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PROJECT TRASH: TOTAL REFUSE ADVANCED SYSTEMS HANDLING.(U)
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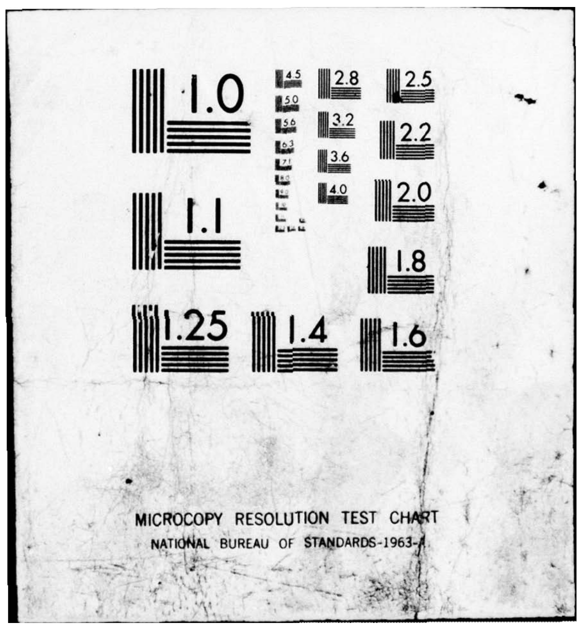
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Technical Report

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CIVIL ENGINEERING LABORATORY
Naval Construction Battalion Center
Port Hueneme, California 93043

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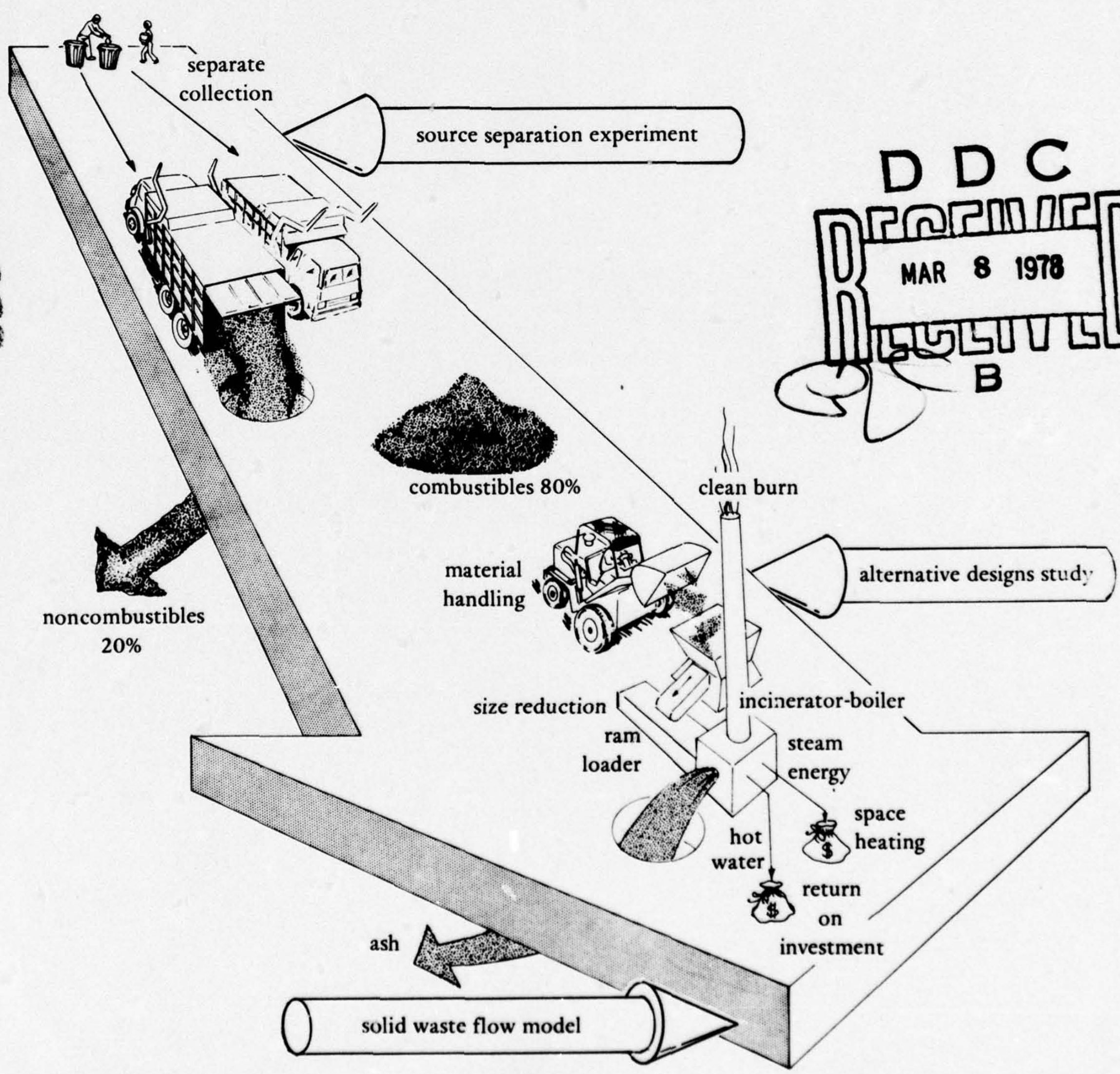
December 1977

PROJECT TRASH: Total Refuse Advanced Systems Handling

by Carter J. Ward, Ph D and William V. Miller



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Preliminary and conceptual designs of alternative approaches to a small-scale solid waste transfer/resource recovery station were developed. Equipment components and processes were examined, and their life-cycle costs were compared. Selected modules were combined to process two types of solid waste: (1) completely mixed waste and (2) waste from which most glass and metals had been source-segregated. All system designs were ranked according to life-cycle cost. A solid waste two-component

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Preliminary and conceptual designs of alternative approaches to a small-scale solid waste transfer/resource recovery station were developed. Equipment components and processes were examined, and their life-cycle costs were compared. Selected modules were combined to process two types of solid waste: (1) completely mixed waste and (2) waste from which most glass and metals had been source-segregated. All system designs were ranked according to life-cycle cost. A solid waste two-component source-segregation experiment was then conducted to resolve questions of workability and to quantify the associated effectiveness and cost factors. In addition, a computer program was developed to aid in the economic analysis of proposed changes in waste practices, such as implementation of source segregation, resource recovery, and transfer station operations.

CONTENTS

INTRODUCTION

Increased costs of solid waste handling at Navy shore facilities have resulted from newly legislated environmental requirements, higher labor and equipment costs, and increases in the quantity of solid waste being generated (1). These have necessitated setting a high priority on development of new methods and equipment to reduce expenditures.

