,000 converters and primary papermakers in the $26 billion U.S. pulp and paper industry, it has been dominated for many years by the vertically integrated pulp, paper, anf forest products giants. These companies in the past 10 or 15 years, competing strongly, tended toward periodic overbuilding and overproduction in pulp and paper. This helped create an active paper pulp market to supply smaller independent manufacturers of paper who are similar to the independents in the U.S. oil industry and who now face some similar problems.

The large integrated producers of forest products, pulp, paper, and paperboard also face many problems in the future. These problems are presently causing a near-crisis in the supplies of pulp and paper while market demand continues to grow. Among these are perennial and new problems such as:

a <u>Raw Materials Undersupply</u> New large tracts of forest land are becoming increasingly expensive or unavailable. Also, there are limits on cutting in federal forests, forestry labor problems, and there has been some poor management of resources in the past.

b <u>Increased Wood Pulping Costs</u> Capital and operating expenses increased in the effort to meet state and federal environmental requirements. High fuel costs and availability problems and higher capital cost for new pulping facilities are linked to general inflation. These effects have reduced the building of new pulping plants and expansions. Another important effect is that pulping has been competing poorly with other more profitable uses of the wood available to integrated forest product companies.

c <u>Competition</u> Strong competition exists for U.S. produced wood products, pulp, and paper in foreign markets. This foreign competition is from countries that re-use more of their consumer wastepaper but have a faster growing paper demand than the U.S. These factors have created high demand for U.S. pulp which will probably continue with minor fluctuations for a long time. This has been indicated in the recent unavailability of virgin bleached pulp and in the drastic increase in the prices of even some of the lower grades of wastepapers.

Another source of raw material for paper and paperboard, especially for independent operators, has been recycled wastepaper and paperboard. Some changes in societal and governmental attitudes toward waste and resource management brought about by the environmental movement may help the paper industry by pushing for utilization of this valuable resource.

WASTEPAPER RECYCLING

Wastepaper is a raw material whose supply depends to a great extent on price and the will and ability to organize collection systems. Interest in recycling wastepaper is now high in community groups, municipalities, and other institutions of society and government. The paper industry has always internally recycled most of its own waste. Overall rates of wastepaper re-use have been higher in the past. In the years before and after World War II, about 30 percent of the U.S. wastepaper was recycled. Up to 60 percent was collected for recycling during the peak World War II years. The present recycling rate is about 22 percent of the paper and paperboard produced. The percentage of paper and paperboard produced in the U.S. which is reclaimable has been estimated to be between 60 and 80 percent. This would include all paper and paperboard produced or imported, minus exports and non-reclaimables such as sanitary tissue, construction paper, and paperboard, and minus small percentages of other paper products.

Price is the primary mechanism by which consumer recycled wastepaper is made available for recycle today. As with other resources such as coal or metal ores, an increased demand and higher prices will bring large quantities and lower grades into the market. Wastepapers for recycling today must be graded and sorted for the processes now available to convert this material into useable paper pulp.

Wastepaper refining technology, known as "de-inking," falls into three basic categories:

(1) "washing out" the ink with caustic and/or other chemicals;

(2) removal by air flotation of ink particles, generally with the use of enabling chemicals; and

(3) reduction and dispersion of ink particles by mechanical means and with chemicals.

The first is applicable to de-inking the widest range of wastepaper sources outside of mechanical pulp with high lignin content. The second has been particularly useful for newspapers. The last is practical only on relatively clean or lightly printed paper or with lower or mixed grades of waste where a relatively inferior product is acceptable.

The first method is generally efficient, but can destroy up to 35 percent of the contained fiber, representing a loss of product and a serious pollution problem. The second method can also be quite effective and has a good recovery but is more limited in applicability, requires high capital investment for machinery, and has high operating costs. The third method, employed by some independent pulp producers and for recycles of internal mill wastes, is usually limited to the most highly selected, cleanest, and expensive wastepaper grades for paper manufacture and cannot serve to supply many grades for paper production. It is, however, effectively used to prepare various waste grades for tissue, writing, book and publication grades, and for paperboard manufacture.

Clearly, the need is for an efficient process which de-inks a wide range of types of recycled paper products, minimizes fiber loss through degradation, is otherwise nonpolluting, and has economically attractive capital and operating costs.

Two new processes that have been developed are discussed below.

a) A process that deals exclusively with classified waste and mixtures of that waste. The process will reduce waste based on chemical pulp as well as groundwood (as in newspapers) and mixtures of both (as found in magazines).

b) A process for dealing with mixed urban waste. This paper waste has its origin in ordinary home "garbage" and waste from offices and institutions. It is the waste that would normally be disposed of via land fill or incineration. This waste contains at least 40 to 45 percent waste paper containing representative amounts of every type of paper that the ordinary individual may use or see.

To augment Processes (a) and (b), a new approach has been developed in bleaching, namely the bleaching of "mixed fibers," essentially chemical fiber and groundwood fiber, together as one entity. This process functions with process (a), particularly when the waste is heavily colored.

PROCESS DESCRIPTION

The Paper Fiber "Refinery"

The whole process may be viewed as a two-phase fiber "refinery." The first step is to "pulp" or defiber a mixture of wastepapers with the chemicals. Most of the ink and other contaminating paper materials, bound by these chemicals, are removed from the fibers by expression and washing. Large "tramp" solids, dirt, and most other such undesirables are mechanically or hydraulically separated in this phase.

The second step is to bleach and condition the de-inked pulp, as required, and to remove, mechanically, hydraulically, and by washing, the residual traces of ink, dirt, flotable solids, and inorganic solutes.

First Phase: Pulping and Primary De-inking

Pulping

Inspected and weighed wastepaper furnish is first pulped at a 6 percent solids consistency, normally with 140 F recycled "whitewater," chemicals, and bleach is required. An average of about 50 pounds of dry, bagged, easily stored chemical is added per ton of furnish. A good commercial pulper with pulping agitator is used to reduce the paperwater mass to fibers by liquid shear forces as it circulates within. Large pieces of plastic, cellophane, sheets of resin coatings, stones, wires, paper fasteners, and larger tramp objects are periodically removed from the pulper system between batches. The pulper will usually run about 50 batches/day of about 25 minutes each. The batches are dumped into an agitated chest wherein stock contact with the chemicals is completed at a 6 percent solids consistency. The process runs in a continuous rather than batch mode from this point on. Collection in the chest also serves to minimize the fluctuation of the composition of the pulp produced from varying bales of furnish.

Primary De-inking

After being held in the chest for an average period equivalent to several batch cycles, the pulp is pumped to a series of standard paper pulp cleaning operations. These remove smaller undesirables, heavy and oversize solids, and complete the "deflaking" or reduction of paper to fibers while helping to mechanically separate adhering ink and coating particles from the fibers.

Dilution The consistency of the stock is automatically adjusted to 3 percent solids by dilution with internally recycled "primary whitewater" as it is pumped out of the chest. The pumping and mixing of the stock and water are done in a special stock pump.

Hydrocyclones One or a set of hydrocyclones next removes remaining pieces of heavy contaminents such as paper clips, staples, rubber bands, metal binder fragments, and stones. The accepts from these units flow overhead and the underflowing rejects can be periodically purged from bottom collection chambers by an automatic, pneumatically operated flush-and-dump system. Flush water can be drained to sewer and the solids sent to landfill. These units purge the stock of damaging materials before flow to the next units, the deflakers.

Deflaking These motorized, stator-rotor slurry reduction mills operate on the suspension at high speeds. The slurry of fibers is forced through a tortuous, labyrinthine path between close-fitting, moving surfaces. Remaining "flakes" or bundles of fibers are broken up and ink particles are freed from the fibers by means of the high liquid shear and sonic shock forces developed. Large flakes of coatings and plastics are also somewhat broken up but less so because of their shape and strength.

Screening The next step is to remove remaining flakes and other sizable contaminants from the slurry by size selection on motorized vibrating screens. Usually only a small amount of solids fail to pass through the screens; these are rejected and can be sent to landfill. The vibrating screens also serve to prevent plugging the dewatering screens of the next operation.

Dewatering Dewatering of the 3 percent stock is done in a three-stage series of screw extractors, wherein two are backwash stages, to finally give an extracted, counter-currently washed, and dewatered thick stock of 12 percent solids consistency. At least 98 percent of the inks, clays, starches, and sizes originally in the furnish are removed from the fiber at this point. Most of the rest is removed in the second phase of the process.

The extractors, usually several units in parallel per stage, draw stock up on stainless steel screw flights and press it against a cylindrical, close-fitting basket with conical holes so that the liquid is squeezed through and drained. The first of this series of three stages brings the 3 percent screened stock to about 12 percent consistency by extracting about 80 percent of the liquid. Most of the suspension of ink and chemicals is expresssed from the stock in this first stage. Valuable fiber is recovered from this aqueous suspension in a separate recovery unit. The recovered fiber is returned to the pulper dump chest. The waste suspension is pumped directly to pollution control operations outside this process, where it can be reduced by further solids separation and by biodegradation to a clean effluent. This effluent represents the main purge of water, processing chemicals, and removed materials from the plant.

The thick stock from the first stage passes by gravity to the inlet of the second stage where it is rediluted with returned wash water removed in the third stage. Water expressed in the second stage (which washes out most of the contaminants not squeezed out in the first stage), after fiber recovery in another separate unit, passes to a Settler Tank for primary whitewater to be used for pulping and dilution. The valuable recovered fibers are returned to the pulper dump chest.

The slurry of solids which come down with a pH adjustment in the Settler is pumped to the pollution control operation outside of this process.

The thick stock from the second stage, also at about 12 percent consistency, is again rediluted to 3 percent with water from the Secondary Whitewater Tank and passes by gravity to the third stage. The Secondary Whitewater consists mostly of recycles from two cleaning and dewatering operations later in the process, made up with fresh water or with water suitably treated outside the process. The third stage also achieves about 12 percent consistency by dewatering the re-diluted 3 percent stock.

Second Phase: Bleaching and Fine Cleaning

The thick stock is now ready for bleaching and additional treating with chemicals, if required, and dilution for the next series of cleaning and washing treatments. The purpose of these steps is to remove remaining flotables, oversize materials, and dirt. Some ink and dirt particles are also among the flotables, but mostly some flakes of such coating materials as waxes and polyethylene are left. The refined pulp at the proper consistency is sent to shipment, storage, or to a paper machine.

Bleaching

The thick stock from dewatering enters a dump chest for dilution to 6 percent consistency with secondary whitewater and for additional bleaching as required. Bleach is introduced as a liquid from a make-up system.

Flotation or Reverse Cleaners

The stock is further diluted to 3 percent while being pumped to the two-stage agitated flotation cells, or reverse cleaners. Flotables are separated with a high removal efficiency by surface adherence to air bubbles produced in a bubbler head with air from a blower. The first stage froth which is produced carries over to the second stage with the rejected flotables an average of about 4 percent, but possibly as much as 20 percent, of the system throughput. The froth is washed into the second stage by a spray of secondary whitewater called "launder" water. The carried-over fibers are recovered and recycled from the second stage. The second stage flotables rejects, diluted with "launder water," are partially purged. Some allowable percentage is pumped back to the pulper for a trip through the plant again, wherein some are reduced in size and thus enter the product. The fiber in the net rejects is 1 to 3 percent of the system throughput but usually only a small part is purged.

Reverse cleaners are a new development whose function is to remove the flotable contaminants such as plastics and wax. It is hoped that they can replace flotation cells.

The flotation accepts, after dilution to an 0.8 percent consistency with secondary whitewater, are pumped to a motorized centrifugal pressure screen which produces a rejects stream containing oversized particles and dirt along with some fiber. Useable fiber in the rejects stream is recovered in a separate unit and the water passes to the secondary whitewater settler. Recovered fiber is returned to the feed box of the flotation system first stage.

Three-Stage Cleaners

Centrifuge accepts pass to a surge vessel which feeds the three stage hydrocyclonic cleaners. The pulp is diluted to 0.5 percent with secondary whitewater in this vessel. This system operates to separate fiber from small particles of remaining ink and other dirt. The separation is done in three successive stages so that a highly concentrated rejects stream is produced which minimizes the amount of fiber passing out with the rejects. Overhead accepts from the second and third stages are passed back to merge with the pumped feed of the preceding stage. The overhead accepts of the first stage are the net accepts product of the system--the bottom rejects of the third stage are settled for secondary whitewater recovery.

Washing-Thickening

The accepts from the first stage of the cleaners feed thickener-washer devices which remove dissolved inorganics, such as salts, by replacing the water of dilution. The units also concentrate the stock as required.

The concentrated, washed stock at 4 to 15 percent consistency can be diluted for papermaking or raised to about 50 percent consistency for shipment, as required.

Process Equipment Availability and Options

Most of the equipment items in the plant are available in some form from several vendors. Some of these items are very similar in principle, in operation, and in the capacity claimed by the vendor. The choice there is made primarily on price and delivery schedule or other economic criteria but can be affected by individual preference or experience. In other cases, a process step or function can be performed by a variety of equipment types operating on differing principles. Here the choice may be again on price or on operating cost, as with powered versus unpowered equipment. Also affecting the choice may be the experience in pilot testing as well as the client's experience with the equipment in other pulp and paper processing.

Pollution Control Facilities

These will be required to dispose of an aqueous effluent of about 8,000 gallons per ton of pulp produced. The form of the effluent is a suspension of mostly inorganic matter which can be easily flocculated and settled by pH adjustment with alum, for instance. The settling and separation could be done in a clarifier or in a mechanical separation device such as a centrifuge. Small flows of sewered spills, bleeds of settled solids slurries, etc., also flowing from the process and usually totaling less than 200 gallons per ton of pulp, could be collected and treated in the same pollution control facilities.

The concentrated solid residue resulting from effluent treatment could be removed to landfill or it may be used in several ways as a construction fill in asphalt, etc. It is composed of largely inert matter except for its content of certain absorbed soluble and organic paper chemicals, which will vary with the type of furnish. The liquid effluent will thus contain only a part of the soluble starches, glues, and other materials removed from the furnish. These, along with a possible small organic component of chemicals, probably will have to be reduced by biodegradation. Water treated in this way could be returned to the de-inking process as make-up or wash water.

It is always possible, of course, that by some arrangement the effluent might be treated in a local municipal or other pollution control facility. Either the raw effluent or the effluent after solids removal might be acceptable to such a facility.

Solid effluents from various separation steps in the process, whose volumes depend on the nature of the furnish, can be easily drained and sent to landfill or to incineration, whichever is more appropriate under the circumstances.

COSTS OF PRODUCTION

Elements of Production Cost Per Ton of Pulp

The appropriate in-process elements of the cost of de-inking typical furnishes are as follows (units are per ton of de-inked, air-dried fiber contained in the 4 percent product):

Chemicals

Chemicals	50 lbs. @ approx. $20

Bleach and Water-Treating Chemicals

Bleach	0 - $4.00 (depending on degree of bleaching and fraction of groundwood furnish)
Water Treating	$0.10 (in addition, approx. $0.50 required for water-treating chemicals in treatment facilities outside the process limits)

Utilities

Power	210 KWH
Steam	2.6 tons
Instr. Air	500 SCF
Treated or Fresh Water	13,000 gallons (includes 5,500 gallons required for 4 percent consistency pulp product)

Costs will vary as the chemical markets fluctuate. The costs here reflect the date of the writing of this paper.

DE-INKING RESULTS

The following are descriptions, and in some cases, detailed results, of some of the many tests made of the de-inking process on pilot scale equipment. The tests chosen for mention indicate how wide the proven range of applicability is for the process, even before commercialization.

Most of the tests and analyses were carried out in the semi-works de-inking plant and laboratory facilities of New York State College of Forestry of Syracuse University, Syracuse, New York.

This pilot plant has a capacity of about 3 tons per day of pulp throughput and uses standard equipment similar to that proposed for the full-scale operation. The college also has a small (40 inch) production type paper machine which was used to make sample lots in some cases.

Tests with Mostly Groundwood-Free Furnishes using Standard Hypochlorite Bleaching

Test 1 -- Student Run (Syracuse) -- March 1971

Nine (9) tons of university mixed wastepaper were collected by students and defibered and de-inked in the college facilities. The resulting white paper made on the 40-inch machine was used for printing a student newspaper and other publications.

The de-inked pulp was made initially into hand sheets (1) and compared with hand sheets made from a commercial bleached virgin pulp as a control (2) and with hand sheets made from a mixture of virgin and de-inked pulp (see Table VIII.1). Machine-made paper results are also shown (see Table VIII.2).

Test 2 -- Mill Run Sponsored by Great Northern-Nekoosa Company -- May 1972

Eight (8) tons of wastepaper containing acrylic inks were defibered and de-inked at Syracuse and converted to paper on an 110-inch commercial paper machine in Potsdam, New York, operated by the Great Northern-Nekoosa Paper Company. The machine ran at 1100 ft/min and the pulp was converted to standard register bond, 15 lbs. basis weight, brightness (bleached) of 85. Nekoosa was pleased with the results.

Test 3 -- Southern New England Telephone Company -- August 1972

Collected waste from one large telephone office building in New Haven, Connecticut, was defibered and de-inked at Syracuse and converted to white paper. The resulting paper had a brightness (bleached) of 85 and was used by the Southern New England Telephone Company for a consumer newsletter.

Tests with Groundwood-Containing Furnishes using other than Standard Hypochlorite Bleach

Test 4 -- Dupont Recycled Magazine Test -- April 1971

This test was run at Syracuse at the request of E.I. Du Pont de Nemours & Company who were interested in de-inking recycled magazines at the time because of the low market price of such waste.

Hand sheets were made from this pulp (which contains 20 to 30 percent groundwood) and were compared to others made from various commercial pulps used as controls. The results are shown in Table VIII.3.

TABLE VIII. 1

HAND SHEET RESULTS

Furnish	(1) Recycled Wastepaper	(2) (control) Weyerhaeuser Softwood Sulphite W	(3) Mixture of 50% #1 50% #2
Freeness-(CSF)	544	436	486
Bulk (cc/g)	2.10	1.66	1.33
Burst Factor	17	36	26
Tear Factor	126	97	113
Breaking Length (Meters)	3395	5510	4425
Stretch, %	1.8	2.5	2.2
Fold (MIT)	6	76	37
BRIGHTNESS (MgO=100)	86	86.1	86.7

TABLE VIII. 2

MACHINE-MADE PAPER

Furnish Composition	(1) 50% Weyerhaeuser Standard Softwood Sulphite, 50% Weyerhaeuser Hardwood Kraft (NBH)	(2) 50% Weyerhaeuser Softwood Sulphite W 50% Recycled Wastepaper Pulp
Clay, lb/ton	125	none
Rosin, %	1	1
Alum, %	2	2
Analysis		
Basis Weight(17x22-500)	20.3	22.2
Mullen	26	20
Tear MD	132	150
CD	132	172
Tensile MD(Kg/15mm)	5.87	6.53
CD	3.59	3.16
Stretch MD (%)	1.7	1.0
CD	5.3	3.8
Fold MD (MIT)	58	82
CD	38	24
Porosity(Gurley-100cc)	44	17
Brightness	86.1	86.7
TAPPI Opacity	83.7	84.5
Ash Content (%)	3.6	0.5

TABLE VIII. 3

Pulp	Recycled Waste Magazines Unbleached	Recycled Waste Magazines Bleached	Bowater Hardwood	Bowater Softwood
Freeness (CSF)	305	390	403	355
Bulk (cc/g)	1.6	1.6	1.52	1.44
Burst Factor	29	28	40	64
Tear Factor	106	107	100	100
Fold (MIT)	29	29	95	628
Breaking Length (Meters)	4825	4887	6445	8980
Stretch, %	2.7	2.7	---	---
Porosity	23	15	---	---
Brightness	66.5	73.3**	84.8*	86.9*
TAPPI Opacity	83	79.8	71.0	57.5

*Unbeaten Pulp Brightness

**0.75% H_2O_2 - 100°F - 6% consistency - 3 hours

Test 5 -- St. Regis Newspaper De-inking and Flocculation Tests -- May 1972

Newpapers were defibered and de-inked using the chemistry in the St. Regis Paper Company circuitry at their West Nyack, New York, facility. This circuit consists of a simple pulper plus three "side-hill" screen washers in series. The important aspect of the test was that the same pulping water was used to de-ink three consecutive batches. Hand sheets were made from the mixed pulp from these batches. The physical tests were up to standard, and the brightness was 53 (unbleached).

The effluents from the test were flocculated in a standard experiment with alum in a static tank. Total flocculation was achieved in 1 hour and 20 minutes. Other tests indicate that total flocculation can be nearly instantaneous with proper agitation in modern equipment.

Test 6 -- Telephone Directories De-inking Test -- October 1971

One thousand (1,000) pounds of complete, intact telephone directories, including covers, bindings, white pages, and yellow pages, were defibered and de-inked at Syracuse. The resultant pulp, after bleaching, had a brightness of 65.

URBAN WASTE

There are several processes for the separation of urban waste into its various functions.

Forest Products Laboratories furnished the waste paper fractions separated from urban waste.

Using standard pulp and paper equipment and the process parameters of process (b) and incorporating the newly developed bleaching process, the following are the test results of the paper made. Comparisons were made with newsprint because of the large amount of groundwood that is present in the waste. Test results are shown in Table VIII.4.

CONCLUSIONS

A. Pulp fiber for the manufacture of paper and related products is a commodity item and a vital resource. As such it plays a vital role in the economic life of the United States.

The recycling of waste paper is more than just the mere saving of trees, or maintaining the proper ecological balance so vital to the maintenance of the land and life itself. The fiber is a resource similar to coal, oil, ores, and so on, and conservation of our virgin sources is needed to maintain our society.

TABLE VIII. 4

	Newsprint Control	*Urban Waste Control	* 140-30	* 140-40	* Direct Processing
Burst	8.95	24.3	15.1	20.1	22.4
Tear Factor	27.2	98.6	101.8	102.3	106.4
Breaking Length	---	4.12	3.5	3.90	3.86
Stretch % (M.D.)	1.07	2.42	1.8	1.89	2.09
Tensile Energy Absorption (M.D.)	7.9	23.3	16.6	18.3	19.7
Brightness	58	48?	73.4	73.1	72.7

*Urban Waste furnished by Forest Products Lab.

A cooperative effort between the federal government and private industry is a necessity. There is no need to enter into an era of shortages of fiber similar to the one that existed in 1972, 1973, and early 1974. Planned utilization of virgin fiber and recycled fiber can meet the world requirements.

B. In view of the higher economic value placed on pulp fiber as a commodity, it should be exploited as such, rather than the waste utilized as a source of energy.

C. The energy requirments for recycling of waste paper is less than that required for the manufacture of virgin fiber.

A case in point is the data compiled for the energy requirements for a virgin newsprint mill. Based on the requirements for electricity and steam a total of 10.3 million BTUs per ton is required.

In a newsprint mill based on the recycling of newsprint, the total BTUs required is 8.5 million per ton.

The difference is 1.8 million BTUs per ton. This, translated for 1 million tons of newsprint based on recycled fiber, is a savings of 11.8 million gallons of #6 fuel oil.

To maintain a healthy viable society, resources capable of recycling must be recycled. The methods and mechanisms must be economic and compatible with the environment.

B. IX: MSW RESOURCE RECOVERY: SOME THOUGHTS ON COSTS, MATERIALS HANDLING, AND MARKETING

J. J. Cordiano and W. R. Opie

Several processes are being developed for recovering the thermal energy and other resources from solid waste. To date, the results from studies and pilot operations utilizing the energy in solid waste as a fuel have been very promising. However, the only operating entity of any size which is actually processing municipal solid waste and burning the fuel fraction in commercial boilers is the Union Electric Company.

As more and more studies and data become available on capital and operating costs, we have seen a dramatic increase in cost estimates. For example, the estimated capital cost for a 1,000 ton per day plant to process MSW for resource recovery has increased over the last three or four years from approximately $3,000,000 to over $20,000,000.

Probably because of the pilot size of the operational studies, there seems to be a lack of appreciation of the materials handling problems inherent in resource recovery plants for processing 1,000 tons or more per day of municipal solid waste through to salable products. MSW is very bulky--on the order of 5 to 15 pounds per cubic foot. For comparison, a scrap metals pile weighing 2,500 tons (with a bulk density of 150 to 200 pounds per cubic foot) would form a pile approximately 15 feet tall, 20 feet at the base, and 200 feet long. Twenty-five hundred tons of MSW would occupy from 12 to 30 times this volume or a pile 15 feet tall, 20 feet at the base, and stretch for a mile in length. Bulk of such magnitude could involve technical problems and economic risks if materials handling and the reliable flow of materials through the plant are not given special consideration within the constraints imposed by environmental and hygienic limitations.

One other point. It appears that very little scrap metals market information has been made available to those who are preparing estimates of the quality requirements and marketability of copper, lead, and zinc bearing MSW recovered products. The scrap metals recycling industry has the knowledge and facilities available to process scrap varying from the very impure to the highest grades and in general, the MSW resource recovery plant products should be marketed as generated or, if necessary, with only that additional preparation sufficient to make it salable to the scrap metals recycling industry.

In establishing a price for recovered products, the scrap metals refiner usually charges a treatment cost on a dollar per ton of material processed basis plus a refining charge in cents per pound for each metal recovered. These charges and any other costs, such as transportation, would be deducted from the market price for each metal that was agreed upon at the time of sale and the difference paid to the MSW plant. A partial payment would be made upon an agreed upon date after receipt of the material at the refiners plant with a final adjustment payment after the analytical assay results had been obtained on representative samples taken at the time the material was received and weighed at the refiners plant.

The following is a description of one of the worlds largest scrap metal smelting and refining plants for processing copper bearing scrap materials.

Amax's USMR (United States Metals Refining Co.) smelter and refinery at Carteret, New Jersey, processes an incredible variety of primary and secondary materials from a wide range of sources, and it manages to recover just about everything that comes through the gate (see Figure IX.1).

All the in-process materials generated are considered to have value. The slags, slimes, residues, and other by-products of the major smelting and refining operations are constantly reprocessed and recirculated to insure the most complete recovery possible of salable materials.

The Carteret plant has been in operation since 1901 and was acquired by The American Metal Co. in 1920. Now operated as a wholly-owned Amax subsidiary, it accounts for about 10 percent of U.S. refined copper production and 35 percent of all refined copper production from secondary sources. In 1974 the plant produced 230,000 tons of refined copper, and recovered about 1 million ounces of gold, making it the largest single refiner of gold in the U.S. Silver recovery totaled 26,000,000 ounces. Platinum group metals, selenium, tellurium, and lead, zinc, and nickel compounds were also recovered as salable by-products.

The Carteret plant's three basic functions are: (1) a smelter and refiner of copper, (2) a producer of sophisticated specialty coppers, and (3) a smelter and refiner of precious metals.

As a smelter and refiner of copper, USMR's production is divided roughly into two-thirds toll material processed for others and returned to the original source for a smelting and refining fee, and one-third material purchased and processed for Amax's account. As a producer of specialty coppers, USMR turns a substantial portion of its copper into one of a number of proprietary "unconventional coppers" for highly specialized applications. As a refiner of precious metals, Amax has grown to the point that its precious metals scrap intake now accounts for a greater percentage of its production than precious metals won from the slags and slimes produced in its copper operations. As with copper, much of the precious metals refining is on a toll basis.

