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Systems Analysis for the Development of Small Resource Recovery Systems

Research and Development Needs

Final Report
October 1980

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Prepared for:

U.S. Department of Energy

Assistant Secretary for Conservation and Solar Energy

Office of Buildings and Community Systems

Under Contract No. AC01-77CS 20026

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October 1980

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ABSTRACT

In response to the increasing need for small-scale solid waste processing facilities, the U.S. Department of Energy (DOE) contracted with Systems Technology Corporation (SYSTECH) to identify the technologies that should be developed to make such facilities attractive to and viable for small municipalities with solid waste between 50 and 250 tons per day (TPD). In addition to identifying candidate technologies, SYSTECH applied a set of criteria to them to determine those that could best satisfy the existing market conditions. The criteria included costs of the alternative landfill disposal, material and energy prices, developmental status of the technology, and environmental impact of the systems. The system types studied included those with mechanical separation, thermal and thermochemical energy recovery, and bioconversion processes. For these studies, the performance of each system was simulated by a mathematical model. After the systems were evaluated, the most promising were analyzed to determine which components and operating parameters had the greatest impact on system viability. Accordingly, the research and development (R&D) needs to advance the state-of-the-art for small-scale solid waste processing facilities were identified.

The study results are documented in four volumes: (1) Executive Summary, (2) Description of Solid Waste Modular Simulator, (3) Research and Development Needs, and (4) System Performance Data.

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SECTION 1

INTRODUCTION

The primary objective of the small-scale systems analysis was to identify the research and development needed to advance small-scale resource recovery. The method for determining these needs utilized a quantitative sensitivity analysis to determine which systems warrant the investment of R&D funds and to identify which system components and operating components could be modified to substantially improve overall system performance. The limited availability of data on the performance of systems and equipment components combined with inconsistencies in the existing data precluded utilization of a totally quantitative approach to identifying and prioritizing R&D needs. As the data acquisition and analysis was performed, a number of R&D needs have become apparent, and a presentation of these needs is made in this report. Those R&D needs having the greatest potential for positively impacting the viability of small-scale resource recovery systems have been discussed in detail with recommended projects outlined. *The criterion used to select high priority needs was the potential for the greatest near-term impact.* This led to selection of R&D needs in the following areas: (1) those involving systems which have been demonstrated in commercial applications, (2) systems or equipment items having the potential to substantially reduce the cost of resource recovery, (3) systems where testing has been performed indicating potentially attractive performance characteristics, and (4) systems where there is insufficient information available to determine their attractiveness at this time.

The general lack of information and of standard methods for characterizing system performance has inhibited the commercialization of resource recovery technologies. Many of the specific needs discussed in this document include tasks aimed at developing standardized methods for characterizing equipment.

The R&D needs presented have been classified according to process type. Major process classifications are refuse derived fuel systems or mechanical processing systems, thermal processing systems, and bioconversion systems. Mechanical processing subsystems or modules have been categorized according to function as follows: receiving, size reduction, fuel separation, fuel preparation, storage, materials handling, aluminum recovery, glass recovery, and ferrous metals recovery. Functional areas that provide the greatest opportunity to reduce processing costs (because of the substantial processing costs associated with them) include size reduction, fuel separation, specialized fuel preparation, and storage. Aluminum recovery and glass recovery on a small scale will require technical breakthroughs or major improvements in the market for the low-quality recovered products before

these processes become viable for small-scale operations. Thermal processing systems have been evaluated according to the type of combustion process employed--excess-air combustion, starved-air combustion, or pyrolysis. However, the research needs that apply to all three process types have been presented according to that specific need rather than process type.

Research and development efforts pertaining to excess-air incineration should concentrate on physical (equipment) configurations and process controls that can be effective at reducing particulate emissions. Starved-air incineration offers the most attractive near-term method for thermal processing because the process control results in fairly low emission levels and improved operation. Research and development needs pertaining to starved-air incineration include improved characterization of system performance and cost, optimization of system control equipment, physical configuration to minimize emissions and processing costs, and standardization of formats used to present performance characteristics.

Pyrolysis systems have not performed up to expectations in commercial applications because of the high temperatures and corrosive nature of the process off-gases and difficulty in controlling the process, both of which contribute to the high cost of pyrolysis systems. A technological breakthrough (e.g., use of catalysts) is required to modify the system operating parameters or improve fuel product yields for pyrolysis to become attractive on a small scale.