Navy development must include small-scale refuse resource recovery facilities because most shore activities are small when compared to municipalities; i.e., 77% of total Navy solid waste is generated at bases which dispose of less than 75 tons per calendar day* (2). The municipal solid waste resource recovery problem has been and is currently being addressed by the U. S. Environmental Protection Agency (EPA). However, the municipal developments have focused on large-scale facilities - 500 tons per day and greater (3).

The Navy also needs to develop alternative methods for disposing of solid waste. A 1972 survey (4) showed that the Navy uses 167 landfill sites to dispose of waste from 147 shore activities. Most of these landfills comply only marginally with Navy mandatory guidelines (5). Up to a hundred years may be required for these landfills to decompose and for related settlements to cease (6). As a result, traditional structures cannot be built in these areas because of the unstable soil (7) and safety problems associated with methane generation (8). Studies by the Civil Engineering Laboratory (CEL) to simulate a representative volume within a landfill by accelerating decomposition proved inconclusive (6). Because Navy land areas are relatively fixed, the Navy will become more dependent on local nongovernment-owned land for future disposal sites.

In addition to the Navy's significantly smaller plant size requirements, Navy solid waste composition is quite different from typical municipal waste (3). Navy waste does not include nearly as much residential type of refuse as does municipal waste. Therefore, the Navy should not become totally dependent on equipment developed for municipalities. Refuse generated in the Navy shore establishment is generally about 70% to 90% (by volume) combustible (9). Also, unlike typical municipalities, the Navy currently uses steam networks in approximately 50% of its shore facilities to distribute heat energy (10).

Though these are not the only Navy-unique solid waste areas that require cost-effective research, they do represent the prime concerns addressed in Project TRASH (Total Refuse Advanced Systems Handling). Project TRASH was comprised of four subwork units within the CEL Solid Waste R&D and Energy R&D programs. This project constituted a coordinated approach amongst the various involved disciplines toward the

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*TPD.

systems analysis and design of a solid waste management RDT&E facility suitable for Navy needs. Technical disciplines particularly addressed by Project TRASH were resource recovery, source separation, and waste heat recovery in packaged incinerators, which accounted for three of the four above-mentioned subwork units. In the fourth subwork unit, a solid waste flow model was developed to provide for computer analyses of the economic impact of proposed changes in solid waste management practices and, also, to estimate the cost-effectiveness of new solid waste management systems.

The primary goal of Project TRASH is the development of cost-effective methods for processing refuse in a form conducive to generating steam energy at Navy shore installations. Resource recovery equipment and other new systems to increase Navy savings in handling, disposing, or reducing the amount of waste being disposed of in landfills are secondary goals.

It is important to note how Project TRASH relates to the Tri-Service RDT&E Plan for Solid Waste Management (11); i.e., problems peculiar to the Navy are generally the same as those of the other services. The Tri-Service Plan was developed so that a combined effort on the part of the military services would address military-unique problems in solid waste management.

Background information in this report covers the origin of CEL's involvement in solid waste research and development for the Navy starting in FY-72 up to and including the systematic approach taken by the CEL solid waste program team. The primary purpose of this report is to outline the strategy of the systematic approach (Project TRASH), the goals set for that project, and its accomplishments.

The waste heat recovery/packaged incinerator work is outside the scope of this report. This work unit was included under the CEL Energy Program, and its results are presented in that program's reports.

ACCOMPLISHMENTS

Preliminary/conceptual designs of alternative approaches to a small-scale solid waste transfer/resource recovery station for Navy shore facilities were developed. Alternative equipment components and processes were examined for each functional module, and their life-cycle costs were compared to identify the most cost-effective equipment and processes. The selected modules were combined to form alternative system designs to process two types of solid waste: (1) completely mixed waste and (2) waste from which most glass and metals had been source-segregated. All alternative system designs were then subjected to a life cycle cost analysis and ranked according to cost.

A solid waste two-component source segregation experiment was conducted at a Navy shore installation on a scale large enough to resolve questions of workability. The effectiveness and cost factors associated with the two-component source segregation of refuse into combustible and noncombustible fractions were quantified.

A computer program was developed to aid in the economic analysis of proposed changes in Navy solid waste practices, such as implementation of source segregation, mechanized collection, resource recovery, and transfer station operations. The program can be used to estimate the cost effectiveness of new solid waste systems, study the sensitivity of system performance to changes in system variables, and to identify critical areas where R&D efforts will yield the highest payback.

BACKGROUND

CEL's research in solid waste began in FY-72 with an objective of improving solid waste procedures and equipment for Navy vessels berthed or operating in shallow waters (12). In FY-73 the objective was expanded to include development of improved systems, procedures, and equipment for the collection, transport, and disposal of solid waste at Naval shore facilities (13). The approach taken in the first 2 years included review of advancements made by government and industry to determine how and where these advancements could improve Naval shore facility solid waste management. New concepts were developed for handling and disposal systems from the point of generation to final disposal. A cost analysis was performed to identify high cost areas needing improvement. This analysis later proved the importance of solid waste in the Navy by surfacing the Navy's annual generation rates for shore facilities (approximately 3,000,000 tons) and associated annual costs for collection, transfer, and disposal of this material (approximately $75,000,000) (14,15).

In FY-74 and FY-75 the following specific research projects were initiated: (1) open-pit incineration of conventional waste; (2) refuse densification processing; (3) truck attachment for mechanizing collection of family housing solid waste; (4) mechanical landfill simulator; solid waste generation factors; (5) transfer station/resource recovery facility study; (6) utilization/disposal of solid waste in landspreading and applications. In April 1975, CEL completed a planning document, coordinating for DOD the current and future programs of military service laboratories engaged in solid waste research. The document, Tri-Service RDT&E Plan For Solid Waste Management (16), was prepared for FY-76 and beyond.

Early in FY-75 the solid waste program was divided into two work units: "Solid waste handling and disposal at Naval shore facilities," and "Advanced solid waste handling and disposal at Naval shore facilities."

In FY-76, four of the seven projects (mechanical landfill simulator, solid waste composition and generation factors, open-pit incineration, and tri-service program plan) were terminated and their results documented (6,16,17). A new Solid Waste R&D Program structure (Figure 1) was developed to include four new projects. One of these projects was in response to a request by the Civil Engineering Support Office (CESO) of the Naval Construction Battalion Center, Port Hueneme, Calif., to develop parametric guidelines for aiding in cost-effective selection of refuse collection equipment for Navy Public Works Centers and Departments; the other three projects, together with one project from the Energy R&D Program, constitute Project TRASH.