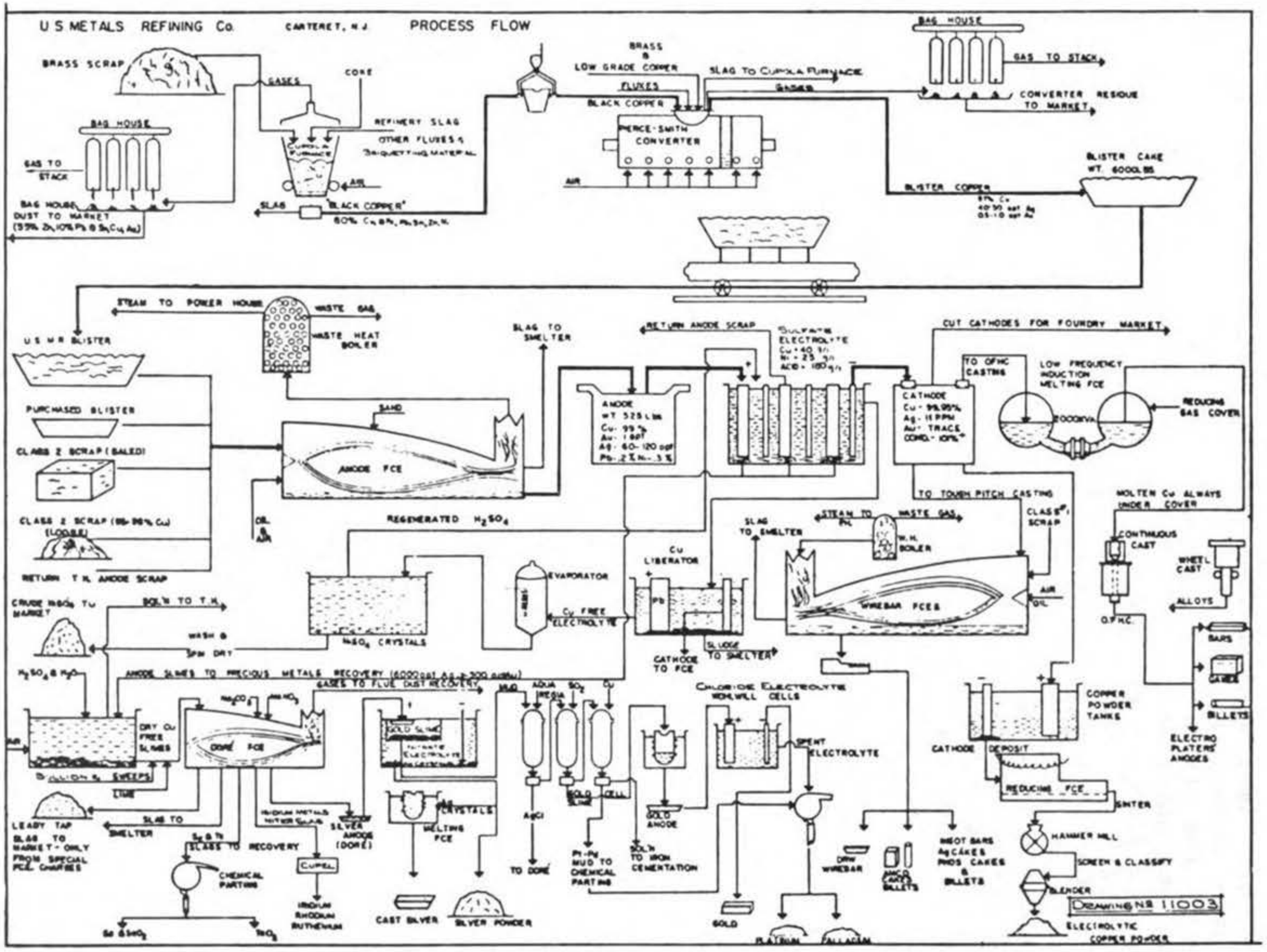

Figure IX.1 Process Flow Diagram

Raw materials intake for the Carteret smelter has in the past included primary copper concentrates produced from sulphide ores. Its last major source of such concentrates, Cuba, was lost when Fidel Castro took over the Cuban Government in the late 1950s. Since that time, smelter feed for the USMR plant has been entirely from secondary sources. The USMR electrolytic refinery processes blister from its smelter, "outside blister" from sources including Africa and South America, and refinery grades of scrap, i.e., No. 1 and No. 2 copper scrap and other high-grade industrial varieties of scrap.

The Carteret plant produces electrolytic tough pitch, fire refined, and OFHC brand oxygen-free copper, a number of proprietary Amax alloys including Amsil, Amtel, Amsulf, and Amzirc, whose names suggest the major alloying elements, and electrolytic copper powder and powder blends.

Depending on its quality, raw materials feed for the USMR plant may enter the processing circuit at one of a number of points. The lowest grades of scrap and slag require a smelting step and are processed through a cupola blast furnace. Better scrap grades and imported blister bypass this step and are fed directly to the anode furnace for intermediate refining followed by casting into anodes for electrolytic refining. No. 1 copper scrap, a grade of raw material of equivalent electrolytic quality, and cathodes received from other refineries, bypass electrolytic refining and are simply blended into furnace charges during the melting cycle for casting into refinery shapes.

Amax buys scrap from as many as 200 dealers in the course of a year and from a number of industrial scrap sources--major consumers of raw copper that generate scrap in manufacturing operations. The Eastern Seaboard of the U.S. is the main source of scrap supply, but all of the U.S. east of the Mississippi regularly contributes to the Carteret smelter's intake.

The utility companies, brass mills, wire mills, and others, constitute the major sources of industrial scrap. The Carteret smelter counts 30 industrial plants among its regular scrap sources. Much of this scrap is processed on a toll basis, with refined copper returned to the customer equivalent to the copper content of its original shipment.

During the average month, the Carteret plant takes in about 7,000 lots of copper scrap. The quality of this scrap intake is subject to constant attention. To maintain control of both incoming raw materials and end product quality, USMR operates a highly sophisticated analytical laboratory, which in a single month may turn out 26,000 assays.

Major copper production units include a cupola blast furnace, a Pierce-Smith converter, anode furnaces, the tank house, and tough pitch casting furnaces. Precious metals extraction equipment includes dore furnaces, electrolytic extraction facilities for silver and gold, and chemical extraction facilities for platinum, palladium, iridium, rhodium, ruthenium, selenium, and tellurium.

The blast furnace charge contains the lowest grades of scrap--best described as high-quality, copper-bearing junk. This material averages about 35 percent Cu, a figure that has declined by about 10 percentage points over the past 10 years. Copper-bearing refinery slags are representative of this type of material.

Because of the nature of feed, blast furnace exit gases are rich in metallic dusts. Metal values in this by-product average about 55 percent zinc and 10 percent lead, with smaller amounts of tin, copper, and precious metals. These by-products are recovered in baghouses and sold to zinc and lead refiners for metals recovery.

The main blast furnace product is "black" copper, averaging about 80 percent Cu and containing additional percentages of iron, lead, tin, zinc, and nickel. Molten black copper is transferred to the Pierce-Smith converter, which also accepts some grades of brass and copper scrap. The converter product called "blister" copper, assays 97 percent Cu, 40 to 50 ounce of silver per ton, and 0.5 to 1 ounce of gold per ton.

Converter gases are routed to a baghouse for removal of particulates, a by-product which is sold for recovery of tin and other metal values.

USMR blister, outside blister, and No. 2 copper scrap are melted down in the anode furnace and fire refined to upgrade quality to 99 percent Cu, 60 to 120 ounces of silver per ton, and 1 ounce of gold per ton. This intermediate product is cast as 525 pound anodes for use in the tank house where electrolysis produces cathodes that average 99.95 percent Cu and tank house slimes containing approximately 6,000 ounces of silver per ton and 200 to 300 ounces of gold per ton.

Cathodes are routed for melting and tough pitch casting either to a shaft furnace, or to a reverberatory furnace which also accepts No. 1 scrap. Melt from these furnaces is cast into a variety of shapes having a minimum of 99.9 percent Cu, with silver counting as copper. Alternatively, cathodes may be melted in a low frequency induction heating furnace that excludes oxygen to produce more than 99.9 percent copper. This copper--Amax's proprietary OFHC brand--is cast or alloyed into a variety of products.

USMR precious metals production started up as a natural adjunct to its copper production, with tank house slimes being treated to extract valuable traces of gold, silver, and other metals. Eventually, this precious metals processing capability attracted precious metals scrap from industrial and other sources, so scrap sources now account for more of the plant's precious metals output than do slimes from the electrolytic plant.

The precious metals treatment plant is a closely guarded unit located for security reasons inside the large copper production complex. Slimes and scrap are smelted in Dore furnaces. The principle furnace product is cast as a silver anode and then electrolyzed in a nitrate electrolyte to produce silver crystals. The crystals are melted and cast into bars suitable for marketing.

Slimes from the silver electrolysis cells contain gold, platinum, palladium, and other precious metals. The gold is separated chemically, cast as gold anodes, and treated electrolytically for final purification. The refined gold cathodes are melted and cast as gold bars.

Platinum and palladium muds remaining after the gold separation are parted chemically and purified to produce the two metals as valuable end products.

Three types of slags are generated selectively: (1) an iridium metals slag which is treated to extract iridium, rhodium, and ruthenium; (2) a selenium-tellurium slag which is treated chemically to produce selenium and tellurium; and (3) the final slag which, defying further individual separation, is recirculated to the smelter for another run through the process.

An active research and development program has been continually supported with the objective of improving metal recoveries, controlling emissions and effluents to meet environmental restrictions, and developing new processes to recover metals from the products of the emission control systems such as filter baghouses. As a result of this program, a sophisticated electric furnace is presently being installed to treat what was a waste slag from the cupola furnace. This installation which was previously piloted will in effect block the door to copper, nickel, tin, zinc, lead, and precious metals which leave the plant in the cupola slag, thus increasing overall metal recovery.

The oxides which are prevented from emitting to the atmosphere by the filter baghouses are complex in nature. A pilot plant is presently under construction to evaluate a process for treating the crude zinc oxides from the Carteret operation as well as similar baghouse or scrubber collects from other nonferrous and ferrous secondary smelters. The products from this process will be 99.99 percent pure zinc and a residue which can easily be treated by conventional processes for lead and tin recovery.

The Carteret plant, after nearly 70 years of operation, remains an important and growing contributor to U.S. copper and precious metals supply. With its emphasis on efficient extraction of all values in its raw materials input, it should continue to lead the way in the recycling and reuse of scrap materials for conservation of our mineral resources.

B. X: UNION ELECTRIC COMPANY'S SOLID WASTE UTILIZATION SYSTEM

David Klumb

INTRODUCTION

Full-scale testing to determine the feasibility of burning suitably prepared solid waste in an existing pulverized coal fired utility boiler has been underway by the EPA, the City of St. Louis, and Union Electric Company since April 1972. Approximately 50,000 tons of St. Louis residential solid waste has been processed providing a burnable supplementary boiler fuel of roughly 40,000 tons.

On February 28, 1974, the Union Electric Company announced that it would build, own, and operate an 8,000 ton per day, 2.5 million ton per year, solid waste utilization system (SWUS) capable of utilizing essentially all of the solid waste generated in the 4,500 square mile St. Louis metropolitan region with a population of about 2.5 million. The SWUS is scheduled for full operation June 1, 1977.

The SWUS, estimated to cost $70 million, will be built without government subsidy. Revenue to support the investment and to cover operating costs will be generated by trash hauler dumping fees, sale of recovered metals, and sale of the burnable fraction of the solid waste. The Union Colliery Company, a wholly-owned subsidiary of Union Electric, will build, own, and operate the system and no monies to finance the system will come from the parent company's electric customers.

GENERAL DESCRIPTION

The St. Louis region covers 4,500 square miles and includes two states, seven counties, plus the City of St. Louis. The region includes over 150 governmental units and over 150 public and private waste haulers. Current solid waste practice includes landfill, incineration, and roadside and promiscuous dumps. Current solid waste generation including residential, commercial, and industrial waste is estimated to be about 8,000 tons per day. The projection for 1980 is 10,000 tons per day.

Union Electric Company is an investor owned electric utility franchised to generate and distribute electricity in the eastern portion of Missouri and small areas in Illinois and Iowa. Over 90 percent of the company's electricity is generated at pulverized coal fueled steam-electric generating plants. The two power plants of particular interest to SWUS are the 2400 MW Labadie Plant some 40 miles west of St. Louis and the 900 MW Meramec Plant about 20 miles south of St. Louis. Coal consumption at Labadie is about 1,000 tons per hour and at Meramec about 400 tons per hour.

The St. Louis region is provided with railroads which radiate from the center of St. Louis like spokes in a wheel. Interstate highways and four-lane arterial roads also radiate from the core city and also encircle the metropolitan area. This railroad and road network along with the remote location of the coal fired power plants provide for the efficient truck collection and rail transport of solid wastes to the isolated power plants.

Figure X.1 is a diagramatic representation of the SWUS.

COLLECTION AND TRANSPORT

Union Colliery Company will not collect the solid waste where it is generated. Public and private trash haulers will be offered a dumping service at five truck-to-rail transfer stations. These transfer stations will be located on arterial highways and/or interstate highways to preclude heavy truck traffic in or near residential areas.

A typical truck-to-rail transfer station will have a capacity of 1,500 or 2,000 tons per day. The 1,500 ton per day station can be expanded to a 2,000 TPD capacity. Residential, commercial, selected industrial, and selected demolition solid wastes will be accepted at transfer stations. Tires, appliances, demolition lumber, yard wastes, and size reduced trees and trimmings will be accepted. Those wastes determined to be physically detrimental to the SWUS or classified as hazardous in SWUS by governmental agencies will be excluded. Only licensed trash haulers will be allowed to dump.

Trucks will be weighed before entering the totally enclosed transfer station building, Figure X.2. The trucks will enter the building and will be directed to dump in conveyor dumping pits or on the floor depending upon truck flow. All sizes of commercially available trash trucks will be able to use the facility including 75 yard transfer trailer trucks.

Front end loaders will load the solid waste from the tipping floor to the stationary compactor conveyor. The front end loaders will also be able to tow a stalled trash truck if it breaks down in the building or on building access roads. Present plans are to accept waste 16 hours per day, six days per week. Hours of operation will be scheduled to meet the demands of the haulers.

The solid waste will be loaded into 100 cubic yard containers by conventional stationary packers having a nominal capacity of about 10 cubic yards. No solid waste storage will be provided for in the stationary compactor conveying pit and there will be only peak dumping storage on the tipping floor. Sufficient packer

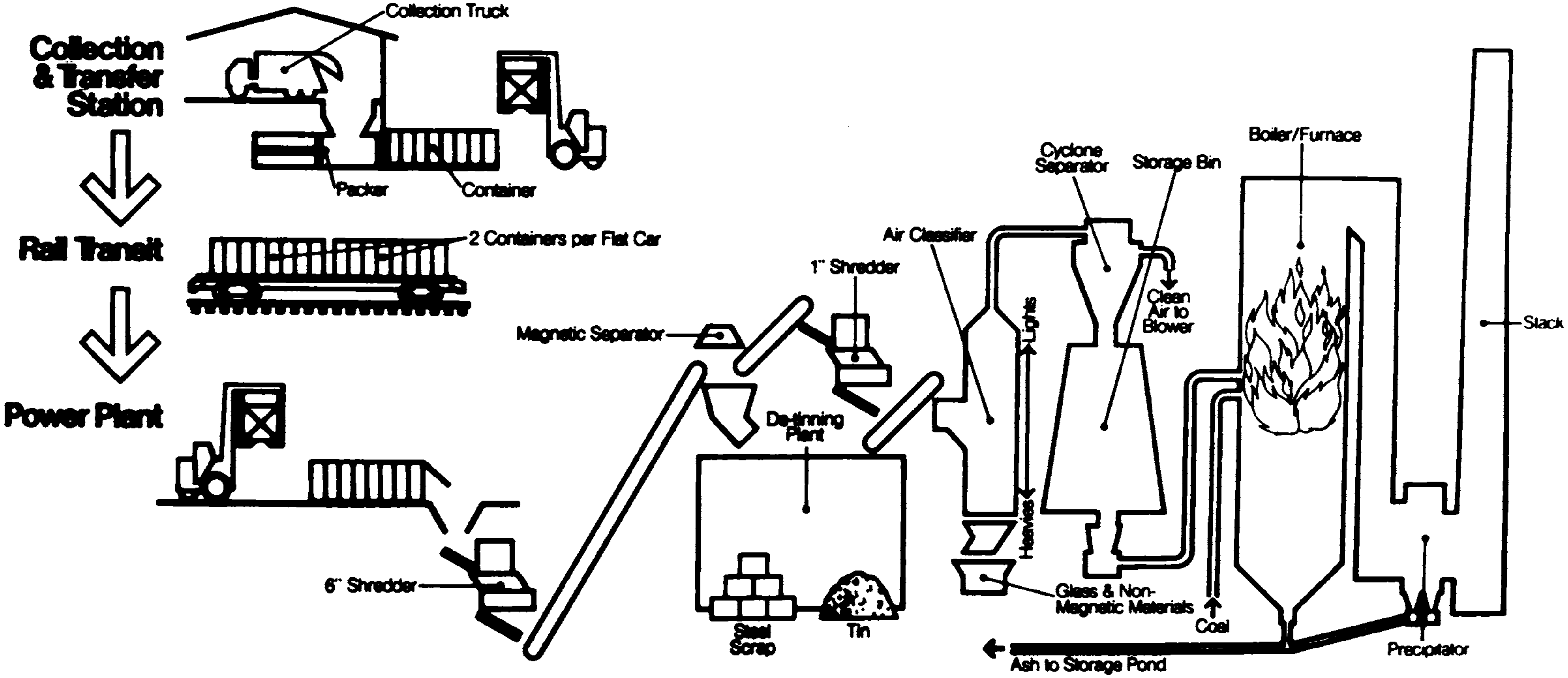

Figure X.1 Flow chart of Union Electric Company's planned Solid Waste Utilization System. Union Colliery Co., a wholly owned subsidiary, will build, own, and operate the S.W.U.S. without governmental subsidy by June 1977.

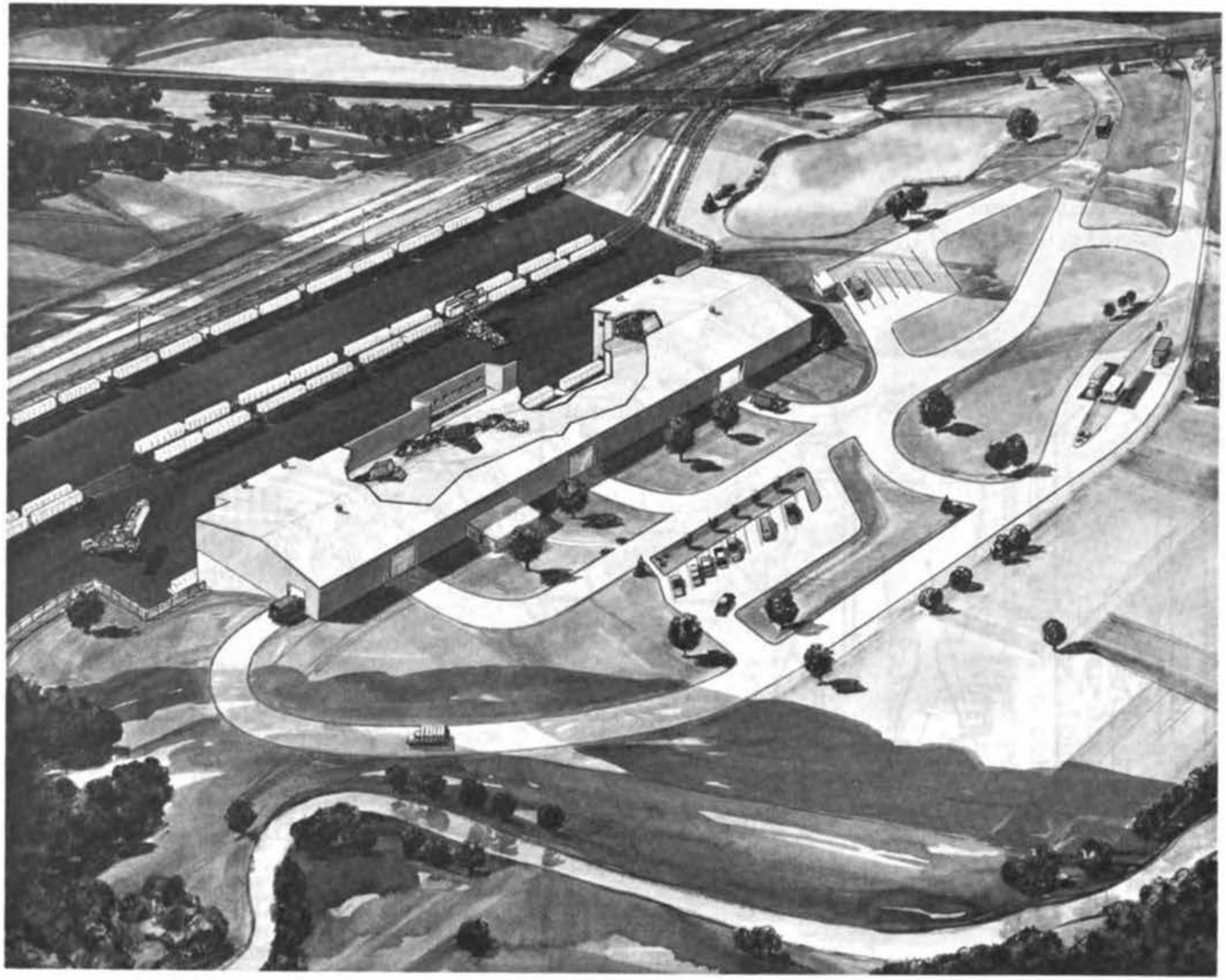

Figure X.2 Artist's rendering of one of the collection/transfer centers to be built as part of Union Electric's Solid Waste Utilization System. When completed in 1977, the system will be capable of handling essentially all of the solid waste generated in the seven-county metropolitan St. Louis area.

capacity is being provided to handle normal delivery with only 2 to 3 hours of peak delivery capacity being provided on the tipping floor.

The solid waste shipping containers are designed for a nominal capacity of about 90 cubic yards. The design is similar to a conventional 75 yard end loading solid waste transfer trailer body. Two containers will be loaded on a conventional COFC flat car. With a tare weight of about 20,000 pounds the container will carry a net solid waste payload of 35 to 40 tons.

The containers will be built to ISO and AAR standards for ship-board containers and can be carried on conventional ship container truck trailers. The 40 foot long containers will be equipped with a telescoping cylinder operated ejection blade and a guillotine loading door.

The container will be set on a movable steel framework which will lock the container to the stationary packer. The loading door will be operated by hydraulic cylinders. Load cells in the container positioning frame will cut-off the packer when the container is full.

The containers will be handled by conventional container handling vehicles. For short-term storage the containers can be stacked two high when full and three high when empty. Normal operation will provide for loading 36 to 50 containers on 18 to 25 rail cars per transfer station per day.

Two solid waste unit trains per day will deliver up to 6,000 tons per day to the Labadie processing plant via two different railroads. About 500 to 1,000 tons per day will be delivered to the Meramec process plant on a single unit train by one railroad.

PROCESSING FACILITIES

The SWUS is being designed to provide a nominal processing capacity of 6,000 tons per day at the west (Labadie) facility and 2,000 tons per day at the south (Meramec) facility. Maximum peak processing capability will be 9,600 TPD at the west facility and 3,600 TPD at the south facility. Both processing facilities will be able to accept truck delivered solid waste.

Containers at the processing plants will be handled by container handling vehicles. Placed on container unloading frames the containers will be unloaded by ground mounted telescoping cylinders which will operate the container ejection blade.

The west processing facility will include four processing lines, each having a capacity of 100 tons per hour. The south facility will include three lines. Each facility will have a redundant processing line to provide for hammermill maintenance. Figure X.3 is the PRELIMINARY process flow diagram for the west facility.

The first stage, reversible, auto shredder type, horizontal shaft hammermill will reduce the solid waste to a nominal 6 inch size. The first stage mill be 2,000 horsepower.

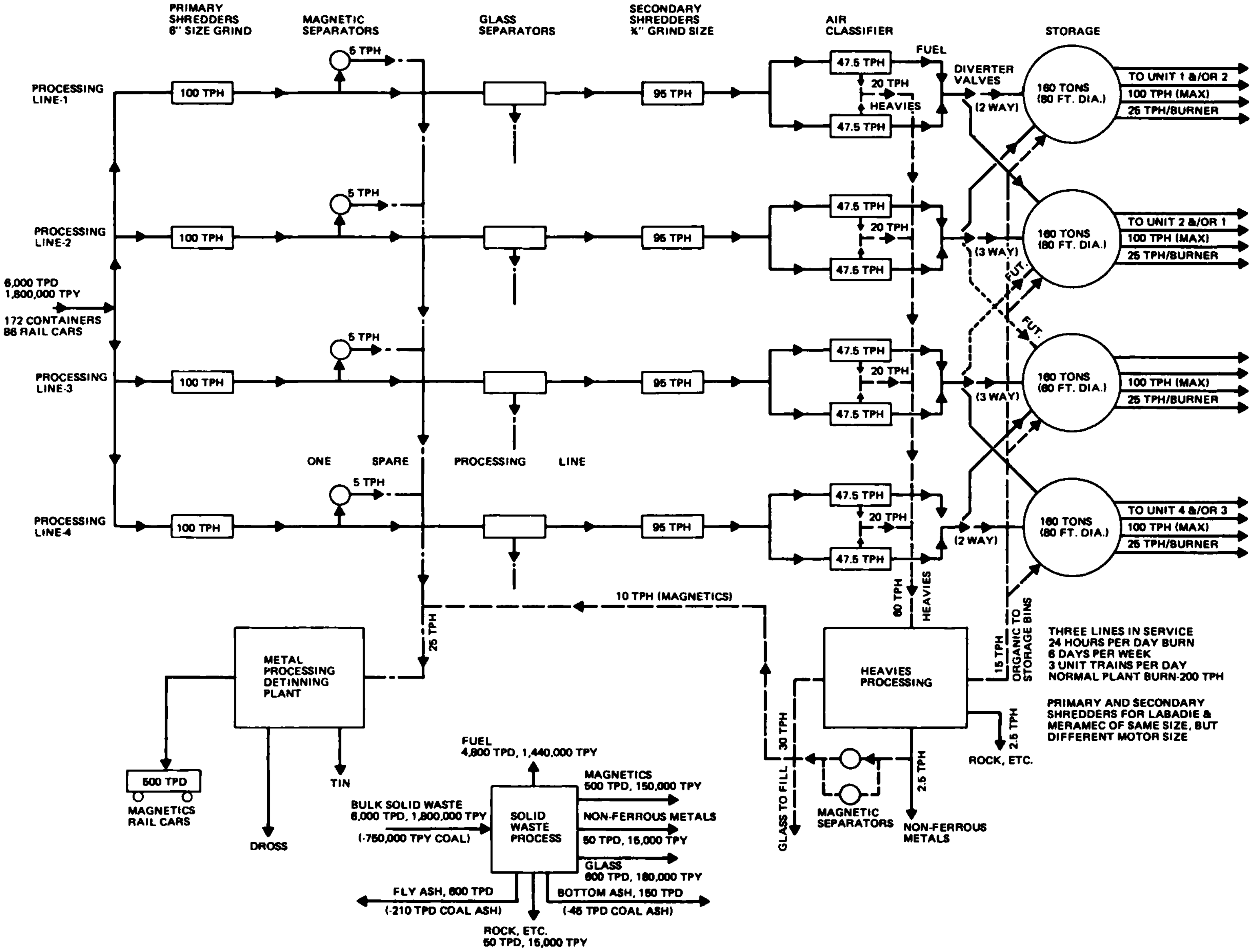

Figure X.3 Preliminary Flow Diagram: West Process Facility

The first stage mill product will be conveyed to magnets for separation of magnetic metals. The selection of magnets has not been made. Both belt and drum magnets are being investigated.

The magnetic metals will be sold to a secondary metal processor for detinning and production of tin and #1 bundle steel scrape. The magnetic metal processor has been selected but not announced at this writing.

The coarse milled waste, less magnetic metals, will be conveyed to a glass removal device. This device has not been selected at this writing. Investigations have been underway for the past few months to develop a device which will serve as conveyor and sizing device. Such a device appears to be commercially available and will be selected before May 1, 1975. The device is expected to remove about 50 percent or more of the glass and grit.

The 1250 horsepower second stage, horizontal shaft hammermills will produce a 3/4 to 1 inch product size. The mill discharge will be conveyed to air density separators (ADS), or classification into burnable and unburnable fractions.

At the west facility there will be two air classifiers for each of the four second stage mills. Each ADS will have a capacity of 50 tons per hour. The south facility second stage mills will each feed a single 50 TPH ADS.

The burnable fraction from the air classifier will be air transported to live bottom surge bins. At the west facility there will be 4 bins each with an outfeed capacity of 100 tons per hour via four outfeed chutes (see Figure X.3).

The west facility surge bins will be equipped with 4 outfeed systems. Each outfeed system will include two drag chain conveyors set into the circular floor on 45° centers. The two conveyors feed into a common chute which feeds the solid waste into a pneumatic, boiler charging system.

The surge bins provide only limited storage. At a boiler firing rate of 80 to 100 tons per hour there will be only 1/2 to 1 hour storage in each bin.

The bin sweep bucket trains and drag chain conveyors will be driven by SCR controlled D.C. motors.

At the south facility the existing experimental prototype bin that has been in service three years will be modified to provide for higher capacity and D.C. power. A new four conveyor bin will be used to provide firing to the two boilers at Meramec that were not used in the prototype. The south facility bins will be equipped with 4 outfeed conveyors and the new bin will have a capacity of about 60 tons per hour.

BOILER CHARGING SYSTEMS

The boilers at the south facility Meramec Power Plant include: two, 140 Mw, Combustion Engineering, tangentially fired units; a 250 Mw, Foster Wheeler, front fired boiler; and a 300 Mw Foster

Wheeler front fired boiler. All are fired with pulverized coal and are equipped with electrostatic precipitators.

The Meramec Unit 1 and 2, C.E. boilers are presently equipped with 4 solid waste burners per boiler. The SW burners will be relocated to fire the SW just above the top level of coal burners. One SW burner will be located in each corner of the boiler furnace at the top of the coal burner assembly.