Biological processes are not widely attractive on a small scale because of the spotty market for the process products (soil conditioners and low-grade fuel gas) and the need for substantial materials separation either before or after processing. Research in the area of biological processing should center on basic research aimed at technological breakthrough.

A list of specific R&D needs is presented in the following section with asterisks placed next to those that have been discussed in detail. The detailed discussion of the research and development needs follow the listing and are presented in descending order of relative importance.

SECTION 2

RESEARCH AND DEVELOPMENT NEEDS LISTING

- I. REFUSE DERIVED FUEL SYSTEMS (The complexity of RDF systems causes high costs to separate materials. The delineated R&D needs are aimed at simplifying the overall separation process and eliminating elements that are not cost effective. There is a general lack of data on performance, costs, and manpower requirements.)
- A. Receiving
 - 1. Traveling auger pit
 - B. Size Reduction - Methods to Improve Costs and Reliability
 - *1. Develop data bank for low-cost, low-energy shredder options; flail mill, shear shredder.
 - *2. Develop performance data for shredders applied after separation; i.e., trommel, air scalping
 - 3. Cost versus particle size and impact on performance on downstream processing equipment
 - 4. Investigation of alternate alloys for hammermills
 - 5. Shot from guns, garbage
 - C. Fuel Separation
 - *1. Develop data bank for trommel performance
 - *2. Identification and evaluation of low-cost materials separation equipment, disc screen, ballistic separator, etc.
 - 3. Air classifier test facilities
 - D. RDF Preparation
 - 1. Investigation of market for densified RDF versus cost of production
 - 2. Data acquisition program for pelletizers versus cubetters versus briquetters
 - 3. Study of cost versus yield; economics of low-yield separation systems; i.e., course air knife separation or trommel (same as Item C-2)

* Discussed in detail in Section 3.

E. Storage

1. Data acquisition program for alternate storage systems
2. Feasibility study of methods to eliminate storage requirements
3. Study baling of RDF for a storage/transport system
4. Develop data on use of trailers for transport and storage of RDF

F. Materials Handling

1. Investigate applicability and effectiveness of alternate types of conveying systems to various material types
2. Development of design parameters for materials handling--densities, angles of inclination, loads, etc.

G. Aluminum Recovery

1. Investigate new reprocessing methods for aluminum to allow for lower product quality
2. Develop strategies for attaining a definite quality/revenue relationship for recovered aluminum
3. Identify new, more cost effective techniques for aluminum separation

H. Glass Recovery

1. Determine whether a definite market exists for recovered glass that can result in net revenues
2. Develop new markets for glass-based product

I. Ferrous Metals Recovery

1. Consolidation of existing data on performance
2. Field tests to determine performance of alternate systems

II. THERMAL SYSTEMS

A. General Needs--Required for each of the generic types of thermal processing systems (excess air, starved air/gasification, and pyrolysis).

1. Standardization of reporting methods
- *2. Emission levels from solid-waste-to-energy systems
- *3. Determination of theoretical efficiencies for thermal processing systems
4. Thermal system versus performance feedstock composition--separated, dried, with other fuels, etc.
- *5. Boiler erosion/corrosion evaluation for systems firing RDF

* Discussed in detail in Section 3.

- *6. Optimization of feed and ash handling systems
- 7. Performance characteristics of grates and other waste handling systems in incinerators--augers, rams, pan conveyors
- *8. Refractory life and maintenance requirements--investigate current experience and determine ways to extend life and reduce cost
- *9. Development of 5- to 20-TPD systems
- 10. Investigate energy use versus cost, i.e., viability of gas turbines and electric generation for small systems
- *11. Optimization studies of control systems for small modular incinerators
- 12. Fluidized bed systems
 - a. media/residue separation and recycle, bed loss rate, bed separation techniques
 - b. wear/corrosion characteristics
 - c. bed plugging
- B. Excess-Air Incineration--Methods to reduce particulate generation
- C. Pyrolysis Systems
 - 1. Effect of "best" catalysts and catalyst poisoning
 - 2. Recovery of energy from carbon in residue (char)
 - 3. Production rates versus temperature, time, air composition, and mixing
 - 4. Separation and treatment methods of gas/oils/particles in the off-gas stream
 - 5. Treatment and disposal of process by-products
 - 6. Basic research on reaction kinetics

III. BIOLOGICAL PROCESSES

- A. Enzyme Hydrolysis--Optimize process operating conditions, develop recovery system for enzyme, and determine costs
- B. Acid Hydrolysis--research previous efforts, determine applicability to solid waste, and determine costs and operating characteristics
- C. Landfill Gas Recovery
 - 1. State-of-the-art survey
 - *2. Optimum design and operation to maximize gas recovery rates
 - 3. Gas cleaning and recovery
- *D. Investigate process configuration alternatives for anaerobic digesters

IV. INFORMATION STANDARDIZATION

Series of programs to format performance data to allow comparison of systems and determine strategy to attain compliance.