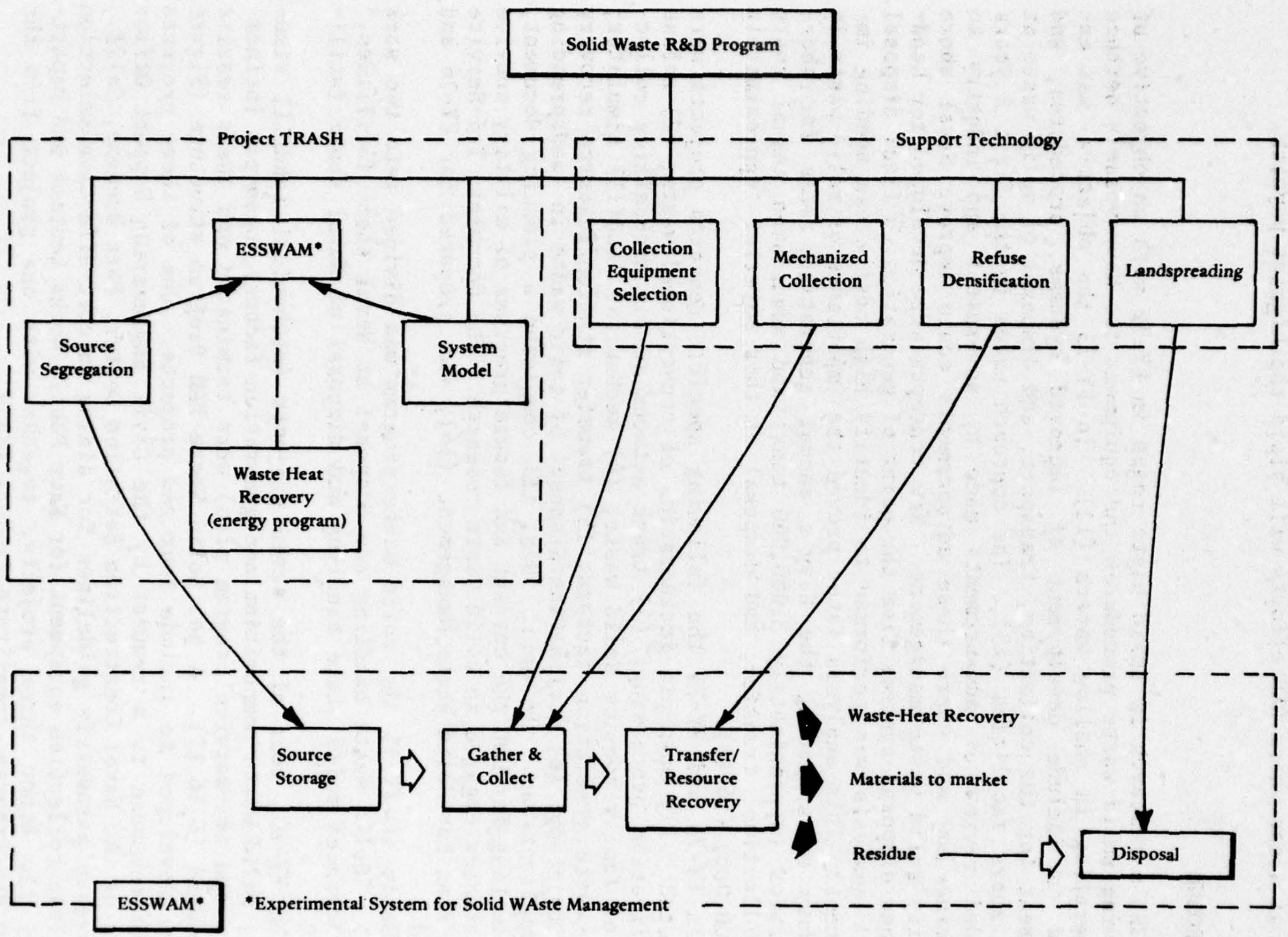

Figure 1. Solid waste R&D program structure/influence on naval base operations.

Project TRASH was CEL's solid waste R&D resource recovery and waste-to-energy program. The project started in FY-76 and included the three following work units: Experimental System for Solid Waste Management at Naval Shore Facilities (18), Solid Waste Flow Model (19), and Experiment on Source Segregation of Solid Waste at Navy Shore Installations (20). The remaining portions of this report will be limited to discussions concerning Project TRASH.

DISCUSSION

The thrust of Project TRASH was to develop cost-effective processing for converting the combustible refuse fraction into steam energy. This is considered high priority since the Navy's solid waste is mostly combustible and steam lines are readily available at about half of the shore facilities. Another point to be considered is that Navy land available for refuse disposal is extremely limited. Development of reliable, inexpensive, low-technology equipment that can economically process small quantities of solid waste was also considered high priority because most Navy generators of solid waste are small, as noted earlier. An additional benefit from developing standard small-scale processing systems is that standardization of component modules would avoid costly custom design and construction. Parallel process lines could be used for the larger generators to improve reliability and give the capacity for higher volumes along with the flexibility for adjusting to changing volumes. Interchangeability, standardization of operator training, low cost procurement of the modules, and ease of implementation at new Navy facilities all bore on the decision to emphasize design studies of a small-scale, standardized, resource recovery plant.

Upon examination of typical commercial solid waste processing equipment used in refuse heat recovery systems, it was found that a large portion of the capital investment went toward equipment used primarily for separating the combustible fraction from the mixed refuse (21). For small-scale systems to be economical, the unit capital cost must be considerably lower than for large-scale systems. A reasonably straight-forward alternative is to segregate the waste at the source of generation into its combustible and noncombustible fractions. While this kind of segregation would not be expected to separate all of the noncombustibles from the combustibles, it would be expected to produce a combustible fraction that does not contain large heavy metal objects and that can be processed at much lower cost with considerably lower expenditures of energy. The RDF (refuse-derived fuel) would be less likely to contain explosive or toxic items, and some of the segregated noncombustibles will have resale value.

Before a sound decision can be made as to which solid waste processing system should be selected for implementation, the workability and costs of source segregation in the Navy shore establishment must be known to allow consideration of this alternative. Design, fabrication, and test of equipment for converting refuse to fuel are required to determine the feasibility of economically converting solid waste into usable energy. An investigation by a commercial research institute into the present state of the art of processing systems and equipment for waste-to-energy applications revealed the need for considerable additional research (22). However, it was felt by the Project TRASH team that elimination of the equipment used for separation of the combustibles from the noncombustibles in refuse would greatly improve system reliability and economics. The question was: By how much? Consequently, a model for computerizing an economic analysis of a large variety of systems was needed for simulating proposed changes as well as proposed new systems in Naval solid waste management practices. The following sections describe the individual work units and discuss their relationships to Project TRASH.

Experimental Systems for Solid Waste Management at Naval Shore Facilities (ESSWAM)

The objective of this work unit was to construct a small capacity (nominal 25 TPD), low cost experimental solid waste plant that incorporated resource recovery and waste-to-heat refuse processing equipment. RDT&E on the waste heat recovery incinerator/boiler package was to be conducted under the NAVFAC Energy Program. Effort in this area was coordinated with the Solid Waste Program but is reported under the Energy Program at CEL. The total system was to constitute a pilot operation for Naval shore activities. The initial effort was expended toward the preparation of alternative preliminary designs from which the most suitable could be selected. Further plans (work not completed) include the preparation of detail working designs, construction of the facility, and test and evaluation. The first phase was contracted to Systech Corporation of Xenia, Ohio. The scope of work included the following four basic elements.