The SW burners for Meramec Units 3 and 4 will be installed in the front wall of the furnace above the top row of coal burners. There will be four burners in Unit 3 and four burners in Unit 4.

The boilers at the west facility Labadie Plant include 4, 600 Mw, C.E., tangentially fired, pulverized coal boilers. All are essentially identical. Each boiler will be equipped with 4 SW burners, one per corner. The burners will be installed just above the top coal burner in the coal burner assembly.

The boiler charging system for each burner consists of one rotary air feeder, positive displacement blower, and piping from the feeder to the boiler burner. The infeed chute to the rotary air lock feeder is fed from a surge bin conveyor(s).

Because the SW will contain residual ground glass and some metals, the SW piping will be installed with removable wear black elbows. Ceramic lined fiberglass pipe is currently being investigated for the straight sections of the SW transport piping. The ceramic lined pipe, at 12 to 15 pounds per foot, is considerably lighter than plain carbon steel pipe and has proven to have very attractive anti-abrasion characteristics.

The boiler charging system is being designed to provide up to 20 percent of the full load heat input requirement of each boiler. Normally the 8,000 TPD SWUS processing capacity will require firing at 10 percent of full load heat input. This system provides redundant boiler capacity. To meet the 8,000 TPD processing rate only requires 2 boilers out of 4 at the south facility and 2 boilers cut of 4 at the west facility.

SOLID WASTE CHARACTERISTICS

Table X.1 gives the analyses for over 350 samples of air classified solid waste taken since November 1973. We also have analyzed over 200 samples of solid waste taken between April 1972 and November 1973 prior to the installation of the air classifier.

The analyses of the solid waste speaks for itself. However, note that the NaCl figure is subtractable from the Cl (total chlorides) figure. It is apparent that the residential SW does not contain critical levels of chlorine which will be released in the furnaces. The chlorine in the salt will not be freed below temperatures of 3000 F. Furnace temperatures are in the order of 2500 F to 2700 F. Over 75 percent of the chlorine in residential SW is in the salts.

The density of the SW after milling to 3/4 inch varies from 4 pounds per cubic foot to 7 pounds per cubic foot loose. However,

TABLE X. 1

Air Classified Refuse Analyses*

380 samples taken November 9, 1973 through December 10, 1974

			As Fired Basis			
	Moisture (%)	Ash (%)	Sulfur (%)	Total Chlorides (%)	NaCl (%)	Btu/lb
Average	27.5	18.5	0.11	0.34	0.27	5,006
Maximum	63.0	53.8	0.31	0.94	0.59	7,593
Minimum	3.0	7.6	0.02	0.13	0.10	2,293

Air Classified Refuse Ash (%)

	Average	Maximum	Minimum
P_2O_5	1.32	2.04	0.41
SiO_2	52.8	66.6	39.9
Al_2O_3	9.71	26.90	3.43
TiO_2	0.89	1.79	0.07
Fe_2O_3	6.40	22.19	2.57
CaO	12.06	16.50	6.92
MgO	1.48	3.17	0.22
SO_3	1.55	3.75	0.54
K_2O	1.68	2.91	0.89
Na_2O	8.22	19.20	3.11
SnO_2	0.034	0.10	0.001
CuO	0.21	1.74	0.03
ZnO	0.34	2.25	0.09
PbO	0.19	0.73	0.04

NOTE: NaCl percentage is subtractable from total chlorides

*Analyses by "Research 900" Division of Ralston Purina Company, St. Louis, Missouri.

when placed in storage to depths of 30 to 40 feet, the density increases to as high as 25 pounds per cubic foot. Moisture content and particle size have a significant effect on density and flow characteristics and these characteristics vary from day to day and through the system.

ENVIRONMENTAL IMPACT

Careful evaluation of the environmental impact of SWUS has been underway since initial operation of the prototype. Boiler gas emission tests conducted independently by the USEPA and Union Electric during November and December of 1973 disclosed no serous emission problems. The solid waste has an average sulfur content of only 0.10 to 0.15 percent.

B. XI: DESIGN AND POLLUTION CONTROL FEATURES OF THE SAUGUS, MASSACHUSETTS, STEAM GENERATING REFUSE-ENERGY PLANT

Walter K. MacAdam

INTRODUCTION

A steam generating plant using refuse for fuel is being constructed at Saugus, Massachusetts, which, on completion, will dispose of an average of 1,200 tons of refuse a day from some 16 communities north of Boston and provide energy to a nearby industrial plant for electric power generation and process steam. The system is designed to meet stringent pollution control standards for odor, particulates, gas, noise, and water emission, and will provide essentially complete refuse combustion without the need for auxiliary fuels. Clean metals and sterile ash suitable for road fill will be recovered initially and provision is being made for expansion of materials recovery sub-systems in the future as markets and technology make them economically viable. The design also contemplates future doubling of all plant capacity to 2,400 tons per day.

Ground was broken for the Saugus refuse energy plant in June 1973, with initial operation scheduled for mid-1975. The 16 communities with a combined population of approximately 500,000 are expected to make their own arrangements for refuse delivery to the plant weighing station and will pay tonnage fee for disposal. Complete and sanitary combustion of the refuse will produce more than two billion pounds of steam a year for sale to the General Electric Company manufacturing plant at Lynn, Massachusetts, across the Saugus River. This energy sale will help reduce disposal charges to the communities and at the same time reduce fuel oil requirements by approximately 70,000 gallons a day. It is significant that a net improvement in air pollution conditions will result since the sulfur and particulate emission from the refuse plant will be even lower than for the replaced facilities burning low-sulfur fuel oil.

An unusual feature of the plant is that it is privately financed, owned, and operated and will pay real estate and income taxes. Stringent requirements for continuity and reliability of refuse acceptance have been imposed since the land fill currently available to the communities will be permanently closed for environmental reasons as soon as the plant goes into operation. In addition, the demand for continuity of steam generating capability emphasizes reliability in the system design and calls for the provisions of adequate standby facilities.

BACKGROUND

The need to provide a modern and clean refuse disposal system became apparent in the Boston North Shore area when state environmental and other requirements resulted in a court order to close down a large sanitary landfill operation in the tidelands at Saugus, Massachusetts, serving the area communities. The concept of constructing a modern, clean total combustion facility to convert the North Shore refuse into steam energy came about as the result of cooperative discussions involving the communities, the General Electric Company, and the M. DeMatteo Construction Company, a construction firm and owner of the landfill operation. A permit for temporary postponement of the landfill shut-down was obtained and discussions were initiated with designers and constructors of refuse-energy systems. After exploring unsuccessfully one tentative proposal, negotiations ultimately led to the formation in April 1973 of the Refuse Energy Systems Company, (RESCO), a joint venture of Wheelabrator-Frye Inc. of New York and the M. DeMatteo Construction Company. RESCO has a substantial equity interest in the undertaking and will operate the facility and arrange for industrial revenue bond financing of the debt portion of the investment. Through the cooperation of General Electric, a contract for sale of steam was consummated, with delivery to start in the fall of 1975.

The system design and construction management is being carried out by Rust Engineering Company of Birmingham, Alabama, a subsidiary of Wheelabrator-Frye and construction is being undertaken by DeMatteo Construction. The plant design is based on Wheelbrator's exclusive license with Von Roll, Limited, of Switzerland and is an updated version of, and similar in operation to, other Von Roll refuse-energy plants in Europe, Australia, Japan, and Canada. In the Saugus situation, however, it meets generally more severe environmental requirements, makes use of advanced technology, and meets a number of specialized demands imposed by site conditions and unusual requirements for reliability and continuity of refuse acceptance and steam production.

Low operating cost over the life of the plant is considered essential as a protection against inflation. The estimated total initial capital cost of approximately $30 million for the plant recognizes these requirements and special conditions and includes land, maintenance shops, roads, weighing stations, vehicles, spare parts, utility bridge, and a one-half mile pipe line system extending across the Saugus River for steam delivery, condensate return, and electric power.

SPECIAL REQUIREMENTS

As noted previously, there are a number of unusual conditions and requirements placed on the design of the plant and reflected in the cost. These can be summarized as follows:

- The present landfill site has been ordered closed and cannot continue in operation after plant completion. For this reason an unusually large storage pit (6,700 tons capacity) is provided to accumulate refuse during shutdown of a boiler for maintenance or repairs.
- Since the plant is constructed on the landfill, the site conditions are poor, requiring all major structures to be supported by piles (over 600 piles; driven to bedrock, some 80 feet below.
- The communities prefer a single type of collection as a cost saving measure. As a result, minimum selectivity will be exercised at the plant in accepting refuse and garbage, provided it has domestic or commercial origin. Stoves, tires, mufflers, furniture, auto wheels, and pipes will be taken as normally present in municipal refuse.
- The steam delivery contract to GE requires not only oil standby jets in the main boilers, but also two auxiliary standby oil fired boilers.
- No intake or discharge is permitted to the river.
- A utility bridge and half-mile pipe line system is required to transmit steam across the Saugus River.
- Local air pollution control requirements are more stringent than federal standards.

BASIC REQUIREMENTS

The basic requirements are to accept an average of 1,200 tons per day of domestic and commercial refuse and provide steam to the General Electric Company at 625 psi and 785 to 825 F. Operation is 24 hours a day, 7 days a week. Peak steam delivery is 350,000 pounds per hour and not less than 65,000 pounds per hour. A minumum of 2 billion pounds of steam will be delivered annually.

A dump charge will be made, scaled in time at approximately half BLS cost levels. Steam charges are based on providing somewhat lower energy cost to GE than would be involved if oil were used as fuel. Charges will, therefore, move with oil price changes.

SYSTEM DESCRIPTION

This physical layout of the plant and its relationship to the GE Lynn River Works is illustrated in Figure XI.1. Refuse trucks will pass a weighing station and move up a paved earthfill ramp to

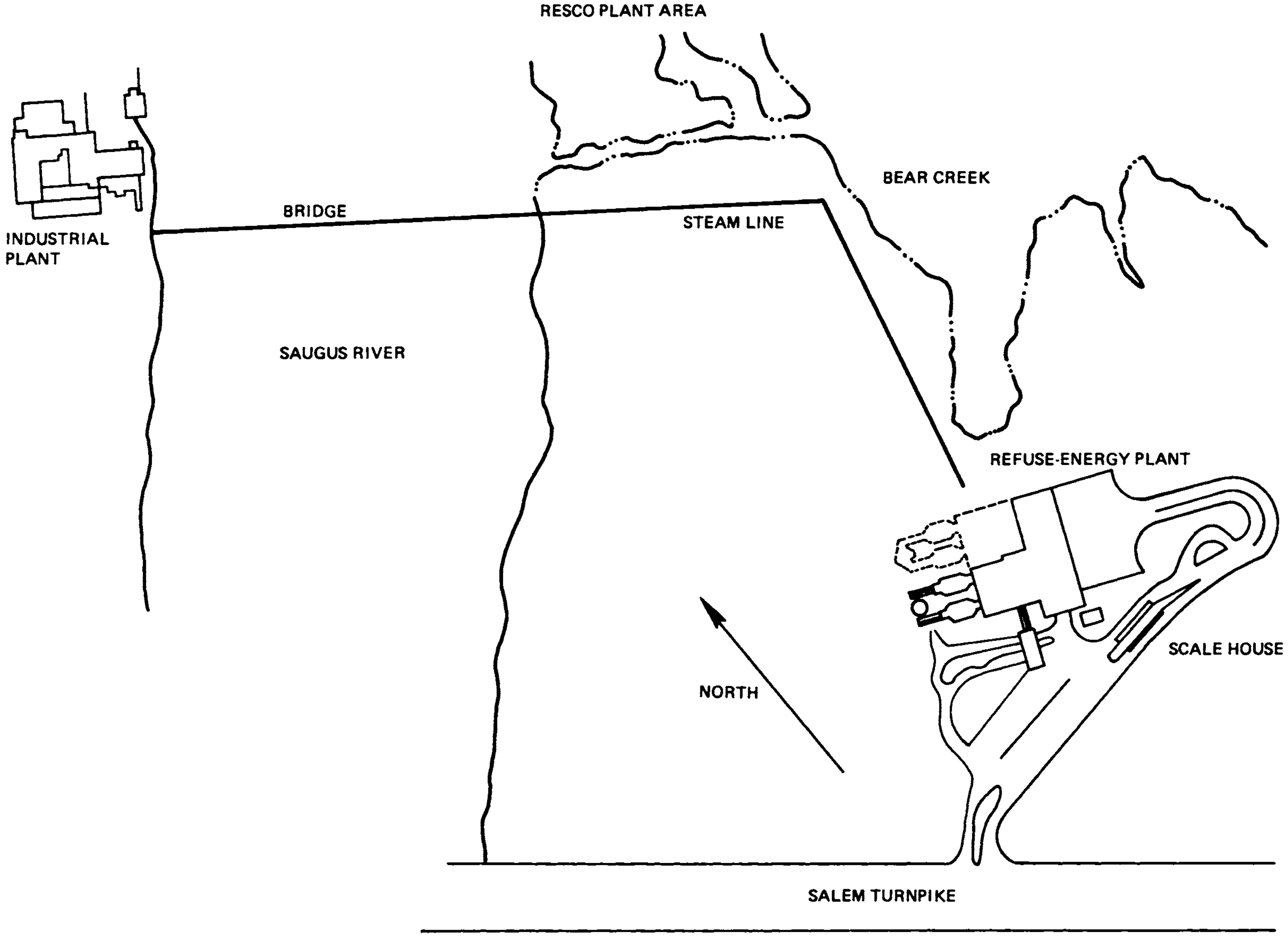
RESCO PLANT AREA
BEAR CREEK
INDUSTRIAL PLANT
BRIDGE
STEAM LINE
SAUGUS RIVER
REFUSE-ENERGY PLANT
SCALE HOUSE
NORTH
SALEM TURNPIKE

Figure XI.1

a receiving area. Here trucks are backed to the plant entrance doors and refuse is deposited in the 6,700 ton capacity pit.

A simplified cross section of the plant is shown in Figure XI.2. As indicated, the pit is served by a traveling crane system which serves the furnace feed hoppers and also permits mixing refuse as required to promote uniformity. Some unusually bulky refuse such as furniture will be transported by crane to a 1,200 horsepower fragmentizing hammermill which will reduce the largest dimension to about 12 inches and discharge the fragments back into the pit.

Two steam generators are provided initially, with a maximum capacity of 750 tons/day each, for refuse with a heat value of 4,500 BTU/pound (lower heating value). Provision is made for addition of two similar boilers at a later date. Two oil fired package boilers are also provided as standby units with a total capacity of 200,000 pounds per hour. In each furnace refuse is burned on a Wheelabrator/Von Roll reciprocating grate system without the use of an auxiliary fuel. This consists of three grates separated by steps over which refuse tumbles to provide complete combustion. Combustion gas temperatures are in the range of 1000 to 1800 F. Under-fire air volume and temperature as well as individual grate operating speeds are controlled to suit conditions and assure complete burnout. Much of this control is automatic.

The flue gas and furnace radiation heats the water walls of the boiler. Heated flue gases then pass through the convection section and come in contact with pendant boiler tubes. Dust and scale buildup is controlled by specially designed boiler tube rapping mechanism. The cooled gases pass to two Wheelabrator-Lurgi electrostatic precipitators, each with two fields, operating at approximately 99 percent efficiency, designed to reduce the particulate emission to 0.025 gr/scf (0.05 required). These are described in more detail later in the section covering to the atmosphere through a concrete stack 178 feet above grade.

Fly ash collected by the precipitators, riddlings, and clinkers are water quenched and passed by conveyor to a rotating screen. Bulky metals are separated for sale and the screenings are further subjected to magnetic separation. This permits sale of the remaining ferrous metals. The residual ash (about 180 tons/day) will be sold or used as road fill or deposited in a specially designated disposal area nearby. Quench water is discharged in wet ash or evaporated. Blowdown water is almost entirely consumed by transfer to the quench tanks.

FINANCING

Initial financing was arranged through Wheelabrator Financial Corporation, a subsidiary of Wheelabrator-Frye. This financing of the plant construction is not contingent on any signing of refuse

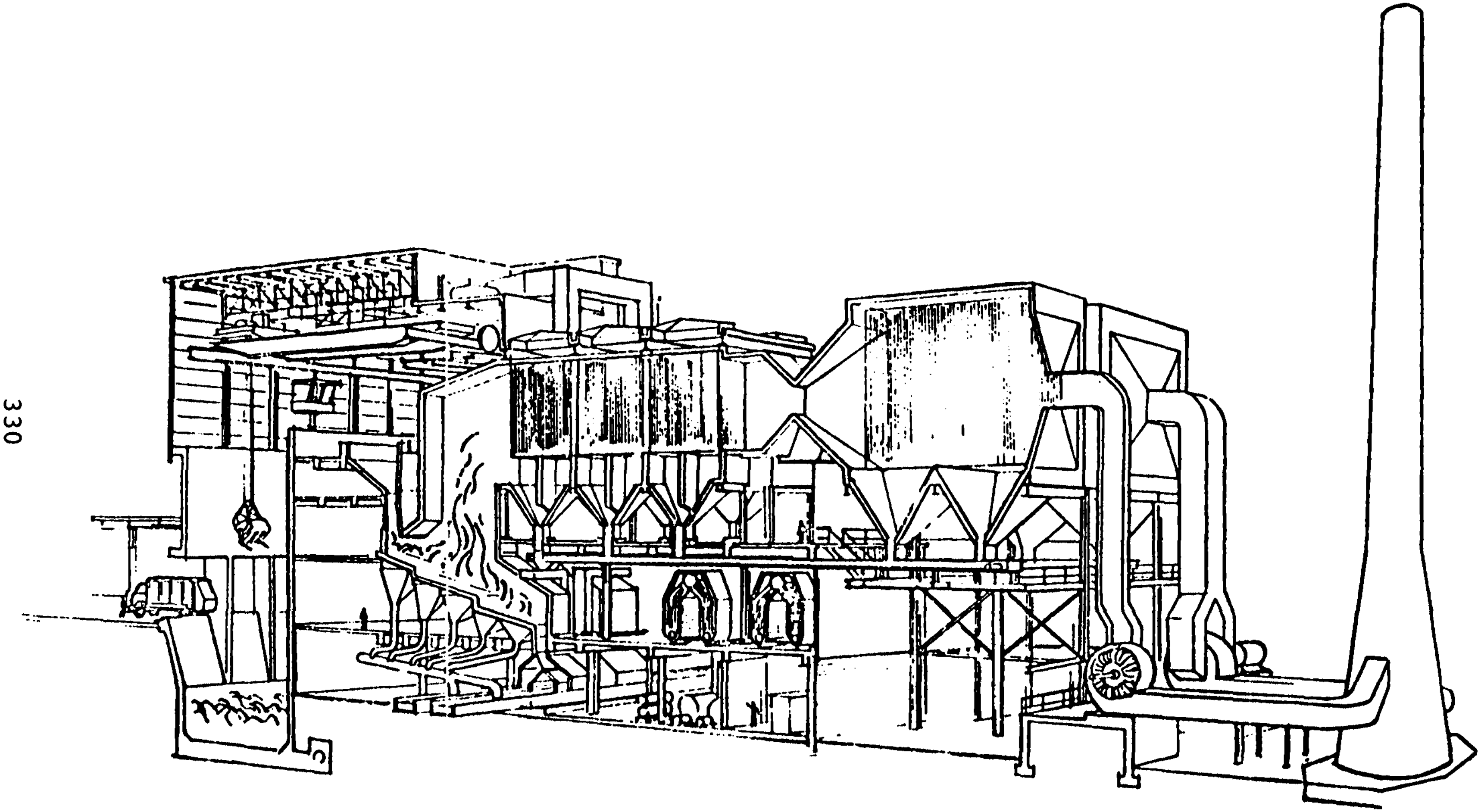

Figure XI.2 Wheelabrator-Von Roll Refuse-Energy System disposal contracts with the municipalities. Subsequent debt financing is being arranged through industrial revenue bonds.

ESTABLISHMENT OF DUMP CHARGE

Dump charges, or so-called tipping fees, are based on individual agreements with municipalities. It is contemplated that initial charges will be lower for longer-term contracts and that a BLS adjustment or similar escalation of rates will apply over the term of the agreements. RESCO has joined a number of the communities in obtaining the services of the MITRE Corporation, a not-for-profit corporation headquartered at Bedford, Massachusetts, to examine the costs of the project and to determine the appropriateness of the proposed charges considering costs and risks. This has resulted in a contract structure and pricing schedule adjudged fair to all concerned.

TECHNOLOGY

The RESCO project is designed to make use of updated technology applied to established concepts proven by at least several years of full-scale experience in similar situations. The importance of reliability, continuity in refuse disposal, pollution control, and steam generation were the principal factors in utilizing the total combustion system concept supported by substantial experience in Europe, Canada, and Japan. No wholesale shredding of refuse will be employed in order to mimimize maintenance difficulties and control operating costs.

The 13-acre site and plant layout has been arranged for maximum flexibility and to permit future construction of additional resource recovery subsystems, either at the front end or back end of the energy recovery unit when and if the technology, economics, experience, and market shows this to be a viable and reliable operation. Additional shredder pile foundations have been provided in the event that the future developments permit reliable, safe, and economical operation with this type of equipment.

POLLUTION CONTROL DESIGN

Odor Control

Odor control was an important consideration in both the construction and operation of the Saugus plant. Since the facility is being built on a sanitary land fill site covered by a layer of deposited refuse approximately 12 feet thick, unusual measures had to be adopted during excavation for the plant foundations and truck receiving area. A total of approximately

60,000 cubic yards of refuse material had to be removed to another area in the existing landfill and covered daily with a layer of earth. Deodorizing units, consisting of five-gallon pails equipped with wicks and filled with Air Kem water soluble deodorizing fluid, were placed at intervals of about 50 feet to the windward of the removal operation. Earth fill was placed in the excavation in a concurrent operation to minimize exposure. These procedures were carried out under permission and inspection of the Massachusetts Bureau of Air Quality Control.

Refuse odors during plant operations will be closely controlled by dumping all refuse into the indoor storage pit. A system of negative pressure will draw fresh air through the entrance into the pit enclosure from which it is drawn into the furnaces for use as combustion air. Furnace gas temperatures are maintained in the range of approximately 1500 to 2000 F, destroying odors in the combustion air and those emitted by burning refuse. The main control room, administrative space, and crane operator consoles are enclosed and air conditioned to produce a temperature and odor-controlled environment.

Control of Particulates

Fly ash and particulates in the flue gas will be reduced well below levels specified by federal, state, and local requirements. This is accomplished by means of collection hoppers under the boiler convection sections, followed by Wheelbrator-Lurgi electrostatic precipitators. Precipitators were chosen in place of wet scrubbers for reliability and to minimize generation of a steam plume from the stack caused by introduction of additional moisture. An individual, dry bottom precipitator is provided for each steam generating unit. Each will handle 240,000 cubic feet per minute of flue gas at 428° to surpass the stringent Metropolitan Boston Air Pollution Control District requirements of 0.05 gr/scf. The precipitators are designed to control particulates to 0.025 gr/scf, and therefore are sized to operate at an efficiency of approximately 99 percent.

The reliability and continuous availability of the precipatator units is enhanced by employing discharge electrode rods welded into pipe frames at 5-foot intervals. The rigid support system was considered to offer advantages over a system using weighted hanging wires by providing improved strength and controlling electrode failure due to material fatigue, corrosion, or oscillation. Any additional cost was considered to be outweighed by advantages from the standpoint of maintenance and continuity of operation.

Air Quality

Since refuse is a low sulfur fuel, typically with only about 0.1 percent sulfur content, no special measures will be required to remove this component. To fully disperse the exit gases, which consist almost entirely of nitrogen, carbon dioxide, and water vapor, a 178-foot concrete stack is being employed, 9 feet in diameter at the top. No problems with chloride emission are foreseen. Flame temperatures are kept below the level at which nitrogen oxides would be produced in any significant quanity. Based on experience with similar installations, these emissions are expected to be much lower than the 0.3 pound per million BTU input permissible for fossil fuel fired systems. Because the standby oil fired boilers are planned to be operated on low sulfur oil when no refuse is available, and will meet emission requirements, permission has been obtained to exhaust through smaller stacks extending over the roof, approximately 125 feet above ground level. Smoke density requirement of less than Ringelmann No. 1 will be met.

Ambient particulate levels have been calculated using Weather Bureau data and predicted emissions from the stack, using a computer program developed on the basis of ASME procedures. Predictions for one-hour concentrations under least favorable conditions indicated that the addition of the stack emissions to existing annual averages would not exceed the allowable value of 75 micrograms per cubic meter. Actually, operation of the refuse-energy plant should produce no net impairment to the average ambient level since this includes the present emissions of the GE plant which will be reduced when the refuse plant becomes operational.

Water Quality

Water for steam production, cooling, and ash quenching will be obtained from the municipal supply in addition to that needed for the sanitary system. Some steam condensate is to be returned over the utility bridge and optimum recirculation and treatment is provided to minimize input water requirements and effluent discharge. No river water will be circulated or used.

Waste water sources are the sanitary system, boiler blowdown, demineralization backwash, and blowdown from a small cooling tower involved with cooling and grate mechanism and similar apparatus. All blowdown and backwash, neutralized as required, is pumped to a holding tank which feeds the ash quench conveyor channels. No ash quench water is recirculated since it is progressively removed in the wet ash. Under operating conditions, total flow to the sewer is expected to consist primarily of the sanitary discharge.

CONCLUSION

Unusual construction conditions and the need to provide essentially uninterrupted availability of refuse reception, control of pollution, and steam generating capacity has resulted in specialized adaptations in the design and pollution control measures for the Saugus Refuse Energy System. It should provide an example of a multi-community refuse disposal service operated in an environmentally sound manner on a private enterprise basis and privately financed. Significant and important elements of the system plan included the cooperation of a large industrial energy user and the decision to employ a design based on demonstrated concepts with minimum preprocessing and selectivity of refuse input.

B. XII: THE ECONOMIC ATTRACTIVENESS OF REFUSE-FIRED GENERATING PLANTS SELLING ELECTRIC POWER TO PUBLIC UTILITIES: A ROLE FOR PRIVATE ENTERPRISE

Walter K. MacAdam

Recent drastic increases in electric power prices have brought home to a large segment of the public a fact known for a long time by power company people--power system operating expenses are controlled almost entirely by fuel costs. The phenonmenal rise in oil prices and environmental restrictions on use of high sulfur coal have placed a critical economic burden on utilities that carries through to the energy using public and to other industries in the form of suddenly increased power costs.

Faced with this problem, industries and government groups in the U.S. and abroad are actively exploring new energy sources and conservation methods.

Such actions include the establishment of long-range plans for expansion of nuclear power and coal resources and developmental work in the areas of synthetic fuels, solar, and geothermal energy from municipal solid waste. Refuse-derived power has particular attractiveness because it simultaneously attacks another serious and growing social and economic problem, the clean disposal of millions of tons annually of U.S. household waste. Moreover, it offers the possibility of recovering large quantities of materials resources in addition to energy.

As a source of supplementary electric power for use by public utilities, however, refuse has been somewhat at a disadvantage in the past compared with fossil fuel. Related to nuclear power it compared even less favorably. The reasons for these shortcomings are several. Refuse heat value, while substantial, is only about one third that of coal by weight and even less by volume. Solid waste is a non-uniform material, offering numerous problems in combustion and varying in its availability on a daily and seasonal basis. Plants processing refuse are limited by logistics of delivery to sizes smaller than fossil fuel fired utility installations. Steam pressure and temperature are limited by possible corrosion and slagging problems. In fact, the principal reasons that refuse has been given any serious consideration as a fuel are the economic supports provided by "dump charges" to the municipality for refuse disposal and potential revenue from recovered materials.

It is small wonder, then, that, even in Europe, where refuse-derived energy has been used for more than 20 years, the chief applications have been district steam or hot water heating or steam sale to industrial plants, with only moderate emphasis on electric generation. In the U.S. the relatively low fuel cost of the past and ready availability of low cost landfill have made refuse-derived energy even less attractive. Until fairly recently, the approach in this country has therefore been directed primarily toward two general fields of application:

- refuse-fired steam generating systems delivering low or moderate pressure steam to nearby industrial plants, with attendant limitations on site location; and
- production of shredded refuse fuel, consisting primarily of the paper and light plastic component, and firing this as a 10 to 20 percent (heat value) supplement to coal in a modified suspension-fired utility boiler.