* Discussed in detail in Section 3.

SECTION 3

DETAILED DISCUSSION OF SELECTED RESEARCH AND DEVELOPMENT NEEDS

I. MECHANICAL PROCESSING SYSTEMS

I. B.1 Develop Data Bank for Low-Cost, Low-Energy Shredder Options

Background--

Refuse derived fuel preparation systems presently being applied to large-scale applications have high capital, operating, and maintenance costs that discourage the application of these systems to small-scale installations. The small systems analysis performed by SYSTECH has indicated that size reduction equipment currently applied in solid waste processing systems contributes substantially to overall system cost. In the 100- to 200-TPD size range, the capital cost for shredders range from \$250,000 to \$600,000; and operating and maintenance costs range from \$2 to \$3 per ton processed.

Several types of shredders were identified that have not been applied to solid waste processing but which appear to have the potential to substantially reduce the cost of shredding solid waste. These equipment items include (1) flail mills; (2) shear shredders; and (3) rotary, drum-type shredders. Shear shredders and flail mills are currently being offered in the United States by several vendors. Facilities that would be amenable to unit testing are currently in operation or are planned. No installations utilizing rotary drum shredders, either on a test basis or a demonstration basis, have been identified in the United States, although patents have been applied for and some marketing activity is occurring in this area. The limited applications of these shredders to resource recovery from solid waste have resulted in a lack of performance data on shredding solid waste with this type of equipment.

The proposed development effort would involve three major efforts--the identification of available equipment and performance data, the identification and securing of a facility that would be used for unit testing, and the execution of a performance test program. The level of effort for this program is estimated to be from 12 to 18 months. Therefore, the results of the project should be available for public use in 2 years.

Statement of Work--

This work will be aimed at determining the advantages that can be realized through the application of low-cost, low-energy shredders in place of the hammermill shredders currently being applied as the first processing item in refuse derived fuel systems. The ultimate goal of the project is to achieve

a substantial reduction in the cost of production of refuse derived fuel from mixed municipal waste. The project will require the acquisition of data on low-cost, low-energy shredder performance and the execution of a test program to evaluate the efficiency and cost of these alternate methods of shredding solid waste. Data that will be developed include the following: (1) installed cost of the unit, (2) required auxiliary equipment and its cost, (3) power requirements, (4) maintenance requirements, (5) throughput capacity, (6) particle size distribution of input and product streams, and (7) operational problems. Based upon the results of the test program, projections should be made of the cost of processing and the optimum location in a processing line for this type of shredder. Projections should also be made of any changes in performance required in upstream equipment or downstream equipment that will result from the use of alternate shredding methods applied in place of hammermills.

To accomplish the above objectives, the contractor shall perform the following tasks:

- Task 1 - Identify suppliers of low-cost, low-energy municipal solid waste (MSW) shredders and the existence of any facilities currently in operation or planned in this country.
- Task 2 - Obtain available performance and cost data on identified shredders, evaluate their potential application to resource recovery processing lines, and project the magnitude of benefits resulting from such utilization.
- Task 3 - Select actual facilities for testing, develop a test protocol, and present a test schedule.
- Task 4 - Install required equipment, effect facility modifications, and perform field tests to characterize system performance.
- Task 5 - Provide detailed analysis of the results of field tests including a summary of performance and the cost of operation.
- Task 6 - Describe those applications where the test system would be most effectively applied indicating how performance and costs compare with those for other available size reduction equipment items.
- Task 7 - Report the results of the tests in such a manner that process designers and engineers can apply them to the design of new systems.

I. B.2 Develop Performance Data for Shredders Applied After Separation

Background--

Refuse derived fuel production facilities have typically initiated waste processing by shredding the mixed waste stream prior to the subsequent separation of the combustible and noncombustible materials. Several test facilities have utilized various separation systems such as trommels and rotating drum air separators prior to shredding. Before these new processing systems can be termed successful in improving the economics of processing refuse derived fuel, it is necessary to determine the effects that these separation systems, and the resultant change in the characteristics of the waste material stream, will have on the performance of various downstream processing equipment.