1. Survey of the existing solid waste system at the U. S. Naval Construction Battalion Center (NCBC), Port Hueneme, Calif. (the intended site for the RDT&E facility).

2. Preparation of alternative preliminary design concepts for the experimental station based on modular construction. In these concepts, each module is complete and self-contained. Each module, irrespective of its physical location, is functionally interfaced with adjacent modules to form an integrated system. Two solid waste stream conditions were considered: (a) the waste completely mixed and (b) the waste partially segregated into combustibles and noncombustibles. Each condition was capable of resulting in a different modular design. The modular design was predicated on suitable application of commercially available equipment, which, in turn, determines the degree of segregation for the partially segregated condition--(b) above. The modular noncombustible (and mixed) process lines included equipment for ferrous metal, nonferrous metals, and glass separation. Accordingly, a market survey of local industry was made to determine sales potential of the three segregated refuse materials.

Three design concepts for processing the combustibles were prepared, one for each of the three different forms of the combustible fraction shown in Table 1. Modular process lines for separating the combustibles from noncombustibles were also conceptually developed for comparison.

3. Preparation of parametric analysis of the integrated modular systems and ranking of the alternative preliminary design concepts based on estimated capital cost, operating and maintenance costs, environmental impact, and safety. Only generation rate, refuse composition, and equipment characteristics were considered in the parametric analysis.

4. Documentation of the findings in the form of a report.

Before the contractor findings are described, a brief discussion of some of the major equipment modules commonly used for waste-to-energy processing will be given.

Refuse Separation Equipment. Refuse separation technology was originally felt to be within the present state of the art; however, through use and testing, engineers have discovered that considerable research and development is required (22). Basically, most of the costly problems in the waste-to-energy systems are found in the hammer mill (shredder) and air classifier (21). The principal advantage of this solid waste processing technique is that it can or was originally thought to be capable of receiving solid waste as it is generated (i.e., mixed). The mill consists of a horizontal axle with articulated heavy arms (hammers) surrounded by heavy walls and grates (23,24,25). The refuse is repeatedly impacted and broken up until it is small enough (usually less than 1 in. maximum dimension) to pass through the grates. The air classifier accepts the shredded refuse and meters the material at uniform flow rate into its throat where an upblast of air lifts the lighter material fragments (combustibles), leaving the heavys (noncombustibles) to drop out (26).

The problems encountered with these equipment components are very basic. Shredders have been proven to work for the mining industry where the material is fairly homogeneous (25); solid waste, however, consists of just about everything. How does one design a shredder to break up a heavy metal object such as a discarded electric motor and also chop up a large discarded rug? Additionally, the power required to operate a hammer shredder is large, ranging from 400 to 2,000 hp (23). Experience has shown that internal parts of hammermills, particularly the hammers, wear rapidly when processing mixed solid waste. In many cases, the hammers must be retipped every day. The exact cause of rapid hammer wear has not been fully investigated, although abrasive materials such as glass and hard metals are known to be major contributors (22). The capital cost of shredders typically ranges upward from $200,000 (23).

The air classifier will only function if the refuse is shredded so that particle sizes are consistent enough to allow gravity to separate the combustibles from the noncombustibles (26). Unfortunately, ex-

Table 1. Three Types of Processed Refuse-Derived Fuels[a]

	Densified RDF[b]		Fine RDF		Coarse RDF	
	Min.	Max.	Min.	Max.	Min.	Max.
a. Moisture content, % by weight	8	22	–[c]	25	–	35
b. Separable inerts, % by weight	–	5	–	5	–	8
c. Density, lb/cu ft	NA[d]	NA	6	–	4	–
1. Unit piece	30	50	NA	NA	NA	NA
2. Average, 1 cu yd random orientation	20	–	NA	NA	NA	NA
d. Dimensions, unit piece, in.	0.5	4	NA	NA	NA	NA
1. 80% of pieces, by weight	NA	NA	–	0.5	–	3
2. 95% of pieces, by weight	NA	NA	–	0.8	–	5
3. 99% of pieces, by weight	NA	NA	–	1.5	–	7

[a] RDF.

[b] Shape of pieces is not specified. No binders or other chemical additives, except water, are acceptable.

[c] Dashes indicate value not specified.

[d] Not applicable.

perience has proven that separation is not efficient (22): a large percentage of the wood, an excellent fuel, reports to the heavies (noncombustibles); many small glass fragments report to the lights (combustibles). This is believed to be the result of the high profile drag caused by the large surface areas of the thin glass fragments and low profile drag of slender wood splinters. The air classifier performance is particularly sensitive to the size, shape, and surface area of material fragments and to the proportion of heavies to lights. Most air classifiers are large, expensive, and require extensive duct work. They also consume large amounts of power and operate at a high noise level. Results of the source segregation project (to be discussed later) have proven that comparable separation of combustibles from noncombustibles can be realized by segregating the waste at the point of generation (27).

Pyrolysis. This process consists of the decomposition of organic refuse into liquid or gaseous fuel by high temperature in an oxygen-deficient environment. For the process to work, the refuse must be separated (organic from nonorganic) and thoroughly shredded (28). Grinders have been used in small-scale laboratory systems to grind the paper and wood (organics) products into 1/8-in. particles. Obviously, just the front end processing is more expensive than the mechanical refuse separation system described earlier. The advantage of pyrolysis is that it converts the solid waste into gas or liquid fuel that can be utilized in more conventional machines such as automotive vehicles. The type of fuel formed from solid waste is more dependent on the method of pyrolysis than on refuse composition (29).

Many methods are being experimented with; but, for clarity, one simplified example will be given for extracting methanol from refuse (29). The shredded organics are first dried and then transferred to an atmospherically controlled heating chamber for pyrolysis. In this chamber, the material is heated to a high temperature (about 1600F) for decomposition. The products are then fed into an air classifier which separates the tar solids from the gaseous materials. The resulting gases are then processed to form methanol. The gas processing includes pressurization to approximately 750 psig. Major losses in the process are: (1) the heat required for pyrolysis and (2) the energy required for gas compression. Approximately 50% of the fuel energy derived from the solid waste is used internally for these two major energy-consuming processes. Additionally, the fuel energy extracted from the solid waste is, at best, 50% of what is available after losses for pyrolysis and gas compression. For 1 Btu of solid waste energy, only about 1/4 Btu equivalent of refuse-derived fuel is produced. When the fuel is extracted and is eventually used, another loss is incurred; i.e., that of the engine or heater burning the fuel (29).

Processing system alternatives to raw refuse incineration (including pyrolysis) have been shown to be generally less efficient (30).

The inefficiency of pyrolysis fuel processing is not the only problem. Plant capital costs are high, and the equipment very sophisticated (31). As a result, Systech Corp. was not requested to research a pyrolysis fuel processing system as part of their contract with CEL.