As a basis for the validity of these past limitations, numerous economic studies had concluded at that time that the level of realistic refuse disposal charges, boiler conversion efficiencies, and competitive utility generating costs could not support economically viable generation of power for sale as electricity to public utilities. The Mid-East oil embargo of 1973 and some recently demonstrated technological advances changed this picture significantly and to a degree that may not yet be fully recognized. Inflationary and environmental pressure also helped tip the economic balance. In summary:

- utility fossil fuel costs increased substantially in relation to refuse plant processing costs;
- refuse-fired boiler design refinements, based on experience abroad, demonstrated the practicality of reliable operation at higher steam temperatures and pressures than had previously been the case, with consequent improvement in power generation efficiency: electric generation was now realizable at a ratio in excess of 650 kilowatt hours per input ton of municipal waste as received;
- advances in boiler design minimized past tube surface cleaning problems and substantially increased unit availability;
- dwindling available satisfactory landfill sites near urban settlements and increased concern for ground contamination resulted in higher value to communities for clean refuse disposal and willingness to pay increased tonnage dumping charges; and
- the emergence of transfer compactor substations permitted tractor-trailer delivery of compacted refuse to the processing site, thus reducing road traffic and permitting larger and more efficient installations.

These changes have produced a radical revision in the economics of power generation in refuse energy plants for sale of electricity to public utilities. Acting together, these factors have brought about what amounts to an important economic breakthrough. In summary, it can now be concluded that:

On the East Coast of the U.S. and in some West Coast areas where there is predominant dependence for the next several years on oil or low sulfur coal, it is now generally economical to generate electricity from refuse and sell it to electric utilities at mutually advantageous rates. Similar situations may also exist in other areas under favorable local conditions.

The emergence of this important possibility introduces three other factors which further increase its attractiveness.

- Electric generation can be connected to a power transmission grid at many alternative locations, thus freeing up the previous need to be adjacent to a steam user. This simplifies siting problems and significantly expands the field of use of such facilities.
- Refuse-generated power is a small fraction of the utilities' generating capacity. Therefore, costly backup power generation facilities are not required at the refuse power plant such as are usually required in serving an industrial user.
- It no longer becomes necessary to match steam pressure and temperatures of an industrial user. The optimum steam conditions for electric generation can be employed.

The reality of these improvements in comparative economics can be tested by the actions of private enterprise in the market place. The following developments will be reassuring in this respect.

- One 25 percent exclusive contract has already been consummated with an East Coast utility for sale to it of refuse-generated electric power at a minimum charge in the range of 24 mils per kilowatt hour and with escalation based on fuel cost.
- A recent competitive proposal request by a major U.S. municipality produced three bids by industry to generate electric power from refuse with tentative prices in the 17 to 25 mil per kilowatt hour range. Disposal charges to the municipality were proposed at levels below $10 a ton.
- Private industry has been willing in selected situations to take an equity interest and be responsible for all financing of refuse energy plants generating electricity from refuse for sale to utilities and recovering valuable materials. Such plants can pay local taxes and the equity ownership can serve as an indication of confidence in long-term reliable performance and economic viability.

In considering the appropriate selling price of electric energy to utilities, it is important to recognize that refuse power is produced essentially on a continuous basis. It is not related to relatively high cost for power delivered during peak load periods. Because of this capability as a long-term continuous power supplement it bears a close relation to a utility's total average generating costs and not merely the cost of the fuel component. This average total generating cost has been the basis of the current successful negotiations with East Coast utilities and accounts for prices currently in the 15 to 25 mil per kilowatt hour range.

WHY PRIVATE ENTERPRISE?

It is apparent from the previous discussion that private enterprise can play and, in fact, is playing an important role in the planning and implementation of systems disposing of refuse and extracting energy and other resources. This is more than coincidental. There are numerous situations where the initiative of private firms can become a catalyst in the early realization of a refuse-energy system, with its attendant social, environmental, and economic benefits. Some factors supporting this capability are the following:

1. when multiple communities are involved, a single firm can take the initiative for a large-scale project which would be unattractive or difficult for a single small community to undertake;
2. a private owner is more inclined to design for optimum life time costs rather than to become preoccupied with low initial cost to which many communities are attracted;
3. marketing effectiveness is enhanced for energy and materials if the owner-operator has a bottom line cost center responsibility;
4. efficient operation is encouraged by private ownership with an appropriate level of preventative maintenance by skilled operators; and
5. financing is simplified if the private owner takes full financing responsibility and no economic burden is placed on the taxpayer. The payment by the owner of local real estate taxes encourages community acceptance.

Looking to the future, all indications point to increased economic attractiveness of refuse-fired electric generation in plants designed specifically for this purpose. The delays being experienced in development and expansion of nuclear power offer numerous locations where, for many years, the principal energy source will be increasingly expensive clean fossil fuels. Here, all reasonable alternative energy sources must be explored, including the socially desirable option of recovering electric energy and resources in the clean disposal of municipal solid waste.

APPENDIX C: INSTITUTIONAL

C. I: PROBLEMS CONFRONTING EFFECTIVE RECLAMATION SCHEMES

Lois Sharpe

INTRODUCTION

It was in the spring of 1971 that the League of Women Voters, all 1,300 plus local Leagues in the 50 states, Puerto Rico, the Virgin Islands, and the District of Columbia, officially began their concentrated work on solid waste problems. Four years is not a long time, really, in terms of what is necessary in the field in which the League works, namely to inform the public, raise the sights of the government officials, and press for new institutional arrangements. But sometimes it seems a long time since 1970, for while there have been a lot of news stories and symposia, forward movement in terms of emplacement of these complex processes has necessarily been slow, with many processes only emerging. Public interest continues, but media attention falls off.

THE PROBLEM

With solid wastes increasing faster than population, with the trend to multiple packaging, to "no deposit, no return" containers, and to planned obsolescence, the problems transcend many communities' ability to cope.

We see the village and city dumps still there. In 1971 we wrote of liquids leaking from open dumps, feed lots, mine tailings, and poorly engineered or operated land fills contaminating surface and ground water. Particulate matter, gases, and odors from burning trash dumps, badly designed and maintained incinerators pollute the air. And these conditions persist. We saw in 1971 and we still see land pollution and urban blight produced by an affluent America using and throwing away abandoned automobiles as eyesores from coast to coast, while paper, bottles, and cans litter practically every spot where man has trod, from city streets to the top of Mt. Whitney.

Cities especially face severe problems. Their central sections need better sanitation services. Population density, inadequate storage facilities and antiquated air polluting incinerators in older buildings, inefficient collection services, vacant lot piles of discarded appliances and rubble from building or road construction--think how these add up in hidden costs of rodent and insect infestation, land value depreciation, and degradation of living conditions.

Why do these conditions continue? We all know that recycling and reclamation are the sensible way to go. The work of the National Commission on Materials Policy, by this body, by the Office of Technological Assessment, by the materials societies, have shown us all the necessity for resource recovery. The OPEC embargo brought home clearly the value of the nondurables and the organic components of solid wastes as an additional energy source. As the new Federal Water Pollution Control Act (PL92-500) and the Marine Protection Research and Sanctuaries Act (PL92-534) operate to restrict disposal of heavy metal and toxic waste in waterways and oceans, we know their presence in leachate from land disposal will increase.

BARRIERS TO RECYCLING

With so many cogent reasons for recycling, why must we meet today in this very necessary meeting to consider the roadblocks to recycling? I know there are technological problems, which a number of you will discuss. But I see the economic and institutional constraints as the most formidable barriers to advance. And I see them as intertwined, reinforcing each other in holding back the time when recycling will cut back the quantity of solid waste for which a local government must provide ultimate disposal.

Institutional Constraints

If our interest lies in resource conservation, not disposal of solid wastes only, it is necessary to consider the following ideas.

1. Institutional arrangements that keep the price of virgin materials down and/or raise the price of reusables, and that make competition in the market difficult. Without a market for the reclaimed materials, recycling of postconsumer scrap will never come about.

Among the institutional arrangements that affect the comparative prices of virgin and reclaimed materials are:

a. federal tax policies that favor extractive industries (capital gains treatment for income from sale or cutting of trees held more than six months, percentage depletion allowances for extractive industries, recapture of mineral exploration and development costs as deductions as current expenses);

b. higher shipping rates set by the Interstate Commerce Commission and Federal Maritime Commission for secondary materials (important because industries locate near sources of virgin resources, but secondary materials, except for prompt scrap, are collected from scattered sources and brought to users): higher shipping rates limit the market to short distances (auto dismantler market size is an example); and c. government labeling and purchasing specifications based on whether the material is virgin or secondary rather than on performance.

Closely related to price, but in a different way, is the point that our production system with its emphasis on planned obsolescence and fashion there is no advantage in making products that last a long time or are readily reclaimable or recyclable. The important last line on the balance sheet favors other goals and is not affected by the adverse impacts of products upon the environment once their days of usefulness are over. The cost to society of disposing of them is excluded from the companies' costs. Nor does our market system reward the consumer in any direct way for buying a product that can be reused or easily recyclable.

2. The whole system of collection of municipal wastes with its bias towards mixing all types of materials together and thus adding the expense and complexity of sorting out again.

A number of communities now require separation of one kind or another--cans out, paper separate, separate pick-ups for large appliances. Sanitation services experts say, I know, that the housewife resists this, that city apartments lack space for separation, and that token response to separation of waste is useless.

But must everyone sort or no one sort? Could not the heterogeneity be reduced if not eliminated? Reliance on polls may not give the answer that could be developed with a strong citizen education campaign to explain the importance of separation at source. Of course, separated materials must be kept separate during transport. Separation need not be into fine fractions; three major categories will be adequate: newsprint and magazines, bottles and cans, all other wastes.

3. Uncertainty of smaller communities about reclamation technologies presented to them. Perhaps the situation is improving, the pressure lessening, but between 1971 and 1975 I heard of many small cities whose elected officials were approached about technology for reclamation and who were at a loss to know whether the system would work; would save the town some money and make its disposal site last longer. The engineering expertise at the command of the town and small city officials was inadequate to supply the answers and no one knew from what unbiased experts to seek the answers.

City fathers confronted by new technologies to convert their wastes into marketable scrap are not going to invest all those dollars until they are sure the systems will work. And with so many demands on local government and all costs rising they are unwilling to invest money to find out. And it may be just as well that they have hung back.

4. The marketing of materials reclaimed in a publicly owned recycling system seems to me to be another institutional obstacle. Governments have developed purchasing arrangements. But I wonder how many have selling skills. Since the expense of recycling will be bearable and its resource benefits obtained only if the reclaimed materials reenter the market, locating buyers, and so on, is essential to success. I do not know whether governmental bodies will be able to establish arrangements with the secondary materials industry, or directly to fabricators, fast enough. They will certainly have difficulties adjusting to the peaks and valleys in pricing.

Recovery of energy from mixed combustible waste could also require marketing but to some extent could be a transfer of services with the governmental entity--heating government buildings.

5. The multitude of small governmental units are a constraint on development of recycling systems.

a. Local communities, lacking adequate funds to go into resource reclamation alone, are yet beset by jealousies and mistrust. They distrust other local governments. They distrust the state or the regional body. They distrust private corporations. Moreover, garbage collection and disposal is an activity in which local people are accustomed to expect a lot of political machinations. (In some jurisdictions institutional arrangements for solid waste management are still so primitive that collection and disposal of household and commercial wastes may be contracted out to private collectors, the street department copes with litter and leaf collection, and the police department with abandoned cars.)

b. Local governments are reluctant to sign long-term contracts, and their citizens are reluctant to approve large bond issues. Even if they were willing, the local tax base is too small to support a recycling system along with other government services. Local governments are not building up any surpluses today. State entry therefore has been especially desirable.

c. Regionalization of services across jurisdictional boundaries is not yet easy, but it is the way to go. The problem here is that most regional agencies, to come into existence at all, had to be toothless tigers with power to persuade but not enforce.

Sociological Constraints

In discussing this subject with League members who are right on the firing line in their home communities, I was reminded that the greatest single obstacle to growth of recycling is that people still have a garbage dump paranoia. Therefore siting and lack of understanding are barriers to recycling.

1. We must remember that politically, if not legally, local approval or support for the site of the recycling center is necessary. No one wants the site near him.

Therefore, site selection is of utmost importance. Opposition to a reclamation facility will be less if the site:

- is already zoned industrial; and
- has direct access from a major road (citizens are inflamed by the prospect of fleets of trucks going through parts of the community to reach an isolated facility).

2. Public opinion is a powerful tool when, through whatever mysterious process, it coalesces. One part of overcoming the institutional and sociological constraints on resource recovery is to educate people:

- to consider their refuse as a source of revenue through sale of separated materials, and
- to look on recycling as an industry that will be a source of tax revenue or payments in lieu of taxes.

CONCLUSION

Because of these institutional constraints and others, I have toyed with the paradigm of a regional solid waste recovery system built and run as a regulated utility by a private taxpaying company for profit (like an investor-owned electric utility) to which the public solid waste management agency delivers waste and the governing body pays a fee no higher than the present cost for waste disposal.

But it will be a mistake for recycling systems to depend on constancy in the mix and to be predicated on the premise that there will be no reduction of waste at source. Public opinion is growing more favorable toward cutting back on the amount of waste we create. Interest in returnables is increasing. Higher prices for goods and energy are also working in that direction.

As the Washington Post editorial of April 2 said:

> Well, resource recovery and recycling is a fine idea, and we don't belittle the approach. But if the efficiency of recovery centers must rely on the maintenance of high volumes of trash, taxpayers may indeed wonder where this logic gets them. Does it make sense to design systems to accommodate

wasteful industry practices, or shouldn't the amount of waste be cut first? More and more government officials--in this region, in Congress and in the Administration--are concluding that the first step is source reduction, which includes legislation embracing a phased approach to a returnable container system.

C. II: RESOURCE UTILIZATION IN APPLIANCES

Robert T. Lund

(Most of the material presented in this paper is based on work done under an NSF-sponsored research project by MIT's Center for Policy Alternatives and the Charles Stark Draper Laboratory, Inc., as reported in "The Productivity of Servicing Consumer Durable Products," June 1974. In particular, the author is indebted to the study by Deh-I Hsiung and J.B. DeWolf in that report.)

Concern over materials shortages has generated an impressive effort to recover value from municipal solid wastes. These wastes, now an expensive nuisance, must become an economic resource. Because of the technical, economic, and societal problems of realizing this goal, however, it may be instructive (and perhaps, even more, conservational of resources) to examine how we can reduce the rate of flow of consumed products into the solid waste stream.

Even the most efficient collection, handling, sorting, and processing techniques for solid waste are expensive. Consequently, the "products" of these processes have a value that is only a tiny fraction of the worth of the products from which these wastes derive. If, somehow, the utility of products could be maintained for a longer time, this would have a beneficial effect both on materials usage and on the size of the solid waste handling problem.

Major household appliances use substantial resources, and are part of the solid waste stream. I would like to use this class of products as a means of illustrating alternative approaches to (1) the reduction of energy and materials consumption and (2) the reduction of municipal solid wastes.

Approximately 40 million air conditioners, major kitchen appliances, home laundry appliances, and water heaters are produced each year. An additional 15 million television sets are made each year. This volume represents approximately $13 billion of annual retail sales (Merchandising Week 1974). In 1972 there were an estimated 330 million major appliances and 115 million television sets in this country. During the 10-year period 1964 to 1973 domestic sales of these products increased at an average rate of 6.5 percent per year. Although there is market saturation of some products (99 percent of U.S. households have a refrigerator), many products, such as dishwashers, air conditioners, and color television sets, still have significant market potential. The 33 percent increase in households predicted for the 1970 to 1985 period should further increase the production and sale of appliances (Axel 1974).

Steel is the principal material used in appliance manufacture. Modest amounts of copper, brass, and aluminum are also consumed. Use of plastics for both cosmetic and functional purposes continues to increase. Table II.1 is an estimate of materials usage for six major appliances as reported in 1971.

The shift toward greater use of plastics is illustrated by a 1975 estimate of materials used in refrigerators, in which the weight of plastic in new refrigerators was 49.4 pounds, 45 percent higher than the 1971 usage, while steel content was 154.5 pounds, 40 percent lower than the 1971 figure (Appliance Manufacturer 1975). Similarly, the use of copper and brass in room air conditioners has shifted from 36 pounds to 4 pounds and the use of aluminum has increased from 10 pounds to over 18 pounds.

Consumption of the major metals by the six most important appliances is shown in Table II.2. Growth in metals consumption by these six appliances over a 10-year period is shown in Figure II.1.

On the basis of these figures and current rates of production, annual metals usage for all major appliance and TV manufacturing is currently about 3 million tons. As Table II.2 indicates, this use represents a fairly low percentage of total metals consumption. However, these products share many characteristics in common with other consumer durables such as the 100 million electric housewares (fans, blenders, hair dryers), the 7 million lawn mowers, and the 9 million automobiles produced annually. Taken as a whole, consumer durables represent a significant fraction of annual use.

The rate of appliance discard is the prime factor affecting both resource use and solid waste generation. This rate is dependent on the number of appliances bought in any given period and the <u>service life</u> of these appliances. The service life is the total useful life an appliance up to the time a consumer decides to discard it. It is only partly a measure of the durability of appliances, because consumers may also discard appliances for reasons of style, appearance, features, or frequency of repairs. Rate of use also affects the service life. Consequently, there is a wide dispersion of actual lives around the average service life of a given class of appliances.

Relatively few studies of appliances service life have been made. They show that with few exceptions the average life of

TABLE II. 1

WEIGHT OF MATERIALS USED IN HOUSEHOLD APPLIANCES

	Weight in Pounds				
Appliance	Average Total	Steel	Copper and Brass	Aluminum	Plastic
Air Conditioner	125	62	36	10	9
Range	200	178	2	2	2
Refrigerator	325	260	12	9	34
Dishwasher	147	120	5	2	20
Clothes Washer	250	207	4	15	7
Clothes Dryer	145	132	2	4	6

Source: NIPCC (1971)

TABLE II. 2

ESTIMATED METALS CONSUMPTION: 1967 (MILLIONS OF TONS)

PRODUCT	STEEL	COPPER/BRASS	ALUMINUM
Room Air Conditioners	0.128	0.074	0.021
Ranges	0.359	0.004	0.004
Refrigerators	0.613	0.028	0.021
Dishwashers	0.095	0.004	0.002
Washers	0.452	0.009	0.033
Dryers	0.175	0.003	0.005
Subtotals	1.822	0.122	0.086
Total U.S. Demand	113.7	2.792	3.702
Appliance Consumption (Percent)	1.6	4.4	2.3

Source: MIT (1974)

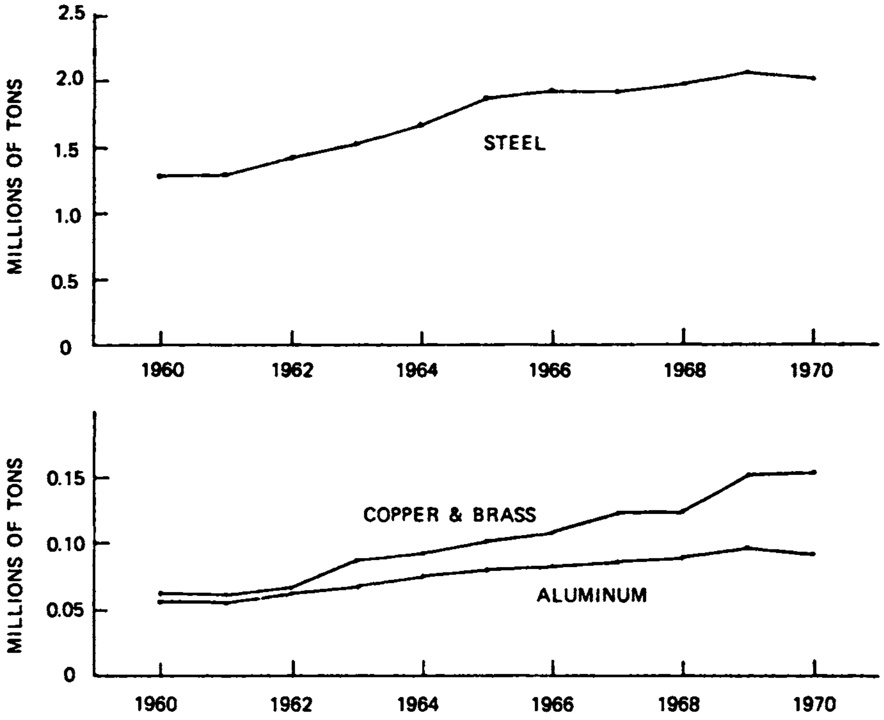

Figure II.1 Tonnage of Steel, Copper and Brass, and Aluminum used for Six Major Household Appliances

Source: MIT (1974)

appliances has not been increasing. Table II.3 summarizes studies in 1967, 1970, and 1972 for new appliances. There is remarkably little change during this period.

The decision to discard an appliance often comes at a point of failure of some part of the unit. Since most appliance failures are repairable at some cost, the service life thus depends in part on the cost of repair relative to the cost of a new appliance. With the cost index for appliance repair services rising 50 percent from 1955 to 1971 while appliance prices were actually declining 16 percent, the option of buying a new appliance rather than repairing the old one has become more and more attractive. This has probably had a dampening effect on the extension of service life through greater inherent durability of the appliances.

The rate of discard of major appliances (excluding TV and electronic equipment) is currently estimated at about 25 million units per year, and is expected to reach about 30 million per year by 1980. Figure II.2 presents an estimated trend of appliance discards as published in 1971 by the National Industrial Pollution Control Council. Trends in television set discard through 1968 are shown in Figure II.3.

As market saturation levels for appliances are reached, the discard rate will approach the rate of new appliance sales. Thus, approximately 40 million appliances and 15 to 20 million television sets will be discarded annually in the 1985 to 1990 period, if the service life of appliances continues to remain static.

The total solid municipal waste collected in the U.S. annually is about 200 million tons, and appliances account for about 1 percent of the total Even though they constitute a small fraction of the solid waste, appliances differ from the newspapers, packaging materials, food wastes, and similar items that make up a much larger fraction of the total.

1. Appliances represent a higher concentration of value--greater value added while they are still usable products, and greater materials value as discards.
2. Even when discarded, appliances usually contain component parts and assemblies that are still functionally useful.
3. Appliances are part of a larger family of consumer durables for which the same options for resource conservation may be open.

Recycling of discarded appliances for metals recovery is uncommon, as is the salvaging of useable component parts. The low value of the salvaged materials as compared to the processing costs to obtain them appears to be the major deterrent. Collection costs are also present, but these tend to be borne by the consumer either in supporting municipal refuse collection

TABLE II. 3

NEW APPLIANCE SERVICE LIFE IN YEARS

Product	1967 Dept. of Agriculture(a)	1970 Manufacturer(b)	1972 Dept. of Agriculture(c)
Room air conditioners	-	12	-
Ranges - electric	16	16	12
- gas		16	13
Freezers	15	18	20
Refrigerators	16	15	15
Dishwashers	-	10	11
Clothes washers	10 - 11	10	11
Clothes dryers - electric	14	12	14
- gas		12	13
TV sets - black & white	11	-	11
- color	-	-	12

Source: (a) Pennock and Jaeger (1964); (b) MIT (1974); (c) Ruffin and Tippett (1975)

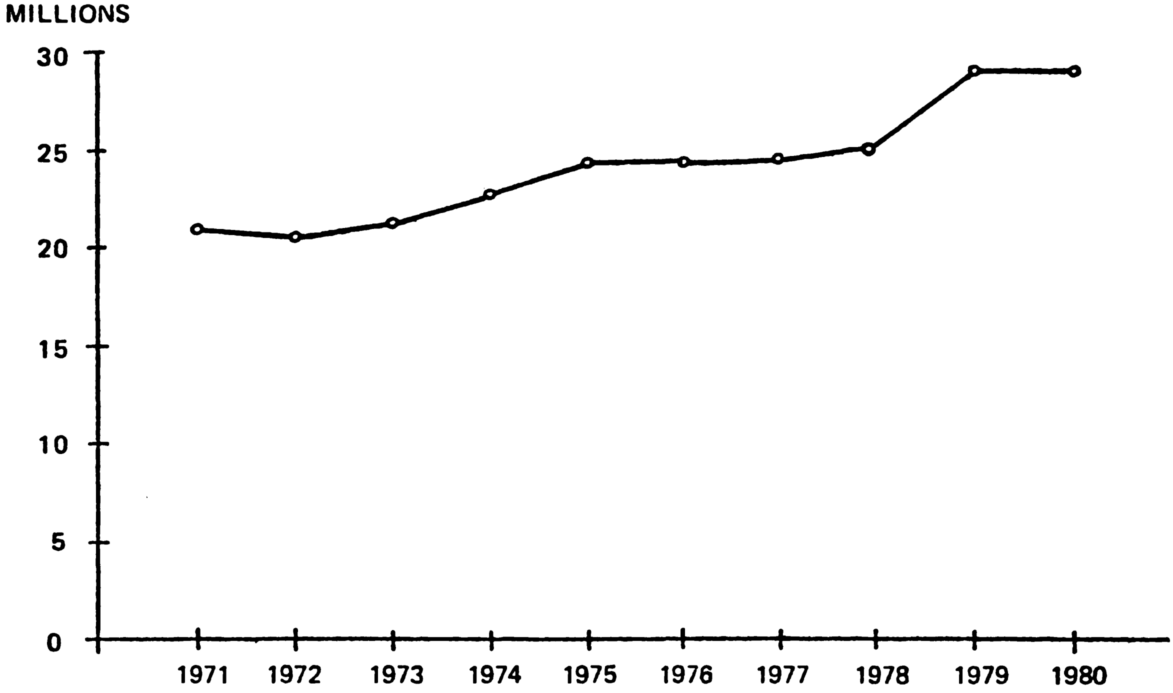

Figure II.2 Total Yearly Discards of Household Appliances Predicted Until 1980

Source: NIPCC (1971)

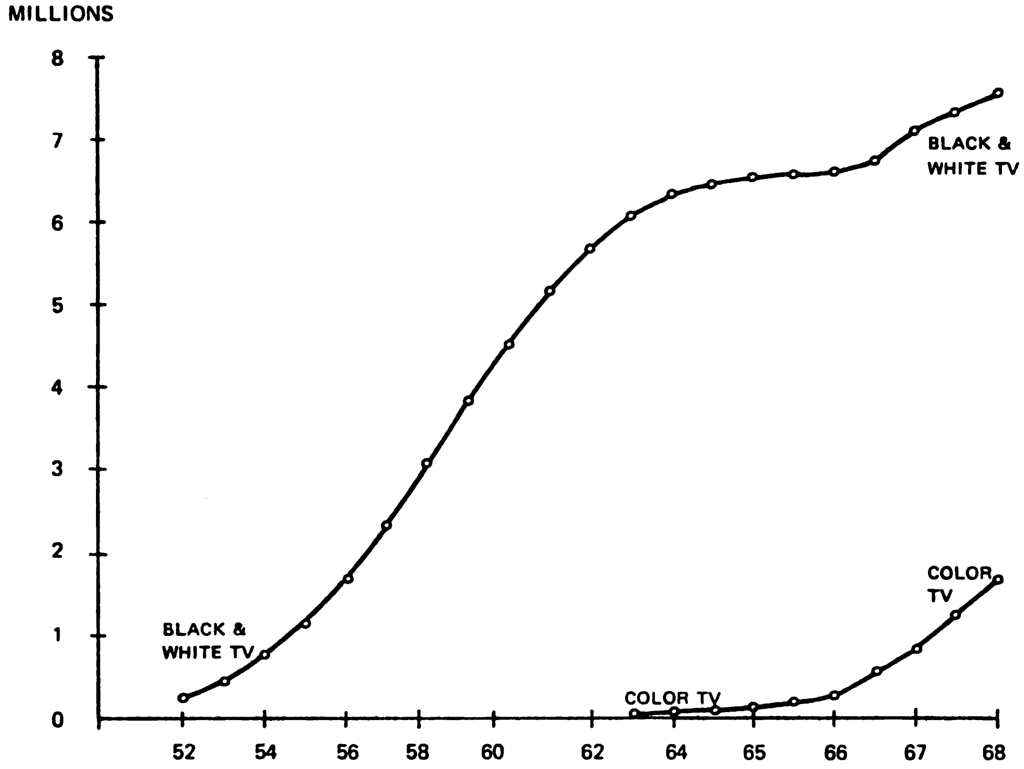

Figure II.3 Yearly Discards of Television Sets

Source: MIT (1974)

services or in arranging privately for the appliances to be hauled away.

If salvage is unrewarding, what alternatives are there that increase resource utilization and/or reduce the volume of solid waste? There are several alternatives, and the remainder of this paper considers four of these.

1. More utilitarian design. Although not likely to prove attractive either to consumers or to manufacturers, appliance designs could become more austere, using less total materials or substituting plentiful for more scarce materials. The shift of American buyers' interests toward smaller, lighter cars and the automakers' response represents a change of this kind. Designing appliances for lower energy consumption is a related approach. The MIT study showed that refrigerators could be designed to use as little as 50 percent of the energy consumed by present models.

2. Re-manufacturing. It might be feasible under certain economic conditions to establish collection systems that would route discarded appliances through rebuilding processes. This would restore the units to approximately their original value, many times the value of the scrap value of the materials in them. This practice has been followed for many years for automotive parts and at least one television manufacturer has used this system for replaceable circuit modules.