Densified Refuse-Derived Fuel (d-RDF). Shredded, or simply chopped, combustible refuse (fluff) requires large storage volume due to its low density, is expensive to transport, and presents a fire hazard (22). For economic heat recovery from fluff, the incinerator/boiler must be located adjacent to the refuse processing plant and have minimum 24-hr storage. However, if the fluff is densified into pellets, it might be capable of being mixed with coal in many coal-burning furnaces. The problems encountered with d-RDF have been primarily with storage and handling in conventional coal-processing equipment (32). For example, because the d-RDF has a higher surface coefficient of friction than coal, it often clogs in the storage silos (32). Also, d-RDF compresses more readily than coal when stored for long periods of time and is more adversely affected by moisture (32). However, the processing equipment required to produce d-RDF is the primary unknown (22). Textiles and hard metals even in small particle form might damage the dies. Also, the process consumes considerable energy, and the waste must be finely shredded prior to densification (32).

Systech Corp. Study Results and Conclusions (21). The approach taken in this study for selecting a resource recovery system suitable for design is believed to be unique because Systech Corp. was specifically directed by CEL to leave the evaluation open and not exclude processing alternatives until the parametric analysis was complete. The modules employed were frequently innovative, and the impact of rearranging them was studied. As a result, the source-segregated waste processing line is original and believed by Systech Corp. to be economical.

The Systech Corp. report on this study contends that implementation of an economical, reliable, small-scale (25 TPD_5*) resource recovery system at Navy installations is feasible. The development of a processing line costing around $900,000 for capital equipment and installation and having net operating cost of $16.00/ton (competitive with alternative disposal methods in populated sections of our country) is indicated. However, it is noted that no allowance was provided for waste-heat recovery equipment or for source separation costs. These cost items are addressed in the discussion of the solid waste flow model.

The Systech Corp. report (21) has implications ranging far beyond the military. The results of their study can have significant impact on the nation's entire approach to solid waste management.

The availability of such a system would benefit the Navy, Department of Defense, and the small communities and towns of the nation. Its further development is clearly indicated.

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*Tons per day for 5-day week.

NCBC, Port Hueneme waste stream characteristics are discussed in the Systech Corp. report. Development of the modular approach to resource recovery plant design is described, and the alternatives are analyzed. The preferred alternative was found to be a plant which processes source-segregated waste, where the categories are (1) metals and glass and (2) all other waste. Included is a process description of the plant, including component descriptions and a construction-cost estimate. Reduced blueprints of the preliminary design concept are also provided. The report also presents the performance and cost summaries for the modules and life cycle costs.

Experiment on Source Segregation

The objective of the experiment was to quantify the effectiveness and cost factors associated with source segregation of refuse into combustible and noncombustible fractions at Navy shore activities. For this experiment, the combustible fraction is defined as paper, plastic, and cardboard; all other materials comprise the noncombustible fraction. Wood was not included in the combustible fraction because compactor trucks are used to collect the combustibles.* The experiment concentrated on source segregation which can be implemented with minimum capital investment. Emphasis was placed on quantification of (1) segregation effectiveness (i.e., percent of segregation at each source type) (2) estimated percentage increase in operating costs attributable to source segregation for each source type, and (3) estimated additional equipment requirements and investment, on a unit basis, at each source type.

The effort was conducted in two phases: Phase I - Planning the Experiment, and Phase II - Execution and Analysis of the Experiment.

Planning the Experiment (33). The source segregation experiment was conducted on a scale large enough to resolve questions of workability and provide a quantitative basis for evaluation of the merit of source segregation in the Navy shore establishment. The approach taken was to conduct a base-wide experiment on source segregation of solid waste into combustibles and noncombustibles at NCBC, Port Hueneme. This Navy base encompasses a variety of activities and work areas, including offices, warehouses, receiving and shipping areas, construction training areas, shops, and deep-water ship docks. In addition, there are mess halls, cafeterias, automobile service stations, commissary, Navy Exchange stores, barracks, and residences serving the 10,000 people working or living on the base – civilian employees in addition to military personnel and their dependents – all of whom discard refuse daily.

Following the initial development of the concept, the objectives, and the scope of the experiment, several steps were necessary in the advance planning and preparations. These have been accomplished, as follows:

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*NCBC, Port Hueneme requested that wood not be collected with compactor trucks because it wedges into the compactor mechanism.

1. The approval and support of the administration at NCBC, Port Hueneme for the experiment and the cooperation of Public Works/Transportation personnel at that activity were obtained.

2. A survey of the entire base was conducted to determine the characteristics of each refuse source and the composition and quantities of refuse produced. Procedures and equipment requirements for segregation at each source were developed; as a result, a relocation/placement list was prepared and used as a guide in deploying additional containers as required (33).

3. A telephone survey of six representative Navy shore facilities was conducted to determine: (a) what procedures and communications media are typically used at such facilities to convey information to personnel on base, including military personnel, their dependents if living on base, and civilian employees; (b) who or what office takes action to direct a new program such as source segregation, and what action is taken for implementation; and (c) what follow-up monitoring is done to reinforce the initial implementation and to assure compliance.

4. Human factors consultants were employed to interview key people in base housing, public works, and public information on base drives, energy conservation, and community structures (34). Subsequently, they personally interviewed a selected sample of the resident population of NCBC housing and evaluated the program to examine the human factors involved in the design and implementation of the experiment.

5. Results of the phone survey of six Navy bases and of the human factors survey were analyzed and a plan developed for public relations phase of announcing, initiating, promoting, and supporting the 4-mo-long experiment at NCBC.

6. A contract was awarded for the measurement of the degree of segregation (effectiveness) achieved and for the determination of additional costs incurred in gathering and collecting the segregated refuse over the 4-mo period of the experiment (35).

Execution and Analysis of the Experiment. The following steps constituted execution and analysis of the experiment:

1. Preparation of containers for segregation. This included the minimum necessary repair, painting, and labeling to identify contents (paper, plastic, and cardboard versus other materials) and the placement of containers in accordance with the relocation/placement list.

2. Public relations with participants. This included publication and distribution of announcements, posters, and instructions, as well as monitoring or followup coordination.

3. Survey and evaluation of solid waste segregation. This included two major tasks, both of which were contracted to SCS Engineers, Long Beach, Calif (35). These are summarized briefly as follows.

(a) Survey and evaluation of source segregation effectiveness. The purity of container refuse was surveyed and recorded biweekly over a period of 4 consecutive months (1 month before and 3 months during source segregation). The degree to which the solid waste was separated at the source into the combustible fraction and the noncombustible fraction was determined.

(b) Assessment of source segregation impact on cost of collection operations. Increases in operating costs attributable to source segregation were determined by means of manpower and equipment utilization surveys. These were conducted once for a 2-wk period immediately prior to the start of source segregation, and a second time, at the exact same facilities, for a 2-wk period during the third or fourth month of source segregation.