3. Greater standardization. Although the use of standardized parts in many models (even competing models) may not reduce resource use per unit, it might lower the replacement parts cost. Standardization would have a very significant effect on total national volume of replacement parts that are held in inventory in manufacturer, distributor, dealer, and service agency stocks. All these stocks constitute a pool of resources which are continuously in reserve. Obviously parts flow into and out of this reservoir, but the total volume of materials impounded in this fashion fluctuates only slightly, and it increases as the appliance population grows. The costs of carrying these inventories, including obsolescence costs, are appreciable. These costs, and the lack of competition in the replacement parts market, are reflected in the much higher price of replacement parts than the original equipment parts cost. If standardization were to reduce appliance repair costs, more appliances might be repaired rather than discarded.

4. Increased service life. Perhaps the most effective approach to the resource conservation/solid waste recovery problem is to increase the length of time that an appliance is kept in use. If the average service life of appliances were to be increased from 12 to 14 years, there would be a permanent reduction in the annual rate of appliance discard of 25 percent. The reduction of materials usage would be equivalent to the number of units "saved" from discard each year. For appliances having a saturated market where replacement sales predominate, the materials usage would also be reduced approximately 25 percent.

It is possible to design appliances to last longer. Two basic approaches are (1) design all parts of the appliance for maximum durability (using gear drives instead of belts and pulleys, for instance) or (2) design for lowest cost or replacement of all components, including cosmetic components. The design question is not the principal issue. The principal issue is the absence of sufficient incentives for the manufacturer to make or the consumer to buy longer-lived appliances. Costs and prices of such items are likely to be higher, replacement sales volume will be lower, and savings to the consumer which will only materialize 12 to 15 years hence will have relatively low value at the time of purchase.

Each of these four options needs evaluation in terms of benefits, costs, and policies required to encourage implementation. Total life cycle cost, which measures the acquisition, operation, maintenance, and disposal costs over the service life of an appliance, is one tool for evaluating a particular approach.

The appliance industry has been offering the American consumer an increasingly better bargain in terms of initial purchase cost, convenience, and reliability. Until now, service life, disposal costs, and resource conservation have not been important factors in the manufacturer-consumer relationship. Innovative approaches are needed if emphasis on these factors is to result in changes in the appliance market. If any of these approaches work for appliances, it should be possible to extend the concepts to other major consumer durable products.

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C. III: A MODELING APPROACH TO REGIONAL SOLID WASTE MANAGEMENT PLANNING

Edward B. Berman

INTRODUCTION

An optimizing model called SWAMP (Solid Waste Management Planning) has been developed for the generation of minimum cost regional solid waste management plans.

The model was orginally designed in eighteen alternative modes of operation (nine static modes and nine dynamic modes) under a MITRE sponsored research project.[1] SWAMP is a fixed-charge linear programming model, using an algorithm developed by Dr. Warren Walker, now with the New York City Rand Institute.[2]

In 1974, a basic static mode of SWAMP was used for a program of operational runs in support of regional design analysis for the Commonwealth of Massachusetts. This program used manually-generated inputs to the algorithm, and a manual interpretation of outputs.[3]

Currently, the Office of Solid Waste Management Programs, U.S. Environmental Protection Agency, is supporting the further development of SWAMP. The EPA program includes:

- the development of a computerized front-end and back-end for one static mode and one dynamic mode of SWAMP;
- an operational test program on the Greater St. Louis Region (the City of St. Louis and seven surrounding counties);
- a parametric exercise program on a region of 53 communities of Massachusetts and New Hampshire; and
- documentation and dissemination.

This paper will describe the model in brief and its application program. The focus of the discussion will be on the use of the model to illuminate political and technical issues.

BACKGROUND

Figures III.1 and III.2 illustrate economies of scale available from two processes from the point of view of a potential processing site in Haverhill, Massachusetts. The costs are based

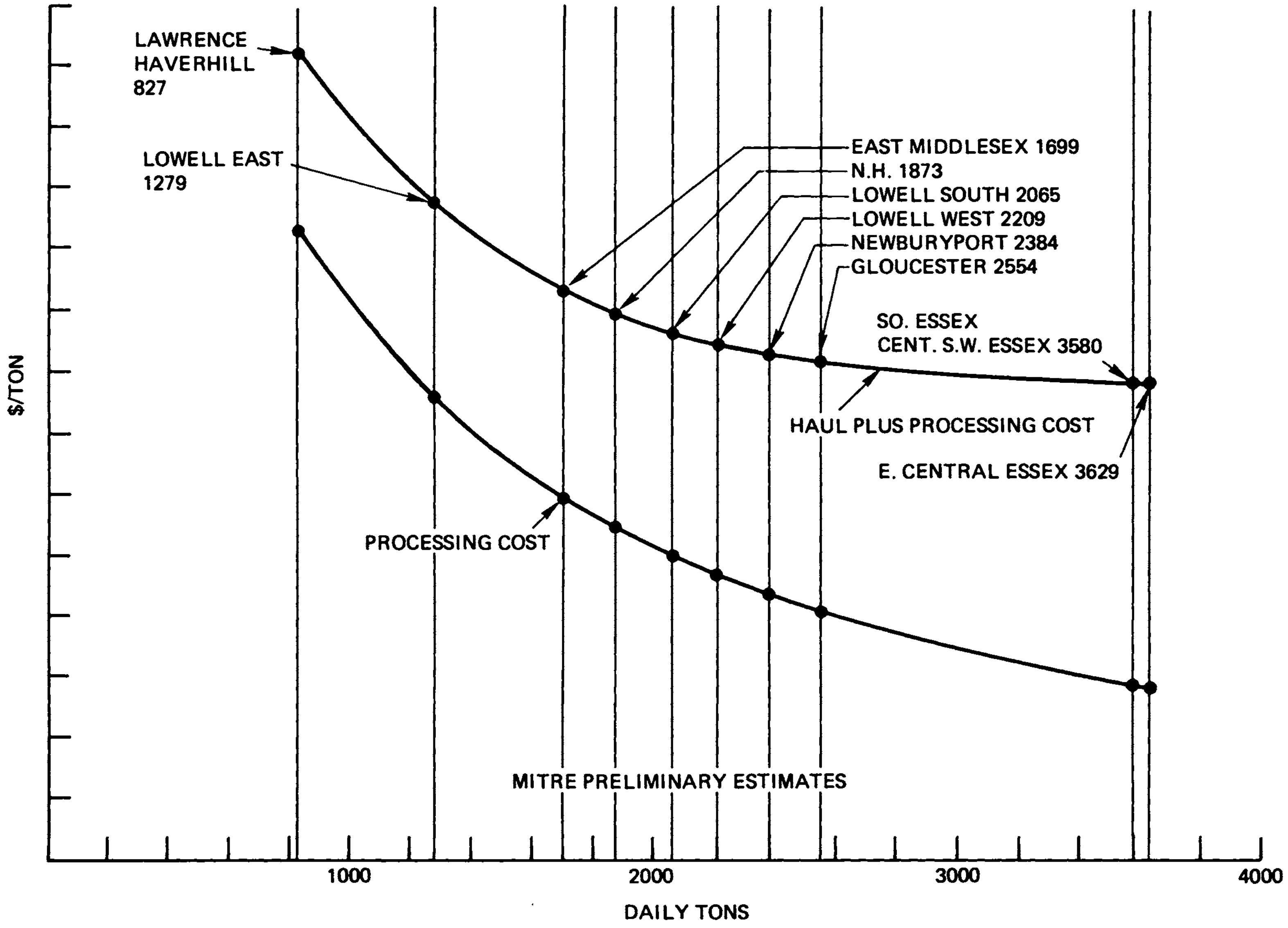


Figure III.1 Economies of Scale in Dried Shredded Fuel/Residue Recovery

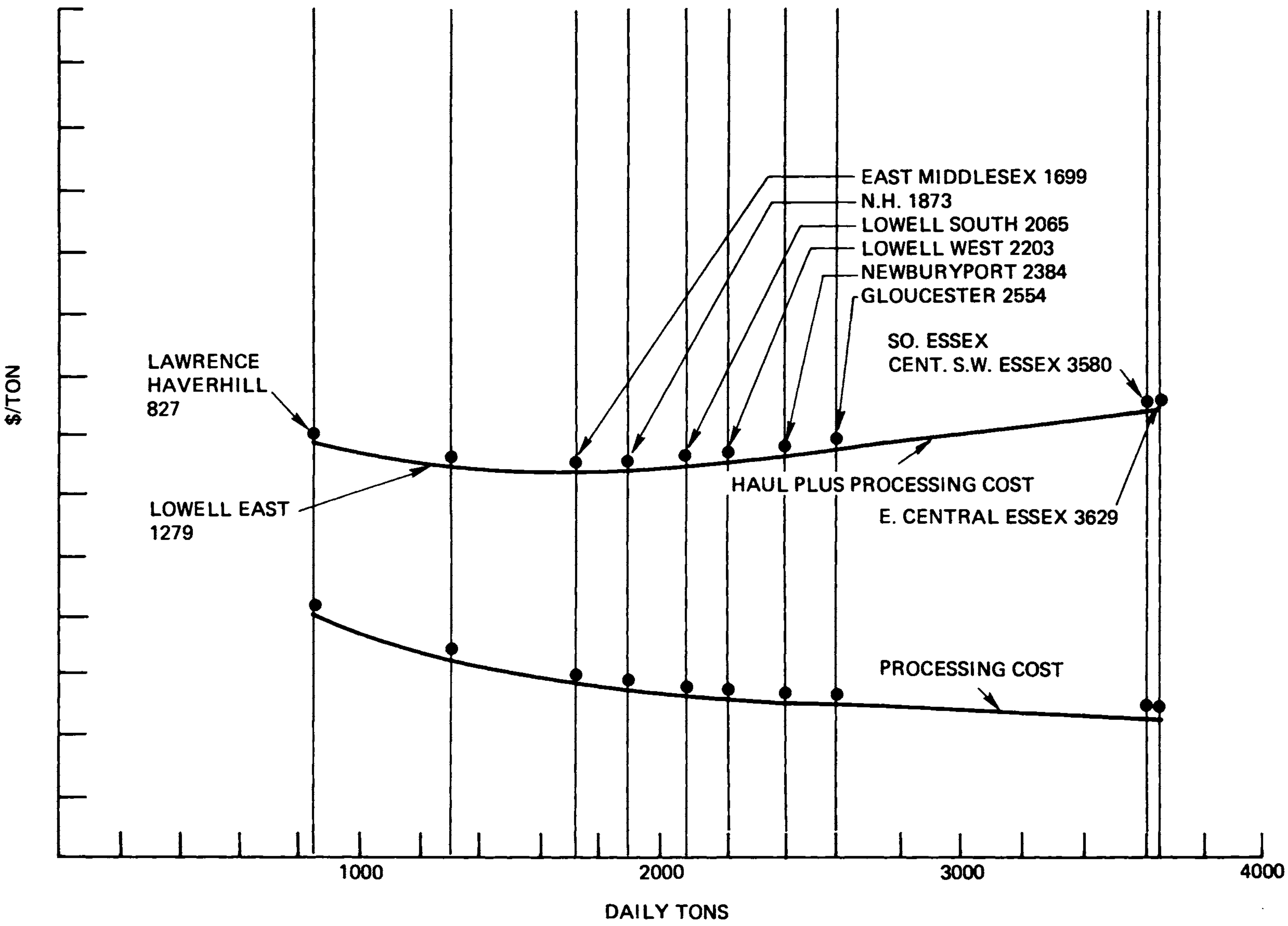


Figure III.2 Economies of Scale in Gas Pyrolysis (MITRE Preliminary Estimates) on MITRE preliminary haul and processing costs for the two processes. Note that the decline in processing costs in Figure III.1 compensates for rising haul costs as the region is enlarged, and the minimum cost available is attained at the maximum region size considered, including all 14 zones (representing 53 communities and 3600 TPD). In Figure III.2, there are less economies of scale available, so that the minimum cost is obtained with the inclusion of only 4 zones (representing 20 communities and 1700 TPD).

Economies of scale in processing are a driving force towards regionalization, but from regionalization two problems are generated:

- a complexity of system design, and
- a problem of political consensus.

SWAMP is addressed to both of these problems; it is intended:

- to sort out the many alternatives on siting, sizing, linking, and process selection for transfer stations, primary processing, secondary processing, and disposal; and to generate the minimum cost plan which will meet all requirements; and
- to illuminate political issues and hence help their resolution.

BRIEF DESCRIPTION OF THE MODEL

Figure III.3 presents an overview of the model, its inputs and its outputs.

Figure III.4 describes the five levels in the model and allowable linkages among levels. Note that linkage from one A-level process to another A-level process is permitted. In the St. Louis application this capability was used to allow a packer-to-van transfer process to link to a truck-to-rail transfer process. Similarly the dual C-level capability permits the model to carry two differential residue commodities (incinerator residue and air classification heavy-end) into secondary processing through dummy secondary recovery processes in which differentiated revenues were generated. This capability was used in the Massachusetts/New Hampshire exercise programs.

A key capability of the model is its ability to trade off the economies of scale in processing, obtainable through centralized processing, as against the haul costs implied by such centralization. Essential to this trade-off capability is the ability to represent economies of scale in process costs. Figure III.5 illustrates a concave total cost function, typical of solid waste processing, as represented by several linear segments. Since the model is cost-minimizing, it will seek out the lowest

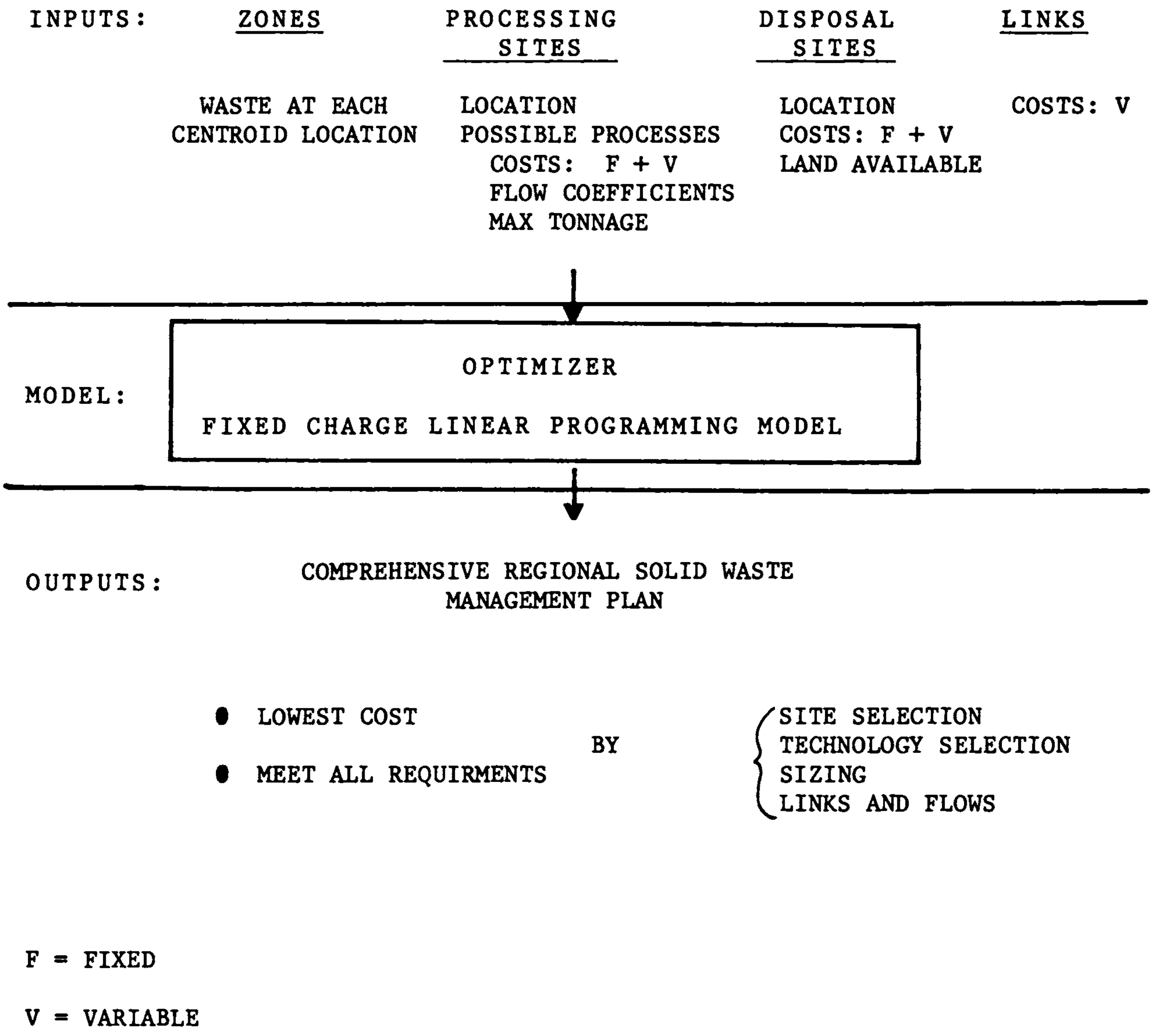


Figure III.3 Model Overview

LEVEL	LINKAGE TO
SOURCE	A, B, D
A. TRANSFER STATION	A, B, D
B. PRIMARY PROCESSING	C D
C. SECONDARY PROCESSING	C D
D. SANITARY LANDFILL	_____

Figure III.4 Model: Levels of Processing

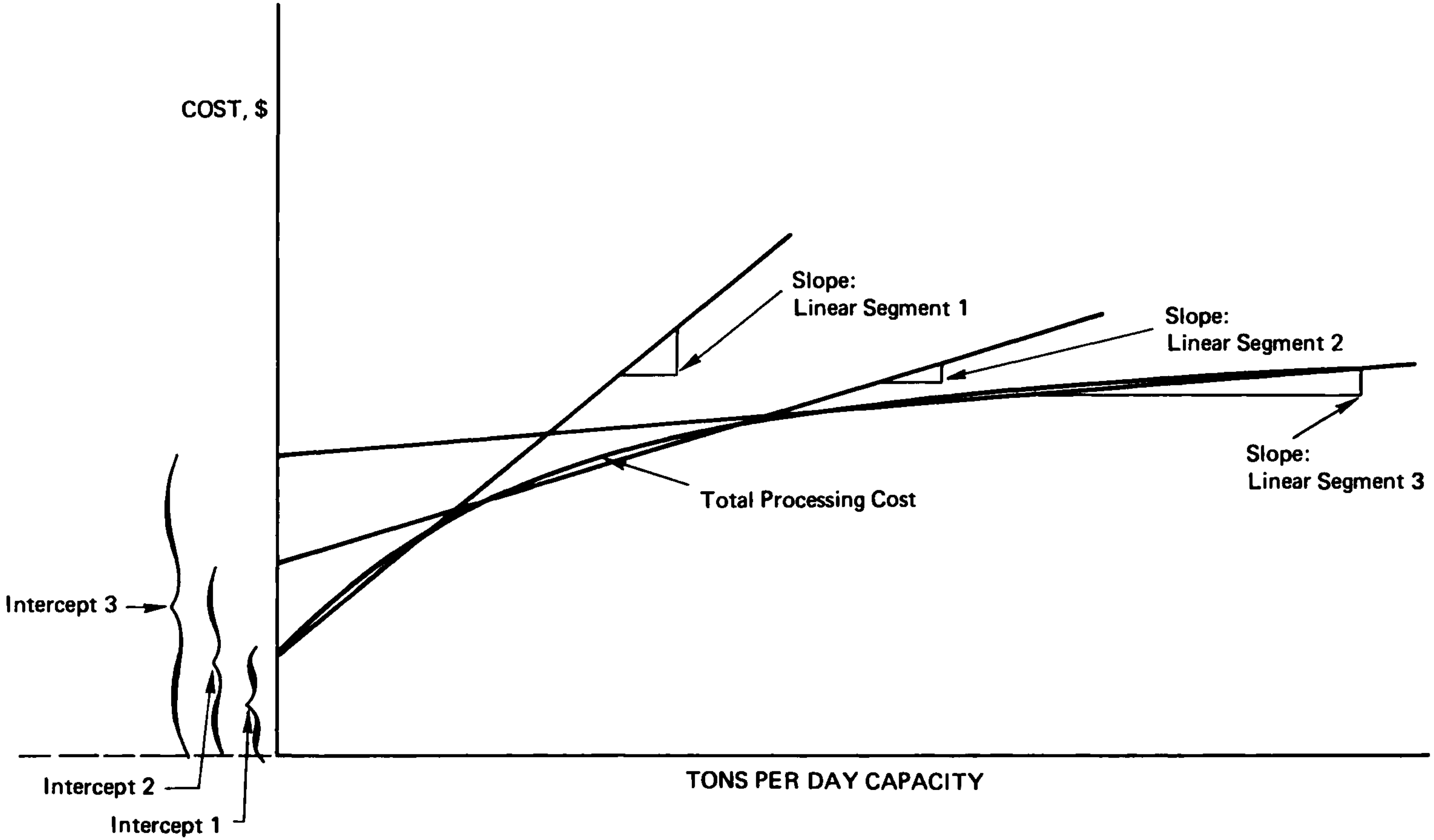


Figure III.5 Piecewise Linear Approximation of a Concave Function (Representing Economies of Scale) cost segment at any level of tonnage. Thus the capability of treating cost in two parameters (fixed and variable, or intercept and slope) permits the model to represent economies of scale at any level of accuracy desired. In the actual SWAMP applications, three-segment representations have been used for nearly all processes.

The model has three essential components:

structure which assures that each alternative considered is feasible, handles all wastes, processes all residues, and so forth;

cost which assures that each alternative is properly costed, including economies of scale where appropriate; and

procedure which is an organized search for the best solution.

Figure III.6 illustrates the operation of the model. The basic structure is rectangular, which means that there are more variables than equations, and hence that the problem is underdetermined. Thus there are many, many solutions. The optimal solution is that particular solution which is lowest in cost.

The structure is a system of equations that assures that each of the solutions examined is feasible in the sense that (1) all wastes generated are entered into transportation; (2) all wastes arriving at a site are processed; that (3) all residues generated are processed at the site or entered into transportation; and (4) no process exceeds indicated tonnage maximums.

Among the many solutions to the system of equations, only that subset which has no negative solution values is considered to be feasible (for a negative solution value implies grinding up the outputs of the process and generating its inputs).

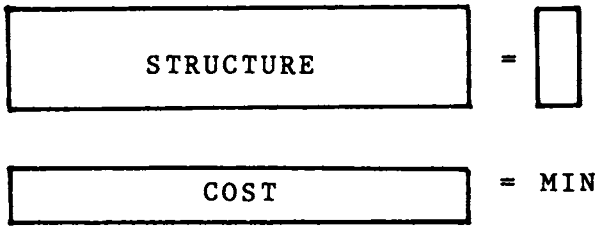
The search procedure requires:

- that those steps which improve the solution can be separated from those that make it worse; and
- that the procedure knows when it can go no further (i.e., it has arrived at the optimum).

The "steps" are transitions from one feasible solution to another.

In the fixed-charge linear programming procedure the algorithm adds the fixed cost (to the system cost) whenever the corresponding solution value goes from zero to positive, and subtracts the fixed cost whenever the corresponding solution value goes from positive to zero. The fixed charge algorithm considers both fixed and variable costs in determining whether a transition is an improvement.

RECTANGULAR



UNDETERMINED CASE

- FEASIBLE SOLUTION: NON-NEGATIVE
- OPTIMAL SOLUTION: LOWEST COST

SEARCH PROCEDURE

- WHICH STEPS IMPROVE SOLUTION
- KNOWING THAT WE HAVE ARRIVED

FIXED CHARGE

- DOUBLE COST ROW F + V
- ALTERED SEARCH PROCEDURE

Figure III.6 Model: Black Box

APPLICATIONS: ILLUMINATING POLITICAL AND TECHNICAL ISSUES

An application, which is a set of runs, is designed to illuminate political and technical issues.

Each run in the set will:

- handle all wastes,
- meet all environmental standards (since only processes which do meet relevant standards are offered), and
- provide the lowest cost solution for its "case."

The "case" is a defined state of political/technical feasibility. SWAMP will generate a plan and a system cost for each case. The incremental costs of moving from case to case are calculated, and in particular the costs of moving from less political acceptability to greater political acceptability. Figure III.7 illustrates a hypothetical plan set.

Figure III.8 summarizes issues which have been illuminated in the (completed) Massachusetts application and in the St. Louis application which is in process at this writing.

THE MASSACHUSETTS APPLICATION

A region of 47 communities in Northeastern Massachusetts and 6 communities in New Hampshire was evaluated primarily to determine how the region would break down under varying circumstances. The region was divided into 13 zones for tonnage generation, as illustrated in Figure III.9.

Process options are listed in Figure III.10.

The residue recovery process in Lowell East was given a reduction in all intercept costs of $634.1 per day to represent the amortized value of an EPA grant which is obtainable only if that process is selected at that location.

The RESCO process is a steam-generating incinerator now under construction in Saugus. The RESCO zone is the host community plus nine communities now considering long-term contracts with RESCO. RESCO community tonnages were locked into the RESCO process.

The seven basic runs in the Massachusetts application, runs E through K, are described in Figure III.11. (Runs A through D were experimental.)