4. Data analysis and reporting. In addition to the contractor's supplying daily reports, monthly progress reports, and final contract report, CEL prepared monthly progress summaries and a Technical Note covering the overall source-segregation experiment (27).

Conjecture has been made regarding the workability and costs of source segregation in the environment of the Navy shore establishment. However, many municipalities formerly required (prior to more stringent air-quality regulations) that residents separate their refuse and burn all paper and cardboard, and it appears that little or no enforcement was necessary. This question has been clearly resolved as a result of the source-segregation experiment. Purity of the combustible fraction proved to be better than 90%, and it continued to improve with time (27). Air classifiers tested under ideal conditions have produced a comparable combustible fraction purity (26). Purity of the noncombustible fraction was better than 70% toward the end of the experiment. While active participation was theoretically better than 50%, it is estimated that in actuality 60% to 70% of the community participated to some degree (27). The success of the NCBC experiment can be attributed to the use of only two categories for the separation. Most other source segregation experiments (36,37,38) included three or more categories (e.g., high quality paper, cardboard, ferrous metal, aluminum, glass, garbage, brass, copper, or other material). Just the material handling logistics alone proved to be a problem in multiple category segregation, and it was all but hopeless for a person trying to properly dispose of an item. Also, once the system breaks down, it is very difficult to reinstate (34).

The cost of the two-category source segregation proved to be surprisingly low. Because no change in volume or in material-handling equipment and practices was made, no large capital costs were added. Only the outdoor containers needed to be augmented. Table 2 gives the overall cost breakdown.

In addition to the questions of workability and cost impact of source segregation, the potential reduction in energy available from the wastes generated at those facilities having a high quality paper recycling program has been conjectured. Concern has been expressed that, after a waste-to-heat system is installed, it might be followed by mandated recycling programs (39,40) which could significantly reduce the waste energy available. The available total energy, if paper were removed for recycling programs, would be reduced less than 10% (38).

Results of the source-segregation experiment proved that a comparable quality fuel product can be produced with less initial and maintenance cost than with mechanized separation. Source segregation has proven workable and does not require sizing for a given generation rate, unlike stationary separation equipment. The system also utilizes proven technology and consumes considerably less energy for its operation than the large mechanized separation systems.

Table 2. Summary of Separate Collection Cost Impact at NCBC, Port Hueneme

Operation	Projected (%) Increase	Projected Cost Increase ($/mo)
Custodial services	5	645
Residential Collection	6	75
Additional Outdoor Containers		433
Additional Indoor Containers		50
Program Administration, Public Relations, Labels		100
Total		$1,303
Total per ton		$2.95[a]

[a] $\frac{\$1,303}{21 \text{ tons/day} \times 21 \text{ days/mo}}$

Solid Waste Flow Model

During the planning of the CEL Solid Waste Program, it became apparent that capability of answering questions such as the following would be very desirable:

1. How would a proposed solid waste management system respond to changes in variables such as the effectiveness of source separation, or the cost of fuel, or the closure of a nearby landfill?

2. How would the random variation in parameters such as the quantity and composition of refuse, equipment reliability, and the value of recovered resources affect performance of the system?

3. To what changes would the performance of a new system be sensitive? What data need to be known with precision, and what data are relatively unimportant? What areas of solid waste technology hold the promise of a high return for an investment in R&D?

The answers to such questions can be obtained only by repetitive analyses of solid waste management system performance. The solid waste flow model was developed to reduce time and cost required to perform these analyses.

Approach. Because of the random nature of refuse quantity and composition, market demands, and equipment performance, a probabilistic approach was employed in developing the model. The solid waste flow model development was based on the following items:

1. Survey of past and present work in solid waste management system modeling and selection of those model elements and data which are applicable to the present problem.

2. Development of a system of equations which describe the costs associated with each unit operation of a solid waste management system (such as collection or processing for fuel recovery) and the interrelationships between the various unit processes.

3. Coding the system of equations into a computer program.

4. Use of the program to help assess the economic feasibility of different solid waste management alternatives.

A consulting engineer was hired to determine the extent of current and previous efforts in solid waste flow modeling, to define the modeling problem as it relates to the CEL Solid Waste Program, and to identify those existing models or model elements which could be used by the Navy (41). He was unable to identify any solid waste models which would be applicable to the Navy problem.

Following the report of the consulting engineer, work was initiated at CEL to develop a system of equations describing the economic and technological performance of the various operations of a solid waste management system; e.g., collection, processing, and disposal, in terms of variables such as refuse generation rate, effectiveness of source separation efforts, labor requirements, and process efficiencies. These equations, together with the necessary control logic, were coded into SWEEP (Solid Waste Economic Evaluation Program) which was exercised and proven with a series of complex test cases.

Since the accuracy of a computer program such as SWEEP is no better than that of the data which are entered into it, reasonably accurate data on current solid waste management practices and costs at Naval shore activities, equipment costs, fuel costs, labor rates, and other pertinent parameters are required.

SWEEP Code. The Solid Waste Economic Evaluation Program (SWEEP) is composed of approximately 1600 FORTRAN instructions organized into 11 subroutines and a master control program. Although the SWEEP code is quite large, it is not especially sophisticated. The majority of the computations performed by SWEEP are straightforward engineering economic calculations. However, many such calculations must be performed in estimating the economic performance of even a simple system; of course, implementation of Monte Carlo analyses requires that hundreds of separate and complete analyses be conducted.

The number of data items, empirical relationships, and assumptions built into SWEEP is very small. Because of this, the program user is required to input a number of routine data items (such as labor rates and fuel costs) and to conduct additional analyses to estimate other required inputs (such as labor requirements). Although this approach to program design results in a substantial amount of preparatory work before the program can be run, it also results in maximum program accuracy and flexibility.

SWEEP cannot at present be used to estimate first costs for equipment or facilities or to estimate system labor requirements. These data must be determined by separate analyses. Also, SWEEP cannot automatically find the optimum system design. The best system must be determined from interpretation of technological performance output. Typical measures of technological performance are the amount of steam generated annually, the volume of process residues, and the daily average number of trips made to the disposal site. Measures of economic performance include unit disposal costs, annual system operating costs, and savings-investment ratios.

SWEEP was designed primarily as a tool for evaluating candidate designs of the Experimental System for Solid Waste Management (ESSWAM) being considered for implementation at NCBC Port Hueneme; to date, the program has been used only for studies relating to that project.

Example of SWEEP Application. As an example of the capabilities and possible uses of the SWEEP code, a proposed new solid waste management system for NCBC is compared to current operations at that activity. The proposed new solid waste management system has the following characteristics:

1. Refuse from most activities on the base will be segregated at the point of generation into two categories: (a) paper products, plastics, and other combustible materials and (b) metals, glass, stone, dirt, and other noncombustible materials. Separate containers will be provided for each type of material and the contract for janitorial services will be modified to insure that the waste streams are kept separated.

2. Refuse will be collected with the present crew and equipment, although some routing and procedural changes will be required. The contract for collection of family housing refuse will be modified to insure that the refuse is kept separated and is delivered to the desired location.

3. Collected refuse will be dumped at a resource recovery facility located close to the base boiler plant. The combustible materials will be processed into a coarsely shredded fuel product and burned in a packaged incinerator unit. The incinerator will be equipped with a waste heat boiler so that heat will be recovered in the form of low pressure steam fed directly into the base steam supply lines.

4. Process wastes, nonprocessible refuse, and refuse in excess of plant capacity will be deposited in a large truck trailer to be hauled to a landfill.

The program input data for the new system are summarized in Table 3, and a plan view of the proposed facility is presented in Figure 2. The current system at NCBC is summarized in Table 4. The program output data for the new system are given in Table 5.

Table 3. SWEEP Input Data for Proposed Solid Waste Management System for NCBC, Port Hueneme

Items	Input Data	
	Original[a]	Updated[b]
Cost of Implementing Source Segregation, k$		
First Costs (engineering, containers, publicity)	19.5	19.5
Annual Costs (increased janitorial services, containers, contracted collection, and program administration)	25	8.7
Cost of Collection, k$/yr		
Janitorial Costs	122.0	122.0
Collection Labor	108.6	108.6
Fuel	3.7	3.7
Vehicle Maintenance	3.8	3.8
Containers	6.9	6.9
Contracted Collection	16.5	16.5

continued

Table 3. continued

Resource Recovery Facility		
First Costs, k$		
1. Engineering	40.0	40.0
2. Fuel Processing Equipment	150.5	150.5
3. Metal Recovery Equipment	82.3	0.0
4. Incinerator-Boiler	240.0	240.0
5. Off-line Transfer Equipment	35.1	35.1
6. Dust Control	25.0	25.0
7. Building	310.0	220.0
8. Contingency	140.0	140.0
9. Startup	100.0	80.0
Annual Cost, k$		
1. Labor	41.8	31.0
2. Energy	16.7	16.0
3. Maintenance	7.5	7.0
Values of Recovered Resources		
1. Steam (based on current NCBC boiler plant and No. 6 oil), $/klb	2.92	2.92
2. Light Ferrous Scrap, $/ton	35	0
Process Performance, %		
1. Source Separation Volumetric Purity	80	90
2. Steam Generation Efficiency	55	55
3. Ferrous Recovery Efficiency	90	--
Operating Characteristics, hr/day, days/wk		
1. Fuel and Ferrous Processing	5,5	5,5
2. Steam Generation	24,5	24,5
Operating Life, yr		
1. Operating Equipment	10	10
2. Structure	20	20
3. Economic Life	20	20
Disposal System (Commercial Landfill)		
One-way Distance From Base, mi	6	6
Disposal Fee, $/ton	2	2

[a]Assumed at the beginning of the Project TRASH program.

[b]Derived from the source-segregation experiment and no metals recovery.

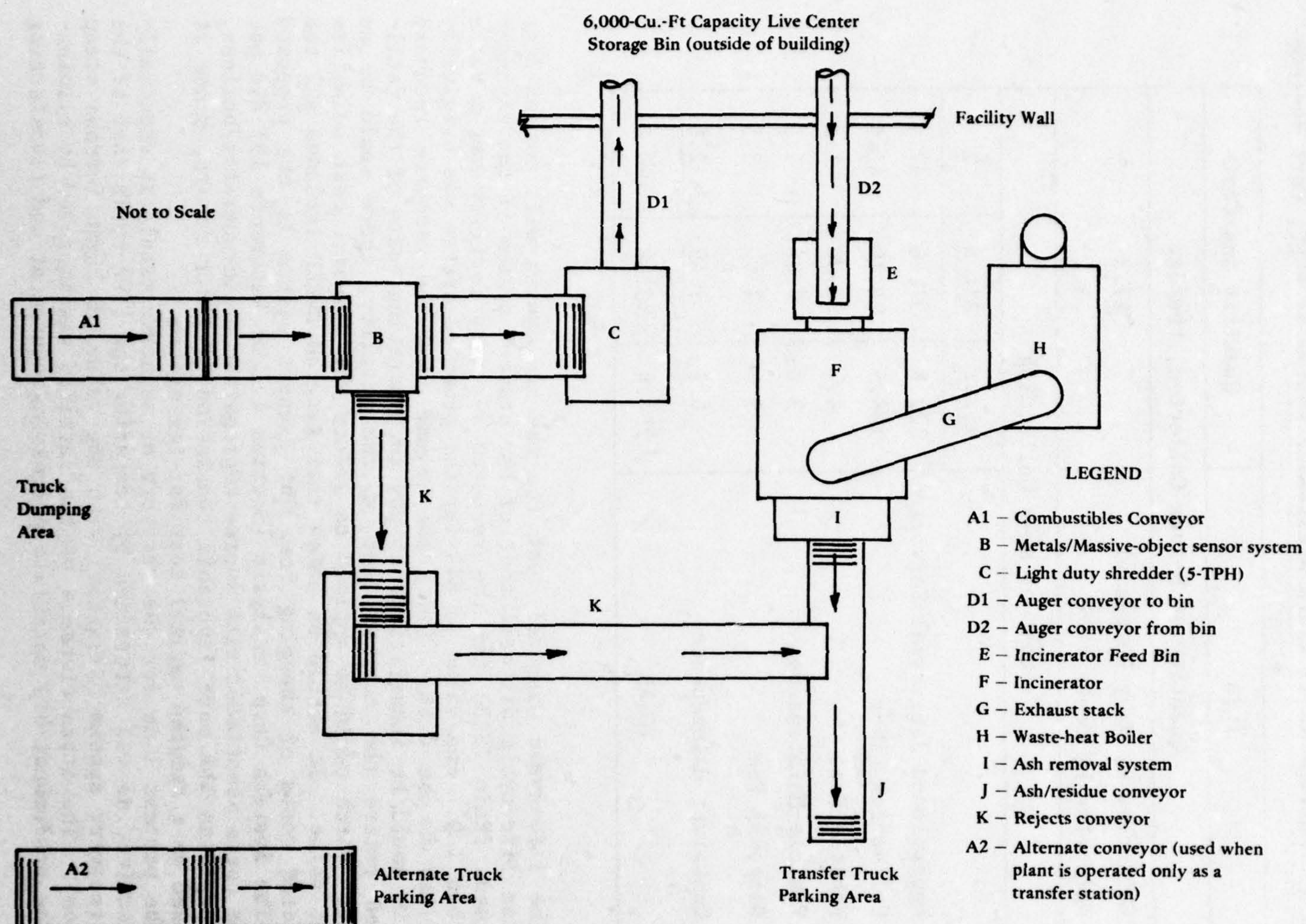

Figure 2. Plan of Resource Recovery Facility.