Note that:

- with all options (run E) gas pyrolysis was selected in two locations;
- with gas pyrolysis removed (run F) landfill was selected in six locations for an incremental $3 per ton (gas pyrolysis is not quite in the state-of-the-art as of this writing);

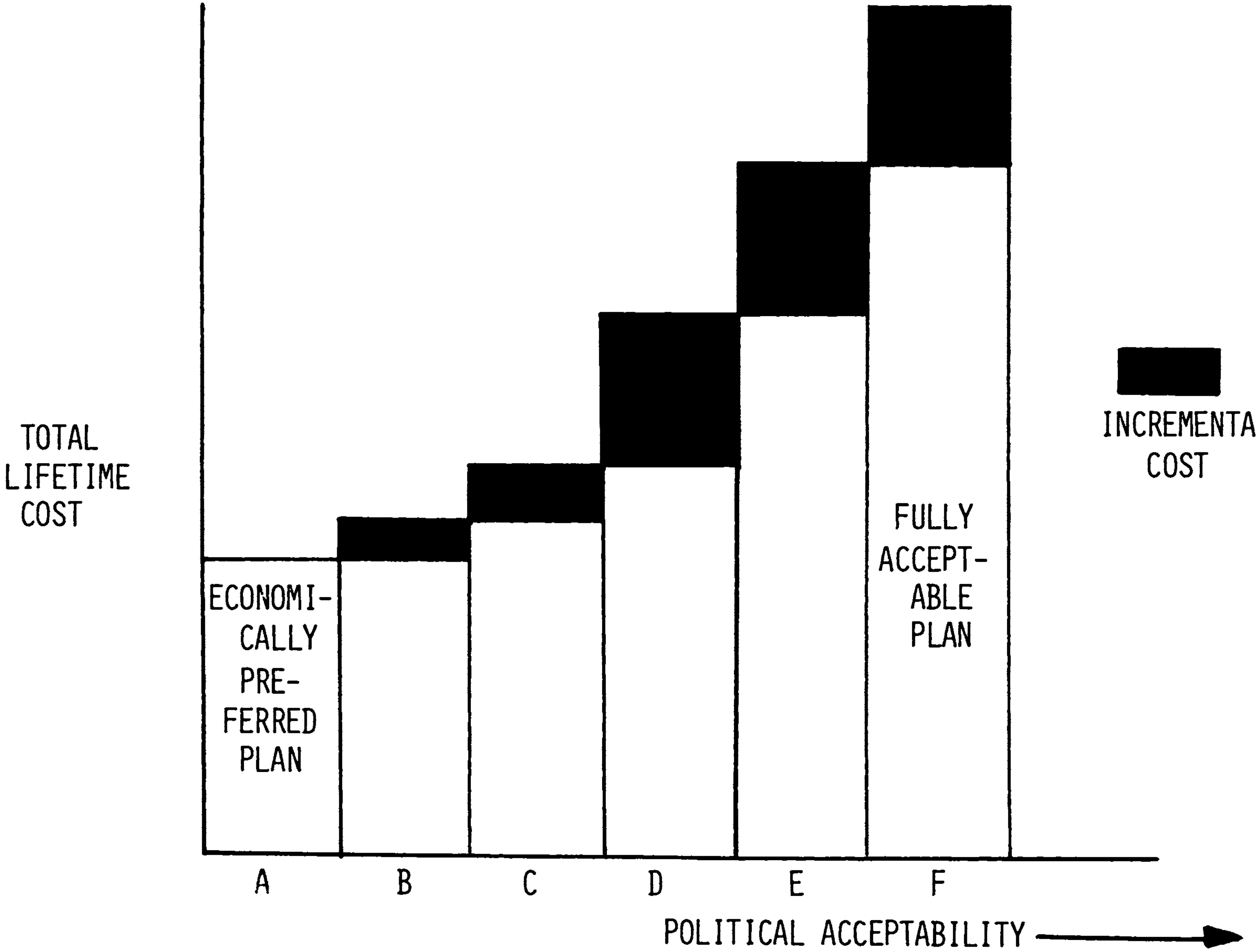


Figure III.7 The Plan Set

- REGION SIZE
    - MASS: LARGE REGION: HOW DOES IT BREAK DOWN
    - ST. LOUIS: REGION VS STATE - BY - STATE
- PROCESS AVAILABILITY
    - POLITICAL
        - LANDFILL IN MASS. & ST. LOUIS
    - TECHNICAL
        - GAS PYROLYSIS IN MASS.
- SITE AVAILABILITY
    - ST. LOUIS - PROCESSING AT PLANT
    - MASS. - SOUTH ESSEX SITE
- MARKET AVAILABILITY
    - ST. LOUIS - ILLINOIS POWER CO.
- SENSITIVITY
    - TONNAGE, MARKET PRICES, PROCESS COSTS

Figure III.8 Illumination of Issues

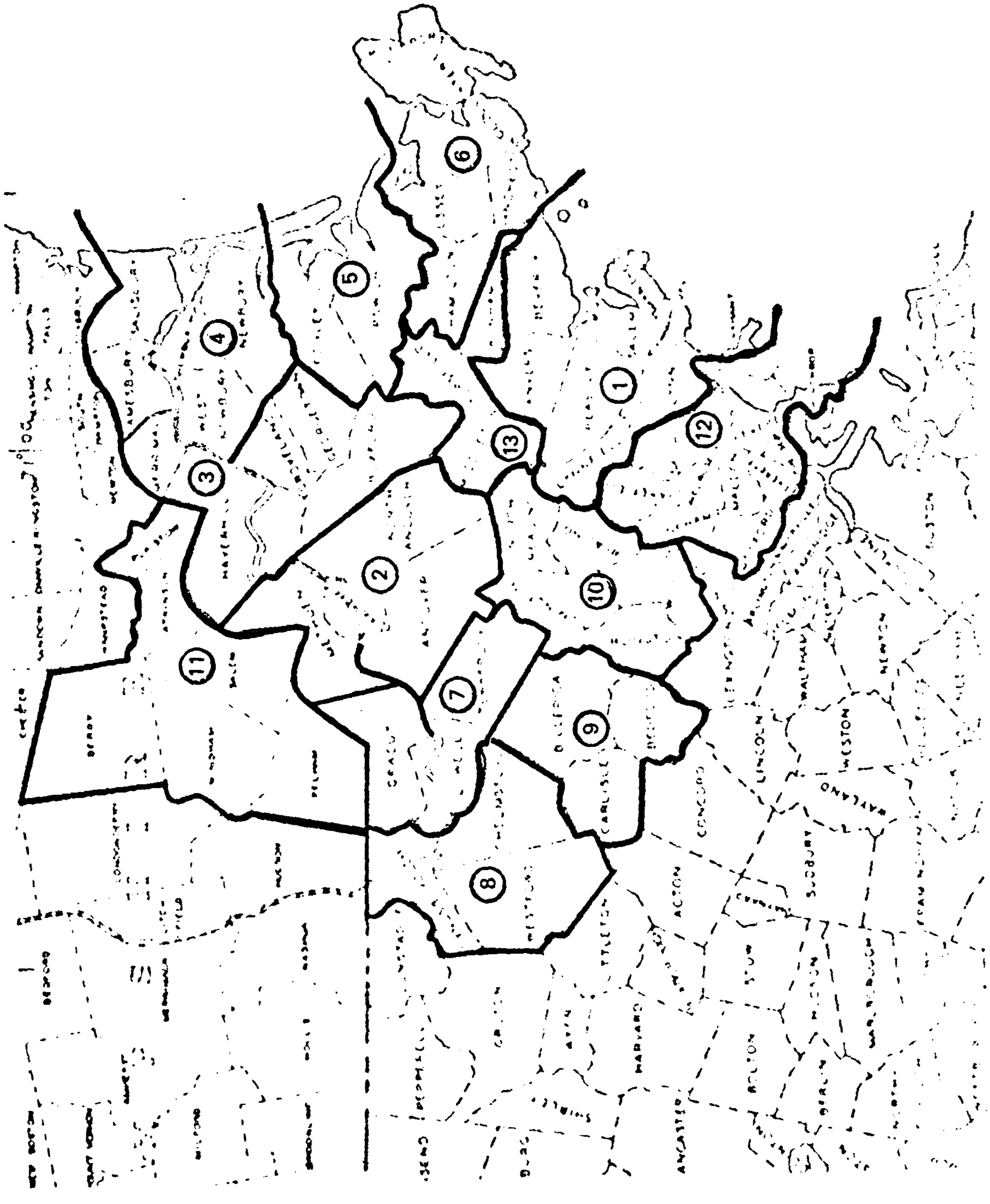


Figure III.9 The Northeast Massachusetts Region

- TRANSFER STATIONS IN SOUTH ESSEX, LAWRENCE, NEWBURYPORT, GLOUCESTER, LOWELL EAST, AND LOWELL SOUTH
- SHREDDED FUEL IN SOUTH ESSEX AND LAWRENCE
- PYROLYSIS IN SOUTH ESSEX, LAWRENCE, NEWBURYPORT, GLOUCESTER, AND LOWELL EAST
- RESIDUE RECOVERY IN SOUTH ESSEX, LAWRENCE, AND LOWELL EAST
- LANDFILL IN NEWBURYPORT, E. CENTRAL, ESSEX, GLOUCESTER, LOWELL WEST, LOWELL SOUTH, E. MIDDLESEX, NEW HAMPSHIRE, RESCO, AND S. W. CENTRAL ESSEX
- RESCO

Figure III.10 Process Options

Basic Run (Options Available)	Structure of Basic Run Solution	Modification of Basic Run	Solution to Modification Run (Change in Basic Solution
E Transfer Stations, Shredded Fuel, Gas Pyrolysis, Residue Recovery, Landfill	South Essex Pyrolysis Lawrence Pyrolysis Gloucester Transfer Station Lowell East Residue Recovery $4.38/ton	H Double tonnage	Additional Transfer Stations in: Newburyport, Lowell E. Otherwise the same $3.45/ton
		K Double intercept of Pyrolysis net cost functions	Pyrolysis in Lawrence only Additional Transfer Station in: S. Essex Otherwise the same $6.85 $6.85/ton
F Transfer Stations, Shredded Fuel, Residue Recovery, Landfill	Landfills in: Newburyport, Gloucester, Lowell South, E. Middlesex, New Hampshire, S.W. Central Essex, Lowell East Residue Recovery $7.34/ton		
G Transfer Stations, Shredded Fuel, Residue Recovery	South Essex Shredded Fuel South Essex Residue Recovery Transfer Stations in: Newburyport, Gloucester, Lowell East, Lawrence $11.23/ton	I Double tonnage in all zones	Lawrence Shredded Fuel, Transfer Stations in: S. Essex, Newburyport, Lowell East, Gloucester, Lowell East Residue Recovery $8.47/ton
		J Remove South Essex Shredded Fuel from consideration	Lawrence Shredded Fuel, Transfer Stations in S. Essex, Gloucester, Lowell E. Residue Recovery $10.86/ton

Figure III.11 Summary of Massachusetts Runs

- with landfill removed (run G) (it is of questionable political acceptability in Northeastern Massachusetts) shredded fuel was selected in one location for an incremental $4 per ton (or an incremental $3.50 per ton with a Lawrence location as in run J); and
- doubling the pyrolysis intercept (run K) reduced the number of processing locations from two to one, and added a transfer station.

THE ST. LOUIS APPLICATION

An operational test is now underway on the Greater St. Louis area, consisting of the city and seven surrounding counties as illustrated in Figure III.12. A set of six static runs and one dynamic run has been designed as described in Figure III.13, using process options described in Figure III.14.

The six static runs generate waste in 29 zones. There are 15 sites for processing, of which four offer transfer, primary processing, and secondary processing, two offer primary processing and secondary processing (the two utility locations), and the other nine offer transfer only. There are up to 13 locations offered for sanitary landfill.

The intermediate and ultimate sites for the St. Louis Application, together with their process alternatives, are displayed in Figures III.15 and III.16.

THE MASSACHUSETTS EXERCISE PROGRAM

A new set of runs will be performed on a slightly modified version of the same Massachusetts/New Hampshire region studied earlier. Zone 1 has been divided into 2 zones, so that there are 14 zones for waste generation in total. Additional processing locations have been added in the new zone 14 and in zone 3 (Haverhill), and the St. Louis shredded fuel process has been made available in Haverhill, Newburyport, Gloucester, Lowell East, and in the new zone 14 (called South Essex Inner). Otherwise, all options made available in the earlier Massachusetts runs were continued.

The run series consists of a base case and four parameterizations for a total of ten runs as follows:

THE ST. LOUIS REGION

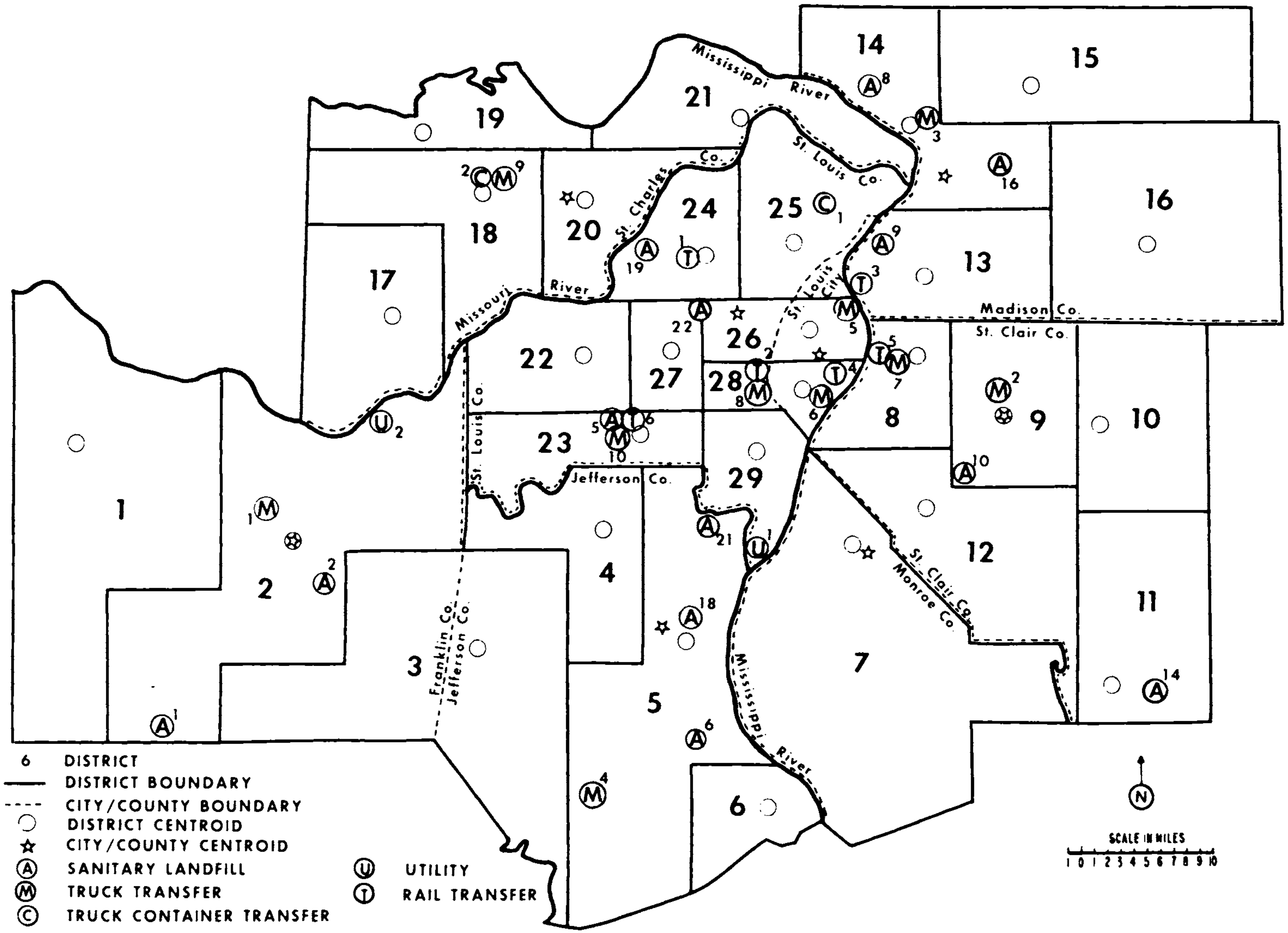


Figure III.12

29 ZONES

A. BASE CASE

ALL RESOURCE RECOVERY OPTIONS

B. LANDFILL ADDED

C. BASE CASE EXCEPT NO INTERSTATE FLOWS

D. BASE CASE EXCEPT NO ILLINOIS POWER MARKET

E. TONNAGE REDUCTION

LOSS OF ONE OR MORE COLLECTORS AS SOURCE
(SIMULATED BY LOSS OF HALF OF COMMERCIAL TONNAGE)

F. FORCE PROCESSING LOCATION TO OTHER OF:

ON SITE (UTILITIES)

OFF SITE

8 ZONES

G. DYNAMIC RUN: 4-PERIOD RUN WITH CAPITAL CARRY-FORWARD

GAS PYROLYSIS AVAILABLE IN 2nd PERIOD

Figure III.13 The St. Louis Run Set

- TRANSFER STATIONS
  - PACKER TO TRANSFER VAN
  - PACKER OR VAN TO R.R. CAR
  - PACKER TO CONTAINER

- PROCESSING
  - PRIMARY
    - SHREDDING
    - AIR CLASSIFICATION
    - MAGNETIC SEPARATION
  - SECONDARY
    - BU MINES PROCESS
  - SANITARY LANDFILL

Figure III.14 Process Options/St. Louis

SITE NO.	SITE	PROCESSES	SITE NO.	SITE	PROCESSES
501	M1	901,903	508	M8=T2	901,903
502	M2	901	509	M9=C2	901,902
503	M3	901,903	510	M10=T6	901,903,905
			610		906
504	M4	901,903	511		
505	M5	901,903,905			
605		906	512	T1	903
506	M6=T4	901,903,905	513	T3	903
606		906	514	U1	905
507	M7=T5	901,903,905	614		906
607		906	515	U2	905
			615		906

PROCESS TYPE	LEVEL	PROCESS TYPE	LEVEL
901 TRANSFER PACKER TO VAN	A	905 SHREDDED FUEL	B
902 TRANSFER PACKER TO CONTAINER: TRUCK AND RAIL HAUL TO UTILITY	A	906 SECONDARY RECOVERY	C
903 TRANSFER PACKER/VAN TO RAIL	A		

Figure III.15 St. Louis Intermediate Sites and Processes

SITE NO.	SITE	LAND AVAILABLE (Acre Feet)	
701	A1	SULLIVAN MUNICIPAL	1,000
702	A2	FRANKLIN COUNTY	1,000
703	A5	WEST COUNTY	800
704	A6	JEFFERSON COUNTY	400
705	A8	ALTON MUNICIPAL	500
706	A9	MAL	5,000
707	A10	MODERN SANITATION	400
708	A14	BROWN MARISSA	400
709	A16	BARTON-ROXANNA	500
710	A18	ANTONIA	250
711	A19	VIGUS QUARRY	3,000
712	A21	VALLEY DISPOSAL	400
713	A22	ALTON BRICK	1,000

- PROCESS FOR ALL ULTIMATE SITES IS 907, SANITARY LANDFILL

Figure III.16 St. Louis Ultimate Sites

Base Case

Run A Base Case

Tonnage Variant

Run B1 double tonnage
Run B2 half tonnage

Region Size Variant

Transportation distances use flat earth straight line measurements from longitude and latitude.
Average speeds are as follows:

Run CL 45 mph
Run C2 20 mph
Run C3 10 mph

The average speed is used as a numeraire of region size.

Economy of Scale Variant

Run D1 all processing cost intercepts are doubled (not including transfer stations and landfill).
Run D2 all processing cost intercepts as above are halved.

The intermediate and ultimate sites for the Massachusetts exercise program, together with their process alternatives, are displayed in Figures III.17 and III.18.

CONCLUSION

The operational experience with SWAMP illustrates that modeling can serve a role:

- to find the lowest cost solution in a maze of technical/ geographical alternatives;
- to illuminate political issues, and thus help resolve them;

and thus to assist the decision process.

501	SALEM	901	507	LOWELL	901, 905, 935
502	LAWRENCE	901	607		906, 936, 946
503	HAVERHILL	905,925, 935	510	WILMINGTON	901
603		906,936, 946	512	SAUGUS	915
504	NEWBURYPORT	901,905, 935	514	DANVERS	901, 905, 925, 935
506	GLOUCESTER	901,905, 935	614		906, 936, 946

PROCESS TYPE	LEVEL	PROCESS TYPE	LEVEL
901 TRANSFER STATION	A	925 DRIED SHREDDED FUEL (ECOFUEL)	B
905 SHREDDED FUEL (ST. LOUIS)	B	935 GAS PYROLYSIS	B
906 SECONDARY PROCESSING	C	936 DUMMY: INCINERATOR RESIDUE	C
915 RESCO (INCINERATOR/ STEAM REC)	B	946 DUMMY: HEAVY END	C

Figure III.17 Intermediate Site/Processes -- Mass Exercise Program

SITE		PROCESS
704	AMESBURY	907
705	IPSWICH	907
706	GLOUCESTER	907
708	CHELMSFORD	907
709	BILLERICA	907
710	WILMINGTON	907
711	WINDHAM, N.H.	907
712	SAUGUS	917
713	TOPSFIELD	907

	PROCESS TYPES	LEVELS
907	SANITARY LANDFILL	D
917	INCINERATOR RESIDUE LANDFILL AT RESCO	D

LAND AVAILABILITY ESTIMATES WERE ENTERED, FOR PARAMETERIZATION PURPOSE ONLY, AT 5,000 ACRE-FEET AT SITE 704, AND AT 1,000 ACRE-FEET AT OTHER ULTIMATE SITES.

Figure III.18 Ultimate Site/Processes -- Mass. Exercise Program

NOTES

1 This design was reported in MITRE Report M73-111, *A Model for Selecting, Sizing, and Locating Regional Solid Waste Processing and Disposal Facilities, October 1973.*

2 Walker, Warren, *Adjacent Extreme Point Algorithms for the Fixed Chare Problems*, Dept. of Operations Research, College of Engineering, Cornell University, January 30, 1968.

3 The runs were reported in E. B. Berman and H. J. Yaffe, MITRE Report MTR 2945, *Region Design Analysis for Regional Resource Recovery System for Northeastern Massachusetts*, November 1974.

C. IV: MATHEMATICAL MODELING FOR REGIONALIZATION OF RESOURCE RECOVERY

Joseph J. Harrington

(Abstract of Presentation)

There are a great many plans for regionalization of resource recovery, but relatively little implementation. In fact, the history of planning for solid waste management, in general, is replete with failures in the sense that reports prepared by commissions, councils of governments, and consulting engineers rarely have been followed by the actual accomplishment of the stated recommendations. The single largest factor blocking acceptance of recommendations has been the undeniable disadvantage of being the "sink," or host, community. In general, communities are willing to participate in, and financially support, the planning studies up to the point that the proposed plan would nominate them to serve as regional sink. Such communities would then withdraw. Our studies are directed toward the application of Paretian Environmental Analysis to delimit plans that are potentially implementable.

One grave deficiency in most current planning efforts is that the usual present-value, least-cost objective functions are imperfect surrogates for the actual situation that is characterized by multi-objectivity. There is not uniform professional agreement on how to include imperfectly assessed externalities, for example, those associated with aesthetic and other environmental insults. Nor does the present-value criterion capture all of the complexities of attitude on the part of municipal managers toward the financial and political implications associated with capital expenditures met by bond issues, as opposed to operating and maintenance expenditures that typically directly affect the property tax. And, certainly, plans based on the usual present-value criterion are often chosen with little regard for their inherent flexibility or possibilities for hedging in the face of (1) errors in parameter estimation (demands or costs, for example), 2) changes in regulatory practice, or (3) new technological possibilities.

Currently, much emphasis is placed on seeking optimal--in the sense of regional least-cost--plans. In the initial computational iterations of a mathematical programming model, the value of the objective function ordinarily improves rapidly. But it is frequently the case that a hundred or more technically feasible plans may differ relatively little in cost terms from what ultimately turns out to be the mathematical optimal. The approach we have found useful is to assess plans associated with values of the criterion function close to the optimal--say within 5 percent of the optimal value. The assessment of the rather disparate plans so identified includes such characteristics as capital intensivity, land requirements, hedging capabilities, and others. The alternative plans are also interpreted in terms of the costs and benefits to the individual communities concerned. The usual practice implies that there is a single decision maker, and regional costs, for example, are his criteria. Unfortunately, those assumptions are never met in practice.

Our NSF-RANN study examined an area of Massachusetts from the point of view of mandatory regionalization. That is, in the face of pending legislation that would require regionalization, the State Bureau of Solid Waste Management sought a procedure for implementation. A mathematical (mixed integer) programming model was used *to generate alternatives*, using a regional present-value cost function. A post-optimality analysis and interpretation, however, took into account among the communities concerned the differences of capital and operating costs, land amounts and locations, tax implications, and relation to per capita income levels. The analysis aimed at practicality and, therefore, relied heavily on the data gathered by a conventional consulting engineering firm.

The main conclusions arising from the numerous alternatives generated by the study were that a number of solutions were close to each other in terms of present values, but could differ greatly in terms of physical options. Since the objective function is plainly imperfect, the need is for these different alternatives to be presented individually to the interested parties, for each to see those differences which would affect his particular interests. The aim was to turn mandatory into semi-voluntary regionalization by showing potentially receptive communities the available options, and giving them the opportunity to make the necessary trade-offs with each other.

GENERAL OBSERVATIONS

1. Every locational decision-making problem has become very difficult in recent years.

    a. There are always groups that attack aspects of a plan because they expect external costs to result from its implementation. Such groups do not always adopt transparently consistent policies. For example, some groups opposed to a regional solid waste facility in Montague, Massachusetts, are in favor of a nuclear power plant. Precisely contrary-minded groups can also be cited.

b. It is usually not worthwhile to try to locate a solid waste processing or disposal facility in a community that has not favored cooperation in any other public sector.

c. As long as a community has enough vacant space it will tend to prefer landfilling within its boundaries to reliance on long-distance hauling to a regional facility.

2. The lack of an acceptable exemplar in the region is often a strong determinant of rejection. In Massachusetts very few facilities are truly acceptable and attractive. As a consequence very few people are in a position to know what a well-designed and well-run solid waste processing facility would even look like.

3. Communities, and in particular abutters of potential sites, do not trust the pledges of the state regulatory or law-enforcement agencies to supervise the operations insuring that the state regulations are obeyed. In only one case in Massachusetts, in recent years, has the Attorney General's office acted to stop unregulated dumping operations.

4. Most people associate a social stigma with everything related to solid waste, perhaps particularly raw residential solid waste. This is understandable considering the practices that are still common. A better understanding of these assumptions and how to modify them is clearly needed. Apparently, the literature in this area is still rather sparse (for example, see Sheaffer et al. 1971).

5. It would be most beneficial for COMRATE to call for the standardization of the terminology, definitions, and procedures for estimating costs of alternative solid waste processing and resource recovery plants. This is most important for making rational comparisons among new flow sheets that may not be out of the prototype, or even pilot plant, stage.*

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* In two recent solid waste studies in New England, for example, the BTU to kw-hr conversions were cited as 11,700 and 10,286, reflecting different assumptions about process efficiency.

Also, in the face of a similar problem of comparing a number of rather different desalination processes, a number of years ago, the Office of Saline Water promulgated a manual of standardized component costs.

REFERENCES

Sheaffer, J.R. et al. (1971) Decision Making and Solid Waste Disposal. Final Report to EPA: Center for Urban Studies, University of Chicago.

For a more detailed treatment of the topic discussed in the above abstract, see

Kuhner, J. and J.J. Harrington (1975) Mathematical Modeling for Regionalization of Resource Recovery. Paper prepared for International Conference on Mathematical Models for Environmental Problems. Southampton, U. K. September 1975.

C. V: THE ENVIRONMENTAL INDUSTRIAL PARKS: A LONG RANGE PLANNING OPTION FOR RESOURCE RECOVERY--SOLID WASTE DISPOSAL

James G. Abert, J. F. Bernheisel, and Harvey Gershman

(Conclusions and Recommendations from a Case Study based on Westchester County, New York, made by the National Center for Resource Recovery, Inc., Washington, D.C.)

The concept of an environmental industrial park appears to have merit. The overall size of Westchester County appears to lend itself to a centralized facility, although this should be determined in a future analysis. The park concept could mitigate against market demand shrinkages for recovered materials and provide a relatively stable demand for energy derived from refuse while minimizing the transportation costs of the refuse-derived fuel (RDF). As such, it could help to achieve the overall goal of maximum utilization of waste materials in Westchester County.

According to 1980 projections, the amount of materials available in the county's refuse is significant and appears to justify the construction of plants for intermediate processing: 200 tons of ferrous metals per day, 27 tons of aluminum, 300 tons of used newsprint, and other materials. In addition, it appears possible to obtain an energy balance such that the park tenants consume all of the refuse-produced energy either in the form of RDF or process steam produced at a central plant on site. No electricity is produced from the RDF.

From a production cost standpoint, a park appears to be attractive as a common facility for all the industries discussed. Such a configuration not only makes sense in terms of land use, but would provide for savings in materials handling and transportation costs. Capital savings in land, building, and transportation costs could thus be realized.

Additional and substantial transportation savings could also be realized if the park were located as close to the source of solid waste as possible. Since only 1,500 tons per week (or 6.5 percent by weight) of the input 23,000 tons per week would need to be disposed in a landfill, the location of the landfill within the park is not at all critical. This represents an obvious economic advantage as well as an institutional one. Siting for the park, without an adjacent landfill, should be less difficult. More remote landfill locations should not excessively burden the operating costs of the total operation.

The park is an option that centralizes the activities involved in resource recovery/solid waste disposal. However, it is not the only centralized option; there are other possibilities utilizing other technologies which may prove to be better. During 1974 to 1977, many of the currently unproven resource recovery/solid waste disposal processing systems will be demonstrated in scales ranging from 200 to 1,000 tons per day. The results of these demonstrations can be incorporated into the park program so that the final plan will be consonant with a long-range time-frame.

The Center (The National Center for Resource Recovery [NCRR]) wishes to point out again, at the risk of repetition, that the park is simply one option among many that can be considered for Westchester County's future solid waste management system. It is a centralized one and relies on the economies of scale in bringing all, or nearly all, of the refuse to a common point for processing. Clearly, when one looks at the concept standing alone, "the bigger the better" is the rule of the day. It is also clear, however, that this maxim does not take into account the transport of the refuse to the park site.

Contrast this to a de-centralized option which could dispose the refuse at several sites, each of which is closer to various refuse generation areas within the county. The optimal disposal/recovery method depends on the sum of the costs of the de-centralized activities plus the associated transportation costs, as compared with centralized options such as the park--again taking into account the costs of transporting the refuse.

The important point is that this comparative analysis cannot be performed at present in a definitive sense for either the park or other systems, since few projects have passed the pilot plant stage. Data based on operating experiences simply are not available for any system. What can be done at present is to estimate a range of cost figures which bound the likely costs of technologies considered and then make the comparisons on this basis. A plan must be formulated to obtain the actual costs as they become available and in this manner validate or disprove the initially preferred solutions.

Where does this document fit into the scheme of things? It should be regarded as a first step in determining the costs and feasibility of an environmental industrial park as a disposal/recovery option. A next step is to bring the level of detail with which the park is analyzed to that level that can be offered by other options, such as pyrolysis or waterwall incineration. A comparative analysis taking into account the likely location for the facilities (and thereby the transportation costs) should then be conducted.

There are definite technical risks associated with the park concept. These risks do not lie as much in the industrial processes or the energy conversion facility as in the materials recovery (front-end) processing. Having been actively involved in a design, test, and demonstration program for such a system, NCRR feels that the risk associated with materials recovery is not any greater than that of other centralized or de-centralized recovery/disposal options which are yet to be demonstrated. NCRR's system will also be demonstrated circa 1976.

The greater uncertainty associated with the park concept surrounds the institutional arrangements that must be made to complete the project. Joining all the pieces of the puzzle together appears to be an extremely difficult task. It is a complicated arrangement and the difficulty of its accomplishment should not be overlooked.

Another uncertainty lies in determining the optimal manner of financing the park. It is not clear whether or not pollution control revenue bonds (PCRBs), a type of industrial development bond, could be issued for financing the construction and operation of the entire facility. Certainly, portions of the park would qualify. Whether or not the entire park would qualify needs to be examined along with other financing mechanisms that are more traditional than PCRBs.