Table 4. Current Solid Waste Management System at NCBC, Port Hueneme

Item	Quantity and Cost		
Quantity of Refuse Collected, ton/day			
Collected by Navy Personnel	17.3		
Collected by Contractor	3.5		
Cost of Navy Collection			
	k$/yr	$/ton	%
Apportioned Janitorial Services	122.0	27.40	47.9
Collection Labor	108.6	24.10	42.7
Vehicle Fuel	4.5	1.00	1.8
Vehicle Maintenance	3.8	0.85	1.5
Disposal Fee	9.0	2.00	3.5
Container Maintenance	6.7	1.49	2.6
TOTAL	254.6	56.58	100.0

The life-cycle disposal cost for the new system will not be less than the life-cycle disposal cost of the present system if the savings-investment ratio (SIR) for the resource recovery facility has a value less than 1.0. The value of SIR for the proposed system was originally calculated to be 0.68. Thus, the income from the resource recovery facility would be insufficient to pay the operating costs of the facility and retire the capital debt of the facility; there would be no "profits" which could be applied to reduce the disposal cost below its present value. It should be noted that program SWEEP included all the associated costs of changing from the present system to the proposed one. The Systech Corp. analysis (Section 1.1 of Reference 19) did not include costs associated with source segregation or incinerator/boilers, which explains the more favorable conclusion of their report, since it was based on a reduced capital cost for the system.

The process line for the recovery of magnetic metals is especially unattractive, as was determined by comparing the life-cycle cost of the metal recovery system ($135/ton) with the value of light ferrous scrap ($35/ton). The attractiveness of the facility was improved by eliminating the noncombustible materials processing equipment and transferring

Table 5. SWEEP Output Data for Proposed Solid Waste Management System for NCBC, Port Hueneme

Item	Output Data	
	Original[a]	Updated[b]
Resource Recovery Facility		
First Cost, k$	$1,143	$951
Annual O & M Cost, k$	66	54
Annual Income/Savings From Resource Recovery Facility		
Sale of Steam, k$	92	92
Sale of Magnetic Metals, k$	4.9	0
Reduced Disposal Fee and Vehicle Fuel Costs, k$	7.4	8.4
Economic Performance Indicators		
Savings-Investment Ratio	0.68	0.82
Disposal Cost, Including Capital Cost Amortization, $/ton	76.11	63.61
Life-Cycle Cost of Fuel Processing System, $/MBtu	0.58	0.58
Life-Cycle Cost of Metals Recovery System, $/ton	134.47	0
Life-Cycle Cost of Heat Recovery System, $/MBtu	1.74	1.74

[a]Assumed at the beginning of the Project TRASH program.
[b]Derived from the source-segregation experiment and no metal recovery.

the noncombustible source-segregated materials directly to the transfer trailer. In the original SIR calculation, the janitorial cost input data for SWEEP came from the NCBC janitorial contractor. Results of the experiment's time study showed these costs to be lower than those provided by the contractor. As a result, the original SIR was modified to include the updated characteristics shown in Table 3. Corresponding SIR for the proposed system is 0.82, with an excess cost, over present system cost, of $11.50/ton.

Upon first examination, the proposed system still appears unattractive. However, only $2/ton was assumed for landfill disposal cost. The Florida Resource Recovery Council, a government organization created by the Florida legislature, says it currently costs $3 to $5 a ton to landfill waste in North Florida and up to $14/ton in South Florida (42).

In Los Angeles County, 50 miles from NCBC, 7 million inhabitants yearly generate 11.5 million tons of garbage, garden clippings, and building rubble. The county buries this trash in a network of strategically located and economically run canyon landfills. But, the landfills are filling fast, posing a serious disposal problem for the county. The problem came to a head in March 1976 when homeowners in the Santa Monica Mountains pressured the Los Angeles City Council into refusing to let Mission Canyon reopen as a canyon landfill - despite the promise that in 20 years a park would "blossom" near their expensive homes (43). Similar problems are anticipated for Ventura County, which surrounds NCBC.

In addition to the rising cost of landfilling, energy costs are escalating. The proposed resource recovery plant can be profitable (i.e., SIR greater than 1.0) if the cost of energy increases 75%, everything else being constant. A doubling of energy costs within the next 5 to 10 yr is not a remote possibility. Also, the example problem computed was for Southern California, a temperate climate zone. Other parts of the country for similar Navy shore facilities could prove to be more economically attractive. SWEEP has been developed to assist in this type of evaluation, and projected energy costs can easily be included in the model.

SWEEP Study Conclusions. SWEEP has been developed to assist in the evaluation of alternative solid waste management systems. The program computes many indicators of the technological and economic performance of solid waste management systems. Among the parameters computed are the amounts and values of recovered resources, energy consumption, disposal costs, savings-investment ratios, and unit process costs. The SWEEP code can also be used to perform probabilistic analyses of the effects of random variations in parameters such as the amount and composition of solid waste.

CONCLUSIONS

1. Solid waste processing concepts developed during the alternative design concept study showed that implementation of an economical, reliable, small-scale, modular resource recovery system, suitable for scaling up via multiple lines, at Navy installations is practical and desirable. Waste-heat recovery appears to be the only profitable function. Material recovery for resale such as metals and glass did not prove to be economical in that it costs more to separate these materials than can be recovered from local markets.

2. Two-component, voluntary, source segregation for waste-heat recovery is workable in the Navy shore establishment.* Source segregation can produce a comparable quality fuel product with less initial cost and less maintenance cost than mechanical separation equipment.

3. A computer program, developed by CEL, is available for computing various indicators of technological and economic performance of solid waste systems. This capability constitutes the most rational and significant basis known to exist, from which to design new solid waste management systems or implement changes of any kind in existing systems.

RECOMMENDATIONS

1. A solid waste RDT&E facility capable of handling a nominal throughput of 25 TPD should be constructed and operated at a suitable Naval base in conjunction with a source-separation program similar to the test program tried at NCBC, Port Hueneme. Emphasis should be on waste-heat recovery.

2. The solid waste processing equipment tried first should include a minimum number of modules. Other labor-saving equipment should be added later, only where warranted by evaluation of cost effectiveness and reliability. Fuel size reduction equipment should be selected according to fuel size specifications of the packaged incinerator/boiler.

3. Equipment selection should be based on examination of all commercially available machinery and known processes and not be limited to only those previously used in other solid waste processing plants. More specifically, it is felt that a small flail mill should prove to be sufficient for size reduction. One small front-end loader should prove adequate for all waste material handling, and a simple stacking wall should be cost effective for storing the refuse-derived fuel.

4. In support of the RDT&E facility, it is also recommended that the computer program SWEEP be exercised to determine the facility's cost effectiveness.

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*Of importance is that the NCBC experiment was conceived, planned, and implemented before issuance of the EPA guidelines on source separation. Thus, the experiment does not reflect or relate to those guidelines which prescribe the recovery of high grade paper from offices and newspaper, aluminum cans and mixed glass from residences. However, it should be noted that paper removal in a recycling program would not reduce the available total energy by more than 10%.

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