It is recommended that the park concept and other centralized or de-centralized alternatives be evaluated on the basis of the best cost estimates that can be obtained at this time. In order to do this, the park concept must be developed in more detail so that it can be compared to other alternatives for which more precise costs are available.

The initial step, then, is to prepare an analysis comparing the cost/benefit effectiveness for each alternative. As an outcome of this effort, a comprehensive long-range plan can be produced which may incorporate more than one alternative. Such a plan would take into account the uncertainty that surrounds <u>all</u> of the new technology alternatives. Neither their effectiveness nor their costs will be known for two to four years. Therefore, if no dominant system emerges upon consideration of the best available information, it would be advisable to carry several alternatives into the future.

Regardless of how many alternatives are found to have merit as a result of this initial comparative evaluation, the plan should incorporate a schedule of "milestones" to verify the projected costs, technical workability, and environmental impacts of the selected system or systems. Data for such verification will be derived from demonstrations currently underway or proposed throughout the country.

If in this initial comparative analysis the desirability of the environmental industrial park is demonstrated, it is recommended that a contingency planning phase is initiated. As developed by the NCRR, the concept of contingency planning is to obtain simultaneously the agreement of all parties whose acceptance is essential to a proposed program. To achieve this goal, the center recommends the use of "contingency contracts." These documents commit the signer to abide by the contract if all others agree to the terms. In short, no one votes last. Through this procedure, the tendency to optimize is checked to some extent, and a "fair" arrangement among all parties can be facilitated on the basis of reasonable operating parameters.

C. VI: FINANCING MUNICIPAL SOLID WASTE DISPOSAL SYSTEMS

Paul D. Speer

Solid waste disposal is a problem which has crept up on the nation and all of its areas and communities. The rapid accumulation of solid waste, particularly in urban areas, has overwhelmed the available facilities and exhausted many of the older methods. It is only recently that attention has been given to other methods of disposing of such wastes.

Quite naturally, any method involves expense both in the construction of a facility and in its operation. A great part of the expense is the amortization of the capital cost and the repayment of the money borrowed to provide the capital. Urban areas and municipalities are the most concerned because they have the greatest problem and the greatest responsibility in waste disposal. It is therefore quite pertinent to review the possibilities of financing such projects by the municipalities, and in turn the means of collecting the necessary revenues to retire the debt.

There are at present a number of local government projects which are going forward. Possibly that of Chicago in conjunction with Commonwealth Edison Company is the largest. The city used the most straightforward and most economical method of financing when it issued $14,000,000 of its general obligation bonds for the construction of a processing plant for the purpose of converting trash to fuel. This plant will be on the southwest side of the city adjacent to a Commonwealth Edison generating facility.

That company has agreed to pay the city $700,000 per year for 10 years for the portion of the waste which is converted to fuel. It is expected that this will be the equivalent of approximately 100,000 tons of coal a year which would be combined with coal in the proportion of 10 percent shredded waste and 90 percent coal. This is approximately the amount of fuel necessary to meet the needs of 45,000 homes. The city will have other revenue from the process of an estimated $500,000 per year from the retrieving of ferrous metals and nonferrous metals. The cost of incineration has run the city approximately $30 per ton and this new process is expected to be less than two-thirds of that cost. Metal, glass, and plastics will be separated and disposed of otherwise.

The initial test plant was probably that operated by the Union Electric Company in St. Louis. Other projects are being undertaken in Fort Lauderdale, Florida, and Ames, Iowa, where they are now furnishing a minor portion of the fuel for the city electric generating plant by conversion from waste. Des Moines, Iowa, is endeavoring to accomplish the same thing as is Lake County, Illinois. There is also a privately owned operation along these lines in and around San Jose, California, but it is not believed to be very profitable.

Kansas City, Kansas, is just completing arrangements to construct a facility for a local subsidiary of a large national waste disposal company. The subsidiary will rent the facility for annual amounts sufficient to amortize the debt.

As noted above, the most economical method of financing is by general obligation bonds which are payable from property taxes, but in some instances the receipts from the sale of the fuel will be used to abate those taxes.

The most popular method of financing would probably be the use of revenue bonds, sometimes known as self-liquidating bonds, payable from user charges. In order to have a successful revenue bond issue based upon charges to those whose waste is originally collected and passed through the conversion process, it is essential that there be an equitable method of charge and one which is readily collectible with few delinquencies.

With the proper legal restrictions on waste disposal by individual units plus the regulation of private scavengers, it would seem that these charges could be made as monopolisitic as the charges for the use of water, electric, gas and sewer facilities. Those are the most respected forms of revenue producing facilities which will support financing. Other functions, such as parking, are not in the nature of a monopolistic service. In nearly every urban area furnishing water and collection and treatment of sewage, these are considered municipal functions and are considered monopolistic. Waste disposal could well become the same.

In order to prepare for a successful financing, the first step, of course, is to be assured of income, and that involves the aforementioned charges which could be on the basis of quantity (very difficult) or per unit, which is much more equitable and much easier to assess. A study must be made by experienced engineers or other people who would recommend the necessary charges, estimate the number of users, and estimate the revenues expected to be derived.

Next is the plant itself. The engineers must determine the cost of the plant within very reasonable bounds, its capacity, its cost of operation and disposition sales, including revenue from the end product. There are only a few engineering firms in the country who have been successful in creating a plant which will produce a saleable product. It goes without saying that the customers for the product are probably limited and contracts must be entered into assuring the sale of the product, and obviously if the plant can be built near the principal customer, it will save transportation costs. Part of the cost of operating the plant of course will be the pick up and delivery to the plant from the whole area. This will probably be a very expensive process.

Attorneys should draft the necessary authorizing and enabling ordinance including establishment of rates, bond authorization, and the various covenants which the issuer will undertake. These should be based upon the recommendations of a qualified consultant in municipal finance who will coordinate the engineer's estimates of revenue, expense, capital costs, and needs, and the financing markets in order to determine the period of time which the bonds will run. This will, of course, be in part limited by the prospective life of the plant.

Included in the authorizing ordinance, in order to provide adequate support for any revenue bond issue, should be a clear statement of the source of the funds to be used to repay the bonds and the interest. These funds would be first applied by the ordinance to the payment of the regular costs of operation and maintenance of the whole facility and the collection system. Operation and maintenance should include only ordinary expenses and should not include any depreciation, replacement, or similar items.

The next available use of the revenues should and must be application to debt service. This will be in accordance with the schedule provided in the bond ordinance itself and the interest rate at which the bonds are sold in the market. Normally, there will be income every month from user charges and sales of products even though user charges may be fixed on an annual or semi-annual basis. Normally, various areas are staggered as to collection and due dates, giving a monthly revenue. A monthly revenue is important in order to be able to meet monthly operating expenses and to provide for regular monthly payments into a debt service fund. These payments should be sufficient to meet when due the scheduled semiannual interest payments and the scheduled annual principal payments.

A debt reserve fund should also be created which should be accumulated in regular amounts over the life of the bonds in an amount of approximately 20 percent of the scheduled debt service. This would be used, if needed, to meet principal or interest when revenues were not available.

The revenues should also be adequate to provide a substantial fund to be set aside monthly for replacement and renewals as well as possible expansions. The size of this fund and the extent of its accumulation should be guided by engineering opinions but it is far better to have it larger than the needs rather than smaller. It is suggested that the amounts be approximately 20 percent or more of debt service as this fund can also be used as a buffer against failures of revenue to meet debt service.

The issuer should covenant to establish charges, rates, and prices sufficient in total to produce net revenue after deducting all normal operation and maintenance expenses in excess of 1 and 1/2 times annual debt service. A far better figure would be 2 times. The surplus would not be wasted but would be devoted to improvements and extensions, or to early retirement of debt.

Inasmuch as a bond based upon this type of revenue is new in the financing markets, it must be presented only with a very careful and thorough analysis of the issuing body, the economics of the area, its potential for growth, its characteristics as to population, wealth, ability to pay, and willingness to pay taxes and other charges. There is no certainty that this type of financing will be successful at this time, but careful preparation may prove it to be.

There are probably many jurisdictions in the country which are unable under present statutes to attempt this sort of financing, if in fact they have the power to devote municipal funds to the collection and disposal of solid waste. In any event, a carefully drawn statute requiring with the issuance of the bonds that the issuer will establish the proper covenants and abide by them, is one of the most important and essential parts of the financing. With the broad spectrum of types of financing and municipal services throughout the country, it would seem logical, if not necessary, that solid waste disposal be placed among them. It will be most interesting to watch the development of financing along these lines.

C. VII: THE CONNECTICUT RESOURCE RECOVERY PROGRAM

Richard Chase

(Abstract of Presentation)[1]

CONNECTICUT'S APPROACH TO THE PROBLEM

Background

The state commissioned General Electric two years ago to do a one-year, $1 billion study of technology, markets, logistics, and so on. They came up with a plan calling for a network of dry fuel plants, and later for pyrolysis plants to convert the organic fraction to types of fuel other than dry fuel. (Connecticut's primarily uranium based fuel means that plants are not geared to combustion of dry fuels.)

The major utilities were asked if they would like to go into the business, but they declined.

Projects

Nine plants are being built to process Connecticut's annual 3.2 million tons of household/commercial waste. Major products to be recovered are: fuel (equivalent of 5 million barrels oil), ferrous metals (300,000 to 400,000 tons), aluminum (20,000 tons), and glass (200,000 to 300,000 tons). The remainder, 8 to 9 percent by weight, will be residue from which some heavy nonferrous metals may be recovered, and the rest goes to clean landfill. Of the three regional systems involved, contracts have been signed for the first (Bridgeport); the second (Hartford) is in the final stages of contract negotiation; and the third (New Haven) is out for bid.

Structure of CRRA

A quasi-government/quasi-public authority, the Connecticut Resource Recovery Authority (CRRA) has no subsidy funds but has power to issue $250 million worth of revenue bonds. The system it operates is entirely voluntary (municipalities do not have to bring their waste to the system), and the bonds have to be paid out of project revenue. CRRA's main problem is to put together the municipalities, their utility customer, and a producer with technical and management skills adequate to design, build, and operate the system.

The Three-pronged Bridgeport Contract

Municipality Agreement

- There are difficulties in persuading municipalities to agree to a 25-year contract for a system involving innovative technology and an uncertain market.
- To reach agreement, municipalities need: a reasonable fixed cost competitive with incineration ($20 per ton); local landfill ($5 to $6 per ton); haulage to more distant landfill ($12 per ton); or guaranteed continuity of collection. (Incineration/haulaway are really the only competitors which need to be considered, since local landfill is difficult to find in Connecticut. The reclamation system is certainly competitive with incineration and haulaway prices.)
- The resulting contract is essentially a service agreement, not involving cost sharing, on the basis of a fixed disposal fee. This fee--$30 to $40 per ton--would not in itself be competitive; the difference is covered by a minimum revenue guarantee of $10 to $12 per ton. If the project is too successful, municipalities are protected by a provision for reducing the fee.

Utility Agreement

- The two major utilities have agreed to buy fuel <u>only</u> on a basis of no risk to themselves, their shareholders, the rate payers, or the reliability of their operation.
- The resulting agreement is that CRRA pays boiler conversion or increased operational costs, and costs of any efficiency loss. (There is a provision for technical arbitration, but CRRA cannot insure because of the numerous uncertainties.)
- There is a discount incentive on incremental amounts, amounting to savings of $750,000 annually, to encourage utilities to change from oil to solid waste fuel.
- Utilities have a right to terminate.

Private Sector Agreement

- CRRA is putting up the capital and providing sites; the contractors (Garrett) invest only the assumption of risk.
- Garrett constructs and operates the 1,500 to 1,800 tons per day plant within the capital funding ($52,000,000) and time frame (2 1/2 years construction, 22 1/2 years operation) provided by CRRA.

- Garrett pays CRRA from their revenues a minimum of $14 to $21 per ton delivered waste, and in addition a percentage of all revenues above that minimum and of net income before tax, and a royalty of 5¢ per ton on other plants of the same type they may set up elsewhere.

DISCUSSION

Mr. Chase agreed with other speakers that the major problem was institutional, rather than financial or technical. A priority task was to help local government to deal with the problem intelligently.

CRRA is prohibited by law from preventing other competitive recycling activities.

On the question of household/commercial source separation, the speaker saw a serious drawback in the need for keeping the waste separate throughout the collection and transportation process. Since this was already the most expensive part of the system, it was not desirable to increase the cost in this way. Some discussion arose (and recurred throughout the meeting) as to whether source separation was a quixotic activity, with little practical purpose, or a reasonable economic route to pursue.

NOTE

1 For a detailed description of the program, see CRRA's 1974 Annual Report.

C. VIII: ECONOMICS OF RESIDUALS USE

Blair T. Bower

(Statement prepared for Hearings of the Subcommittee on Fiscal Policy of the Joint Economic Committee, November 9, 1971.)

The present concern for, and attention being given to, the use of residuals stems from the growing recognition that the increasing quantities of residuals generated in an affluent society require consideration of alternative strategies for handling residuals, strategies in addition to the traditional one of simply trying to find less damaging sinks in the environment into which to dispose of them. This leads to the focus of this statement: what factors affect the economics of using residuals?

A definition of residual and an explanation of the title are in order. Residual is defined operationally. Into essentially all activities there are flows of materials and energy. From these activities flow equal amounts of materials and energy. One or more of the material or energy outflows will be the desired "product" or products. The other material and energy outflows are residuals in economic terms, because they have zero prices in existing markets, or at least prices less than the variable costs of production. The market, at any point in time, involves the current technology and relative prices among different factor inputs into various production processes and the current spatial distribution of economic activities. It is a critical factor with respect to use of residuals.

The explanation relates to terminology. Because terminology may affect the understanding of the economics involved, some attention thereto is essential.

Both the terms "recycling" and "reuse" are subject to some undesirable connotations. With respect to the first, Webster (1961) defines cycle as, "an interval or space of time in which is completed one round of events or phenomena that recur regularly and in the same sequence." Literally interpreted, this definition means that material discharged from the end of the process is immediately returned as an input into the same process or activity. There is no intermediate processing nor temporary storage in the environment. In the context of the planet earth as a whole, this definition has some relevance. However, when applied on less than a global scale, this definition tends to obscure the many flow paths of residuals which are possible and which have different economic, technologic, institutional, and ecological implications. Only a small portion of the problem of use of residuals involves this type of direct return flow.

The term "reuse" is deficient because a residual as such is not likely to be reused. Rather, some material in it has the potential for being reused, such as the steel in the automobile body, the copper in copper wire, the cellulosic fibers in discarded magazines. In essence, a residual is simply a potential raw material, with characteristics similar to other raw materials; hence the preferred terminology, "the use of residuals."

A final introductory comment is that there are three assumptions which seem to be inherent in the current interest in, and the pressure for increasing the extent of, use of residuals in society. The first is that "recycling" or "reuse" means making use of something that has not been utilized previously. The second is that doing so will result in a decrease in the residuals--particularly solid residuals--management problem, thereby improving environmental quality. The third is that use of residuals is less environmentally damaging--however that is defined--than use of alternative factor inputs for which they substitute. The following discussion will hopefully shed light on these current assumptions.

SOURCES OF RESIDUALS AND COSTS OF RESIDUALS HANDLING

Table VIII.1 is an attempt to provide a classification of the sources of residuals in society. The classification does not purport to be exhaustive, nor will the terminology used necessarily be accepted by all. However, the operational definitions should make clear what is meant. Figure VIII.1 illustrates some of these definitions, along with possible subsequent flows of residuals, using paper residuals as the example.

Materials recovery is also referred to, as indicated in Figure VIII.1, as direct recycling. By-product production is also referred to as indirect recycling. As with all classification systems, this one is not perfect. The definition of residual given previously implies that all materials recovery and all by-product production which is economically justifiable with a given set of prices does not involve the use of residuals. That is, within the "black box" of many production processes are flows of materials and energy which are normally recovered and reused. Broke from a paper machine is an example. (Broke is the term applied to paper scrap from trimming and slitting the paper sheet and from miscellaneous sources in start-up and shut-down of a paper machine.) Direct recycling of broke is an integral part of the production process, as shown in Figure VIII.1. Chemical recovery systems to save input chemical costs and hot water recirculation to save fuel costs are other examples. Hence, no residuals are defined as being generated to the extent that such internal recirculation of materials and energy is instituted in

TABLE VIII. 1 CLASSIFICATION OF SOURCES OF RESIDUALS WITH EXAMPLES OF USE OF RESIDUALS

PRODUCTION RESIDUALS

Without storage in the environment

Materials recovery (residual is input into same process) --- e.g., second stage of collector on recovery furnace stack of kraft pulp mill

By-product production (residual is input into another production activity at same or different site) ---e.g., food processing residuals as animal feed, fly ash from energy generation as raw material for brick manufacture, waste heat from energy generation for catfish production or for maintaining ice-free navigation channels

With storage in the environment

Materials recovery -- e.g., reworking of copper mine and copper ore processing tailings for additional production of copper

By-product production --- e.g., use of gold mining tailings for production of aggregate

CONVERTING RESIDUALS

By-product production --- e.g., converting residuals from making folding boxes or printing newspapers returned to paper mills as raw material

DISTRIBUTION RESIDUALS

Separated --- e.g., used corrugated shipping containers stored and handled separately by supermarkets and manufacturing plants for subsequent input to paper mills.

Mixed --- e.g., used corrugated shipping containers as part of mixed solid residuals from supermarkets, drug stores, department stores, et al, for collection and disposition or reclamation by public or private agencies

USER RESIDUALS

Without storage in the environment

Separated --- e.g., newspapers stored separately in residences for collection by philanthropic groups, used computer printout stored separately

Mixed --- e.g., newspapers in mixed solid residuals collected by public or private agencies for disposition or reclamation

With storage in the environment

Separated --- e.g., abandoned vehicles

Mixed --- e.g., mixed solid residuals in landfills

Note: The term "reclamation" is applied to the recovery of materials from mixed solid residuals, e.g., metals from incinerator residue, glass containers from mixed solid residuals.

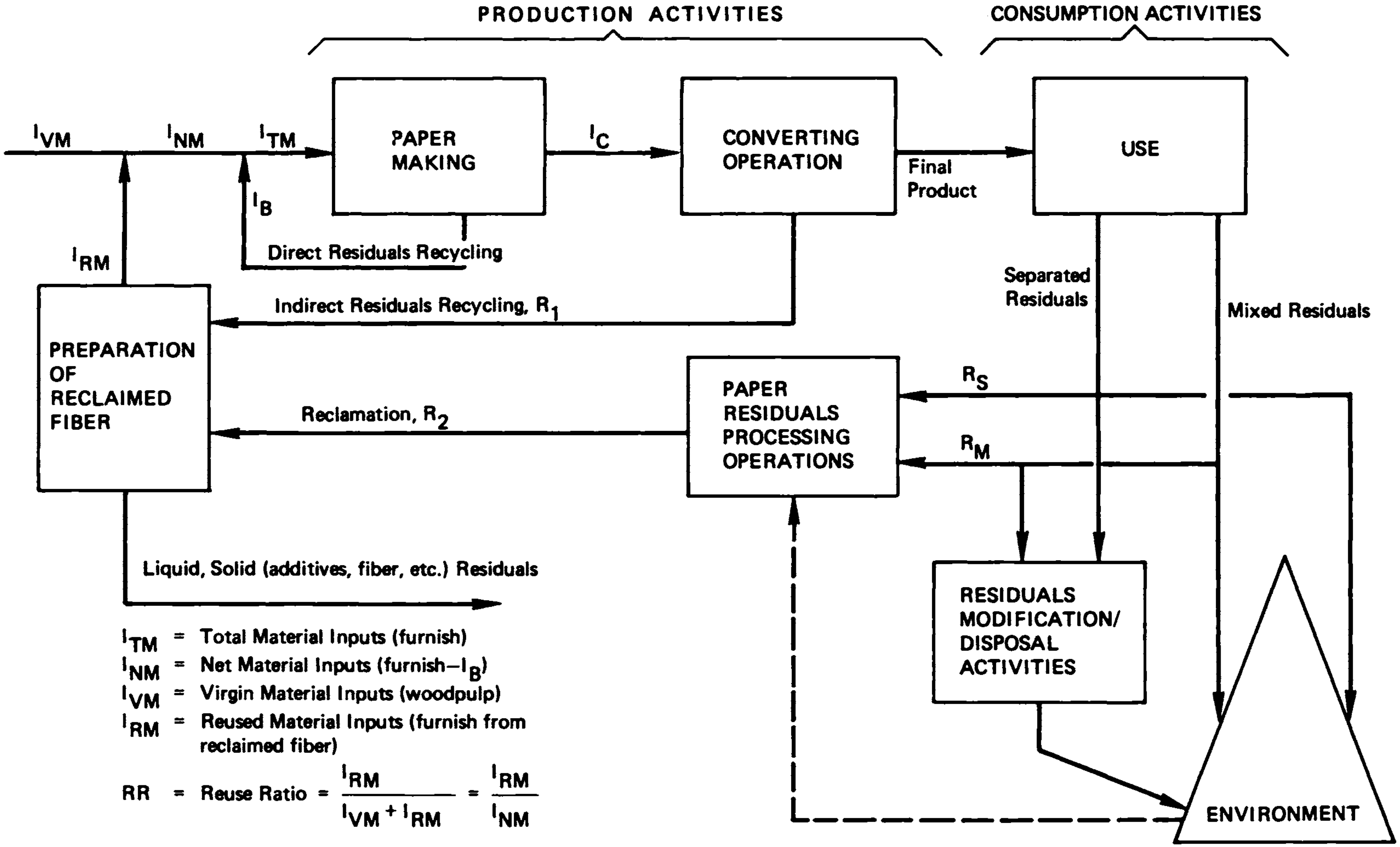


Figure VIII.1 Paper Residuals: Sources and Potential Use

Source: Spofford (1971)

the absence of pollution controls, i.e., is economically justified in relation to the costs of factor inputs given present prices. Obviously, as relative prices change over time, some materials and energy generated in production will become residuals; others will move out of the category of residuals to become part of the "basic production process."

Applying the terms "materials recovery" and "by-product production" to the use of residuals means these are possible options which might be adopted instead of waste treatment at the end-of-pipe or internal process modifications which have no savings stemming from material or energy recovery. They are noneconomic in the sense that returns do not cover costs. Thus it may not be economical to produce bricks from fly ash, but the net cost to the individual firm and to society may be less than the alternative of disposing of the fly ash to a landfill or in the ocean.

Costs of course are fundamental to the economics of use of residuals. What costs are involved? Figure VIII.2 indicates the various components of costs relating to the use of residuals--paper residuals in this case--and the alternative raw material, virgin pulp, and the variation in those costs as the degree of use of paper residuals increases. Both raw materials can be utilized to provide identical inputs (furnish) to a paper machine. The costs include:

1. the costs of furnish from the virgin raw material, including costs resulting from environmental controls imposed upon the pulp mill;
2. the costs of furnish from paper residuals, including necessary costs for managing residuals generated in processing paper residuals;
3. the costs of handling and disposing of used paper residuals via incineration and/or landfill, i.e., the solid wastes management costs, which of course decrease with increased use of paper residuals; and
4. the external damages associated with all of the remaining residuals discharged from all of the operations.

Some of these costs are borne by the producer of the paper product; some are borne by the public sector in the form of solid wastes management costs; some are borne by individual receptors, in terms of damages stemming from the remaining residuals discharged at various points in the system to the environment. It is the total cost to society in terms of resource inputs which is relevant for analyzing the economics of use of residuals.

Before discussing the factors which influence the economics of residuals use, an example which will illustrate the impact of increasing use of residuals on solid wastes management costs may be helpful. Figure VIII.3 shows estimated annual costs of solid wastes management for the New York region for about the year 2000 under each of two different degrees of use of paper residuals, 20 percent and 80 percent. In addition to the difference in solid residuals handling costs, about $90 million, there is a

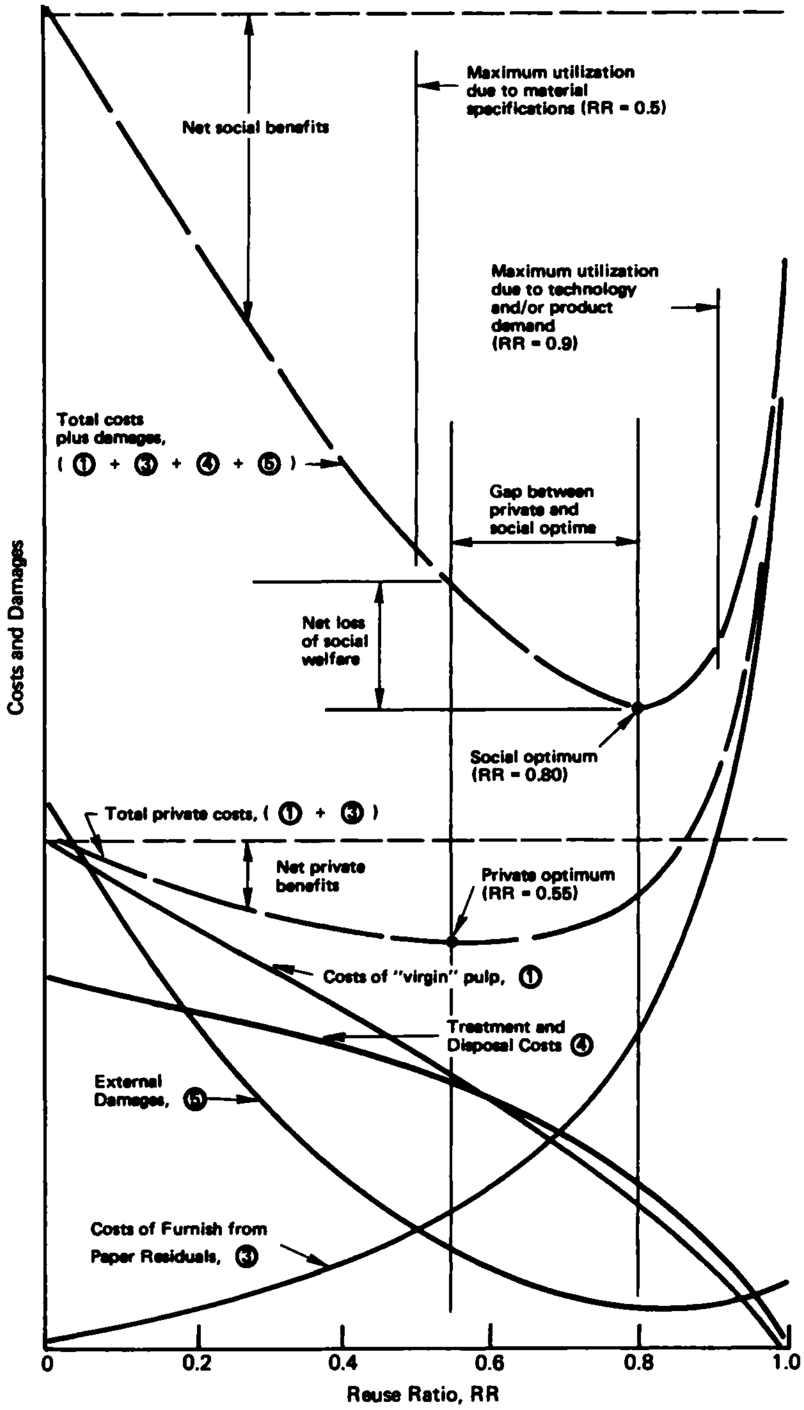
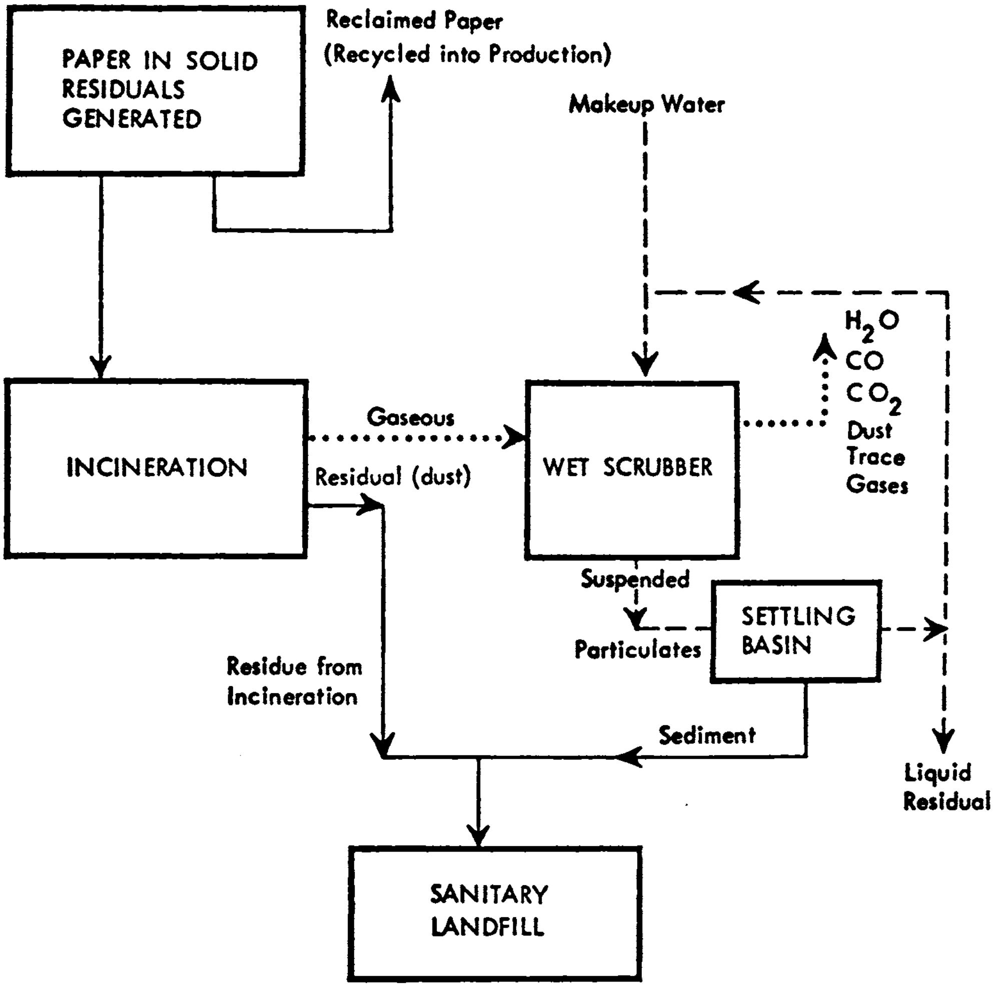


Figure VIII.2 Components of Costs, Use of Paper Residuals

Source: Spofford (1971)



Assumptions ---

1. 56.8×10^6 tons of solid wastes are generated in one year, 50% of which is paper.
2. All solid wastes are incinerated, except the portion of paper which is recycled, in collective incineration facilities; no on-site incineration
3. Incinerators are operated 24 hours per day, 250 days per year.
4. Adequate facilities and operational inputs are provided to insure that good incineration is achieved, i.e., 10 pounds of particulates emitted per ton of waste incinerated.

Results --- Annual cost with 20% of paper recycled: $300,000,000
Annual cost with 80% of paper recycled: $210,000,000
Particulates emitted to the atmosphere with 20% of paper recycled: 25.6×10^4 tons
Particulates emitted to the atmosphere with 80% of paper recycled: 17.0×10^4 tons

Figure VIII.3 Handling and Disposal of Residuals Generated in Consumption of Paper

Source: Bower et al. (1968)

significant difference in the quantity of particulates discharged into the environment, the resulting decrease in damages not having been amenable to quantitative estimation. Against these savings there may be a net offsetting cost, comprised of the difference between the value of the paper residual and the costs of its collection and transport.

In this connection it should be noted that the use of residuals is not necessarily "environmentally desirable" in comparison with the use of virgin materials. Virtually all residuals must be processed. For example, the insulation must be stripped from copper and aluminum wire; dirt and other contaminants in paper residuals must be removed and the paper residual repulped and sometimes bleached before becoming the input to the paper machine. Although use of residuals may decrease residuals management costs for a municipality, the costs of managing the residuals generated in the processing of those residuals for use may be substantial, and must not be ignored.

ECONOMICS OF USE OF RESIDUALS

The extent of use of residuals is a function of the relative costs of alternative factor inputs into economic activities, i.e., residuals as raw material versus alternative raw material, usually termed virgin raw material. As with any raw material, the important characteristics which affect its value, or the cost of the material as a factor input into production, are location, quantity, and quality. Large mass of high quality, i.e., high concentration, close to the locus of production, and/or market, are desired characteristics. This is as true for a residual as a potential raw material as it is true for a virgin raw material. A high grade iron ore in comparison to a low grade iron ore is similar to the comparison of high grade newsprint residual with low grade newsprint residual. The quantity and quality of the raw material affects the cost of its processing and the quantity of residuals generated in that processing and hence the residuals management--pollution control--costs associated therewith. It is true that there is likely to be a wider variety of contaminants or nonusable materials in residuals than is true for many virgin raw materials. In some cases these contaminants, while small in quantity, may be difficult to remove, thus increasing the cost of processing the residual for use. Table VIII.2 lists the major factors influencing the costs of the two alternative types of raw materials.

An Example: Steel Scrap and the Production of Steel

It is instructive to look at the steel industry, and its two basic ferrous raw materials--iron ore and steel scrap--in the context of the listed factors. The relative values of these two raw

TABLE VIII. 2 FACTORS AFFECTING RAW MATERIAL COSTS

RESIDUAL	VIRGIN
Quality, i.e., contaminants	Quality, i.e., concentration of ore
Technology of residuals processing, i.e., stripping mine, deinking waste paper, shredding vehicle bodies	Technology of processing virgin material, i.e., pelleting ore
Residuals management costs with respect to residuals processing	Residuals management costs with respect to virgin materials processing

Note: ResMgtCosts = f (RM, T, PO, E_c), where RM = raw material;

T = technology of processing; PO = product output specifications,

E_c = effluent controls*

RESIDUAL	VIRGIN
Transport cost, both of raw residual and processed residual	Transport cost, both of raw virgin material and processed virgin material
Technology of production process, i.e., paper making	Technology of production process, i.e., open hearth vs. basic oxygen furnace

Product output specifications[+]

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*For a more detailed discussion of this relationship, see Bower and Sewell (1971)

[+] Assumed same for both raw materials because cost comparison relates to use in making the same product, i.e., newsprint, steel.

materials have fluctuated substantially over the last two decades, as a result of changes in the technology of steel production, and--to some less clearly defined degree--the design of automobiles. The following is a simplified summary of these interacting factors.

As the high quality iron ore deposits of the Mesabi range neared exhaustion, costs for processing iron ore increased, thereby making scrap more attractive as a raw material, given the predominance of the open hearth method for producing steel. The next event was the development of pelletizing, which enabled economic upgrading of low grade iron ores, 35 to 40 percent, to high grade ores, 66 to 67 percent. (For example, see Anon 1969.) This shifted the balance back toward iron ore as the raw material.

Traditionally the technology for processing junked vehicles involved compressing a stripped and burned out hulk into a chunk of impure "No. 2" scrap. As long as the open hearth was the predominant method of producing steel, this raw material had utility, for about 70 percent of the charge to the open hearth could be relatively impure scrap (Reinfeld 1968). With the advent and growing use of the basic oxygen furnace (BOF) for producing steel--a less expensive production process than the open hearth--the bottom dropped out of the scrap steel market, because the maximum charge to the BOF is about 40 percent, the limiting factor being the impurities in the scrap raw material (Reinfeld 1968). By 1970 BOF steel production exceeded open hearth steel production in the U.S. (Neely 1970:48).

Around 1960 a technological development on the residual side was introduced, the automobile shredder. This process takes whole automobile hulks and grinds them into small pieces, enabling better extraction of impurities and producing a raw material of far better quality than the old No. 2 bundle. A shift in relative prices in favor of the residual tended to result.

The shredding plants installed in the decade of the 1960s have typically been highly capital intensive, large-volume operations, i.e., plant cost--$3 million; plant capacity--one car per minute (Haltenhoff 1971). This means that almost all such plants have been located in major metropolitan areas, leaving significant numbers of abandoned vehicles still resting in the environment.

Even so, the growth in the use of the BOF process and the increasing number of available abandoned cars, stemming from the continued increase in the U.S. car population, tended to keep scrap prices low. This availability of low cost scrap in turn stimulated the initiation of a number of small steel mills around the country based on the electric furnace, with annual capacities of 50 to 500 thousand tons of steel. By 1969 about 40 of these mills existed, producing about 2.3 million tons of raw steel (Neely 1971:56). Essentially 100 percent of the charge to an electric furnace can be scrap. This evolution, and the development in the last few years of the mobile automobile crusher and the mini automobile-shredder (Haltenhoff 1971) suggest a likely increase in the use of the abandoned vehicle residual.

Technological developments can affect not only the type of residuals which can be used in a production process but also the quantity of residuals generated in that process. Continuous casting, a recent development in the steel industry, reduces scrap generated internally in a steel mill. Such scrap is generated, in conventional steel production, in ingot and slab trimming and in rolling operations, in an amount up to 30 percent of the steel poured. Continuous casting cuts these losses to 10 percent or less (Neely 1971:55). Because the BOF operates on a low scrap charge, minimizing internal scrap generation is desirable. Thus the BOF and continuous casting go well together, further tending to shift the relative prices of virgin ore and scrap as raw materials and inducing more electric furnace capacity, which will tend to counteract that shift.

At the same time as these various technological developments have taken place, there has been a change in the product output specifications for automobiles, in terms of the component materials. As indicated above, the value of a residual is a function of the quality of the material which can be produced from it, and of course of the cost of processing. But the quality depends in turn on the original quality of the residual. The more impurities in scrap steel, the lower its value. With respect to automobiles, the trend has been ever upward in the amount of nonferrous materials utilized. The average 1970 model car contained about 100 pounds of zinc, 75 pounds of aluminum, 38 pounds of copper, and about 100 pounds of plastics. The last was about five times the amount used in 1960 (Anon 1970a, 1970b). Increased impurities in the residual increase the cost of processing and/or decrease the quality and hence the value.

An Example: Paper Residuals and the Production of Paper Products

There are three types of possible raw materials for production of paper products: (1) virgin roundwood or chips from such roundwood, the latter in situations where the chipping is done in the woods; (2) residues from wood products operations, such as saw mills; and (3) paper residuals. In turn, the last is comprised basically of two subcategories, converting residuals and user residuals (see Figure VIII.1). Neglecting any imperfections in the market, the relative quantities of the three types of raw materials utilized for production of paper products is a function of their relative costs to the manufacturer. Even before the advent of air pollution controls in recent years, and before the current agitation for increased "recycling," wood products residues were comprising an increasing proportion of the raw material input for paper production. This stemmed from the fact that the cost of this input has been becoming less than the cost of the alternative source of raw material, virgin roundwood. In Northern California, Oregon, and Washington, by the end of the 1960s, 60 to 70 percent of the input into paper manufacture was wood products residues. Even in the southeast, the area of fast growing pine, the proportion rose in the decade of the sixties from 10 to 20 percent.

Virgin pulpwood costs are tending to increase for various reasons; perhaps not the least of these is the increasing competition for alternative outputs from forest land--recreation in particular. Labor costs have continued to rise and although productivity has increased, the net result has been, and is likely to remain, a trend toward increased cost of the virgin roundwood. Note that these trends in costs and use would take place in the absence of any pollution controls or any pressure for recycling. Consequently, basic use of wood products residues does not meet the first assumption noted above, namely, that recycle means making use of something which previously had not been utilized. It <u>is</u> valid to say that in the last few years <u>increased</u> use of wood products residues has been stimulated by air pollution controls, at least in the Northwest where air quality standards could not be met with use of the traditional tepee burner. But the incremental addition to total use because of this factor appears relatively small.

Turning to the third category of raw material, paper residuals--specifically converting residuals--the percentage of residuals generated in converting operations varies from 2 to 3 percent in printing newspapers to about 20 percent in making folding cartons. Converting residuals have desirable characteristics as raw materials--large quantities in a single location, high degree of homogeneity or little contamination, and if contamination exists it is of a known, specific nature. Consequently the large bulk of converting residuals has been used for many years. In 1969, about 5 million tons of converting residuals were generated, of which about 4 million tons were used. This use has occurred by virtue of the fact that the raw material cost represented by converting residuals was less than that of the alternative raw material of virgin roundwood. Thus, the bulk of converting residuals has been and is being used in the absence of pollution controls or "recycling" pressure.

The significance in relation to the second assumption noted originally is obvious, both with respect to wood products residues and with respect to converting residuals. That is, there would be little decrease in the solid wastes management problem because the bulk of converting residuals and much of wood products residues are being used. What it means is that in cases where costs for pollution control and residuals disposal are imposed directly on converting and wood products operations, these costs will stimulate some further use of residuals.

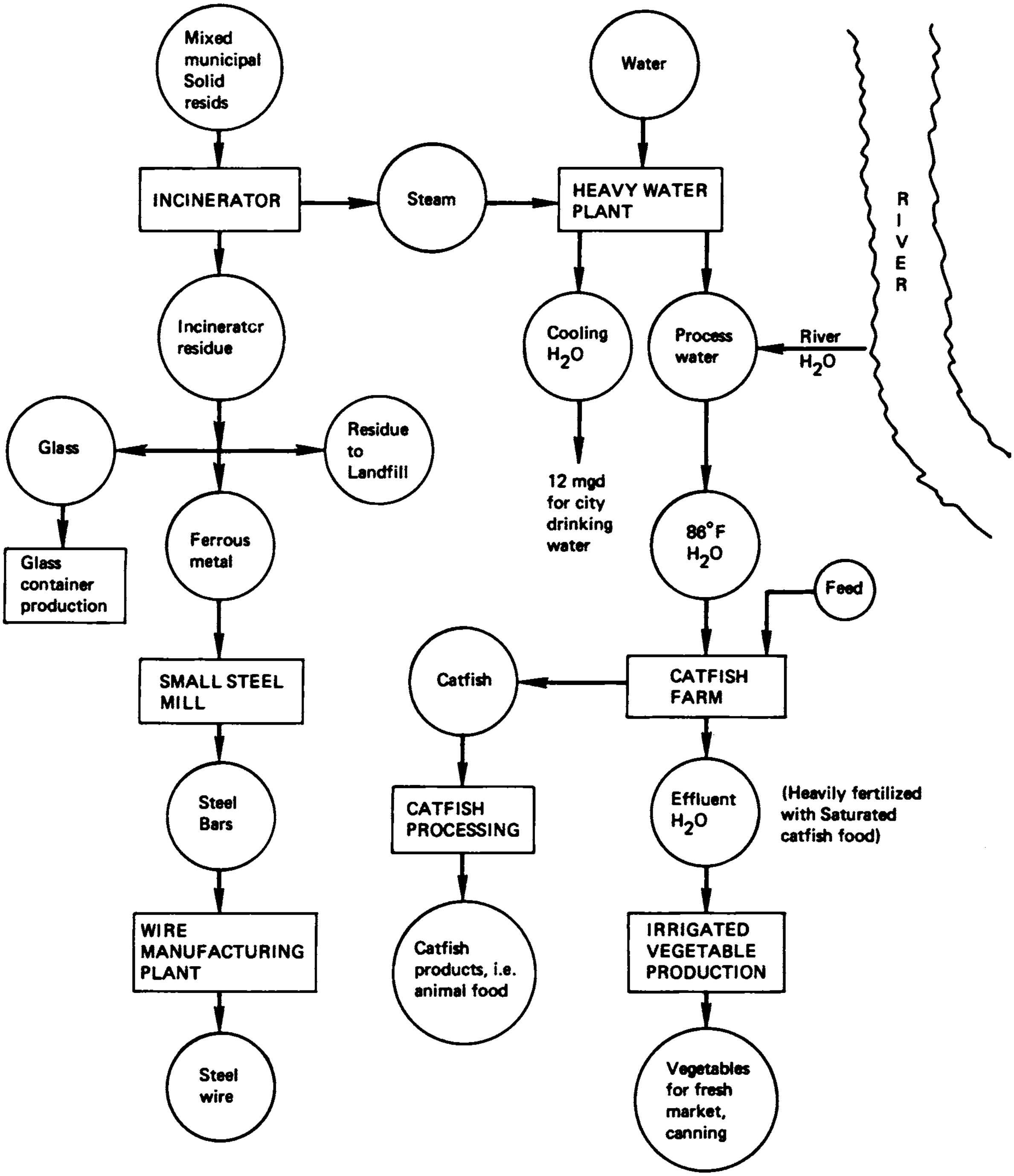
The third assumption may or may not be valid. That is, in order to utilize paper residuals--or any other type of residuals--as raw material, processing of the residual is required, just as the raw iron ore must be processed. The processing operation itself requires inputs, such as energy, and results in the generation of residuals. Whether or not these residuals are less environmentally damaging than those generated in the use of virgin raw material depends on the quantities and characteristics of the residuals generated and the costs of reducing or modifying the residuals before discharge into the environment. For example, if 100 percent waste paper is used to make a paper product in contrast to softwood using the kraft pulping process, the former results in the generation of no gaseous residuals, but substantially more dissolved and suspended solids than the kraft process. Whether or not the gaseous residuals generated in the kraft process are more damaging and/or more costly to modify depends on the particular situation.

One other point merits mention in the context of comparing the economics of using residuals with using virgin raw materials, namely, the importance of product specifications. Depending on those specifications, greater or lesser amounts of paper residuals can be used, and greater or lesser amounts of residuals are generated because the degree of processing required is directly related to the product specifications. For example, if a brown paper towel is acceptable rather than a white paper towel, no bleaching is necessary either for the paper residuals as raw material or for virgin roundwood. Because bleaching is a major generator of residuals, this takes on added significance. But it should be emphasized that different paper products require different component inputs, computer punch cards in contrast to newsprint, for example. Many paper residuals simply cannot physically be used for certain products.

CONCLUDING COMMENTS

The above examples show the multiplicity of factors affecting the economics of residuals use. As emphasized, the extent of use of residuals is a function of the price of a residual as a raw material compared with the price of alternative "virgin" raw materials. In addition to the factors discussed above which affect these relative prices, there are other factors, the effects of which are less clear. These include: depletion allowances on virgin raw materials; possible differential assessment on land and processing facilities between those located in metropolitan areas--typically the location of residuals processing, and those located in small towns and rural areas--typically the location of virgin raw materials processing; possible differential effects of capital gains taxes; attitudes of purchasing agents who specify virgin material rather than utilizing a performance specification; and labelling requirements which require designations such as "used oil" and "reprocessed wool"--even though there is no difference in performance of the product.

The pervasiveness of residuals, i.e., generated in essentially all economic activities, the finite assimilative capacity of the environment, the necessity for the use of some assimilative capacity as an input into essentially all economic activities, and



Note: Not all residuals streams nor all factor input streams shown.

Figure VIII.4 Residuals/Multi-Product Complex

Source: Based on account in New York Times, 2/21/71, p. F13 the substantial damages which can result from the excessive discharge of residuals to the environment, require that much more rigorous analysis be made of the factors which affect the use of society's residuals. Other than by changing final demand--the mix of goods and services desired by society--and changing raw materials and/or production processes to generate fewer residuals, the increased use of residuals is the only alternative for reducing--or potentially reducing--the quantities discharged into the environment.

One approach which may be helpful is analogous to the traditional "industrial complex analysis" (Isard 1960). This type of analysis looks explicitly at the outputs of multiple processes, as possible inputs into other processes, to determine what the optimal mix of activities is for a given location--in relation to alternative raw material sources and markets. Traditionally such analysis has not considered residuals explicitly. But it could readily be extended to take the possible uses of residuals directly into account, along with all transport costs of raw materials, products, and residuals, and the associated energy costs. This approach is reflected in Figure VIII.4. But whatever the approach, far more explicit consideration of the use of residuals is essential.

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C.IX: CAPTIALISM AT THE CROSSROADS: INCENTIVES FOR RESOURCE CONSERVATION

David Gordon Wilson

There is an analogy between the person who builds on a flood plain and someone who becomes dependent on a bountiful but eventually uncertain supply of cheap energy. The plain may flood only once in every hundred years. At any one time the probability of flooding is small. But an eventual flood, perhaps predictable, perhaps relatively unexpected, is almost inevitable. When such a region is flooded it is usually found that the plain dwellers have no flood insurance and that the general population must come to their rescue.

In a rather similar way we in the United States have built on low-cost supplies of many commodities, some of which have an uncertain future supply. The uncertainties are sometimes due to increasing world scarcity. Some minerals such as chromium might fall into this category, although we might have to redefine scarcity to mean "scarcity of low-cost easily accessible ores in the 'free world'." The uncertainty in the supply of oil is due to the international political action of a cartel. Uncertainties in the supply of water in some areas and of food in others may be principally because of uncertainties in the weather, although crop diseases and vector infestations may play a disastrous part. Unexpected increases in demand for resources by other countries cause additional uncertainties in the supply of some commodities.

Government action is obviously required. But what action? The ease and inexpensiveness of building on flood plains lead, in a completely free market, to the rapid establishment of whole towns. Future dangers might be foreseen, but we always discount future costs. Residents enjoy easy living so long as there is no flood. When a flood comes, the cost is extremely high--too high in most cases for individuals to bear.

Government cannot allow this kind of social discounting of the future to the extent that communities condemn themselves to eventual self-annihilation. Therefore, an alternative course to allowing unbridled capitalism to reign in land use is to control the economy by zoning. The government decides who builds for what purpose in which place.

The decision as to which areas are subject to flooding and which are not is a clean, easy one for government to make. In practice there are many other aspects of the use of land, such as the air and water pollution which might result, or the congestion, or the loss of scarce farming land, or the limitation of access to other land, and so forth. All these other factors are external or social costs--costs which are incurred by others.

When society contemplates action to compensate society for these unpaid social costs, it finds it easy to propose controlling every aspect of land use, not merely whether or not building should be allowed on a flood plain.

In this analogy, and in the energy area, government stands at a crossroad, faced with not just two but three roads among which to choose. We have illustrated two of them. One is the free market of unbridled capitalism, and the second is the controlled economy--gasoline rationing and fuel allocation. There is a third way. It is the way we shall advocate here. It can be called the modified free market (MFM), or the route which incorporates feedback of social costs.

In the case of the flood plain this third way can be illustrated relatively simply. Those who build on the plain would be required to take out comprehensive flood insurance and to pay the premiums year by year, whatever the cost. If their building on the plain caused other social costs such as water pollution, they would additionally be required to pay full compensation to people downstream who could be regarded as having a right to expect unpolluted water. The significant feature of the MFM approach is the feedback of the compensations to the people adversely affected. And an incentive has been given to avoid the low-cost but risky alternative.

If the insurance rates and the various external-cost compensation rates could be worked out (they would vary from one place to another and would change from year to year) the government could allow a free market to exist. It would be freedom considerably modified from the pre-existing type of free market, but it would still be free in the sense that there would be no government control over individual choice. However, the incentives which would result would mean that only people with very strong reason for doing so would build on the flood plain. We believe that this condition is preferable to both the pre-existing condition and to complete government control.

To translate this analogy to the situation as it exists today in the uncertain supply of energy, some changes are necessary. We cannot require the insurance industry to issue policies to all users of low-cost energy protecting them against future uncertainties in supply or increases in price. So many people would be involved that the funds required could not be held ready for emergency use. In fact, the premiums would simply amount to a periodic transfer of funds from users to nonusers of energy. That being so, we might as well abandon the concept of insurance and simply have the government carry out the collection and distribution (the feedback) of the premium funds. Pragmatically, the effects would be entirely in a favorable direction. Heavy dependence on low-cost energy would be discouraged by the increased apparent price, while the funds redistributed to consumers would be available for alternative uses not judged (by society, through the political process) to entail the risks of uncertainty.

Here in practice is how the MFM would work.

Just as the insurance industry decides its rates based on a consideration of many factors, so the government would determine rates for various commodities and resources based on essentially political assessments of the effects of uncertainties, or known shortages, in supply. To use energy again as an example, the government might decide that it is politically and socially desirable to reduce energy use just to the point at which present domestic energy supplies and apparently reliable imports of petroleum could meet all foreseeable near-term demands. In this case a quite small rate or surcharge might be chosen--for instance, 50 cents per million BTU, equivalent to a little over 6 cents per gallon of petroleum. Or the government might choose to achieve, by degrees, total independence from foreign sources of energy. In this case, the energy surcharge would need to be increased by increments eventually (perhaps after two or three years) to at least $2 per million BTU (to judge from recent evidence of short-term elasticity in energy use). This would amount to about $11 per barrel.

Let us suppose that the government chose this second alternative (if only because the effects would be more dramatic for illustration). These are the effects of such a policy.

1. Total U.S. energy use would drop by perhaps 18 percent from about 7 x 10^{16} BTU per year to 5.7 x 10^{16} BTU per year. This amount can be met by domestic supplies.

2. The revenue collected from the surcharge would be $114 billion per year.

3. A politically acceptable distribution (feedback) of these funds would be to divide them equally among all U.S. adults (about 132 million). Each adult would then receive an "energy refund" of $865 per year, regardless of the amount of energy he or she consumed.

4. All energy prices would be decontrolled, and the effects of the surcharge could be passed through. (Monopolies like utilities would still be regulated, of course.) The prices of all goods and services would rise in proportion to the energy use involved. However, energy from sources where there are no shortages or uncertainties or other social costs, such as solar, wind, wave, or geothermal energy or that recovered from solid wastes, would bear no surcharge and would become relatively more attractive.

5. The hypothetical average energy user would find that the increased cost of all goods and services regularly consumed would be exactly paid for by the energy refund received. Below-average energy users--in general, the poor--would receive more in the refund than the additional increased costs would amount to, and would become better off. Conversely the rich would be somewhat worse off. This approach is therefore progressive, in contrast to the highly regressive gasoline tax which is occasionally proposed.

6. Many people would be able to live without the welfare assistance formerly needed.

7. All people would have an incentive to move towards reduced consumption of nonrenewable energy. For instance, there would be an incentive towards spending the energy refund on home insulation rather than on fuel.

8. While goods would cost more, labor costs would not rise, and service industries would become more attractive. With increased purchasing power available, employment in repair and maintenance industries would increase. (It would become much more worthwhile having a five-year-old car or a two-year-old TV set repaired than it is at present.) Consumers would want to buy higher-quality, longer-lasting, more-easily-serviced goods. Farming would become less energy-intensive and farm employment would increase. Low-energy manure and compost would find increased application at the expense of high-energy fertilizers. Presently, marginal forms of energy saving and production, such as district-heating systems based on generating-station waste heat, would be introduced by utilities. New industries exploiting solar and wind energy for special applications would grow up.

9. Government research into "new" forms of energy production could be phased out. The Federal Energy Office could be disbanded. Sixteen other federal agencies presently trying to outdo each other in energy research could be shrunk to the status of monitors, if in fact they need be kept in being. Government in general would shrink. Taxes supporting these agencies could be reduced.

10. Existing taxation agencies would not need to be made larger, because it takes no more effort to impose a larger tax than a smaller. Likewise the Internal Revenue Service would take in less and refund more but in general the same staff would be adequate.

11. The balance of trade for the nation would be dramatically improved as our dependence on petroleum imports lessened.

12. The high profits of the oil companies would be reduced because consumer resistance to higher prices would be such that the companies would absorb part of the surcharge in order to remain competitive. No excess-profits tax, something very difficult to legislate, would be required.

13. Inflation would be reduced because the existing positive-feedback spiral would be replaced by a negative-feedback economic control system. "Stagflation" would be replaced by a readjustment of the economic system, increased employment, and a new price stability. The outflow of dollars would be eliminated.

14. The precipitate and almost irreversible actions required to introduce gasoline rationing and fuel allocations, with the attendant large number of bureaucrats and inspectors, would be made unnecessary. In contrast, the MFM policy can be introduced gradually and the effects measured before the next increment of surcharge and feedback is made. And the policy is reversible

without major costs to the economy so long as changes are introduced relatively slowly.

15. Industry would be able to make intelligent plans for future production, without the expensive and stultifying contingency planning presently necessary to guard against the possibilities of arbitrary government controls being suddenly imposed, or of devastating price increases occurring.

The modified free market, or the feedback economy, has features which seem counterintuitive to much present-day thought. When shortages occur and prices rise, the prices would be further surcharged and consumers would be given additional income. This is in sharp contrast to one branch of present political and economic opinion, which calls for prices to be reduced by actual or equivalent subsidies, and for incomes to be reduced by the inevitable tax increases which these policies require. It is also in contrast to the other principal branch of opinion which advocates strict government controls on virtually all production and consumption. It is even contrary to a third, rather small, group which asks for an increase in the gasoline tax alone, which ignores other uses of petroleum, and which specifies no basis for the use of the enormous funds thereby removed from circulation.

A fourth group would have the government take no action except that of exhorting people to drive less, heat their houses less, fertilize their gardens less, and so forth. This policy, or absence of policy, is one which clearly leads to widespread anger and resentment at the so-called cheaters, to guilt complexes on the part of many who cannot do without certain types of energy consumption, and, insofar as the exhortations are successful, to a loss of jobs in industries affected.

These alternatives to the modified free market are clearly costly and economically dangerous. The virtues of negative feedback are as beneficial in an economic system, as enumerated above, as in a home-heating system in which the thermostat prevents the house becoming too hot or too cold. And, like the thermostat, the MFM can be adjusted as finely as we wish, to give a temperature suited to the supply of fuel.