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Experience gained at the Recovery I facility in New Orleans indicates that the cost of shredding the separated waste stream is far below that for shredding the unseparated waste stream due to reduced maintenance and operating costs. However, quantification of this experience is not yet adequate to project equipment performance for other installations. It would be the goal of this program to quantify the performance of shredders applied to a separated waste stream. This will enable systems performance projections for systems utilizing separation of the solid waste stream before primary shredding.

The effort would consist of a test program requiring identification of test sites or facilities, execution of performance tests, and an analysis of the test results. The level of required effort would involve approximately 2 to 3 man-years. This effort would be expended over a 12-month period. This study would analyze and quantify the performance of systems using first step separation versus those using first step shredding.

Statement of Work--

This work is directed at quantifying the effect of materials separation processes applied before primary shredding of mixed municipal solid waste streams. The ultimate goal of the project is to determine the cost reduction potential for refuse derived fuel production from mixed municipal waste achieved by the lower costs involved in shredding separated solid waste streams. The project should be coordinated with studies of the performance of primary "separation equipment applied ahead of shredders."

The primary activities of this study will be the acquisition of data on the performance of shredders processing separated solid waste material. Based upon the results of the test program, projections will be made of the cost of the separation and shredding process studied compared with the similar costs incurred for "typical" refuse derived fuel systems.

This effort will involve the following tasks:

- Task 1 - Develop test plan and schedule to characterize shredder performance. Parameters to be monitored shall include but not be limited to the following: (a) throughput capacity,

(b) power consumption, (c) composition of waste stream being processed, (d) particle size of incoming and product streams, (e) maintenance requirements, and (f) operational problems encountered.

Task 2 - Locate appropriate facility for performance of equipment testing (if necessary).

Task 3 - Install required monitoring equipment and perform field tests to characterize shredder performance. The number, type, and duration of the tests will be mutually agreed upon by the project officer and the contractor.

Task 4 - Perform a detailed analysis of the results of the field test. This will include a summary of shredder performance, cost of operation, description of applications where the separate/shred concept could most effectively be applied, and a projection of the cost of processing using this concept versus a standard shred/separate concept.

I. C.1 Develop Data Bank for Trommel Performance

Research and Development Needs--

This research and development need is aimed at determining the nature and efficiency of separation achievable with a fine trommel (small diameter openings). Determination should also be made of the locations in the processing stream where trommels could be most effectively applied. Trommels have been successfully used to separate glass particles, cans, and other items from both shredded and unshredded solid waste streams and have done so at low costs. However, performance tests and economic projections have thus far been limited, and a coordinated effort is necessary to completely characterize the cost and performance of these items in their several applications. The successful completion of this effort may permit the recovery of desirable components from the solid waste stream at a relatively low cost and an acceptable quality. This is particularly so for RDF fuel which can be vastly improved by removing additional undesired components.

Completion of this effort is expected to require multiple programs of approximately 3 man-years each. It is expected that this effort could have a significant impact on the field of resource recovery within 1 year, with a major impact within 3 years.

Statement of Work--

This work will be directed at identifying the optimal configuration and operating conditions as well as the optimum locations in process lines for fine trommels utilized for any of several acceptable purposes in separation, cleaning, or refining products recovered from municipal solid waste. Applications of fine trommels are not to be restricted in this procurement to any one specific product stream.

It is obvious that separation efficiency of a fine trommel for any specific application will depend upon the nature of the process stream fed to it. Thus the operation and effectiveness of a fine trommel will depend upon its location in the process stream, i.e., what levels of size reduction and precleaning have occurred and what the purposes of the separated streams emanating from fine trommels are. In addition, the efficiency of separation of the fine trommel for each specific purpose will be dependent upon its configuration and operating characteristics. That is, the separation efficiency will depend upon such factors as trommel length, inclination angle, rotation rate, hole size, size and configuration of any lifters, etc. It is the intent of this particular program to identify research and development efforts and to implement those efforts that will define, for at least one specific application, the optimum location, configuration, and operating conditions of fine trommels for that specific application. It is expected that much useful information about the theory of operation of trommels will be garnered that will serve as guidance for use of trommels in other related applications in solid waste processing. In order to accomplish the above objectives, contractors shall perform the following tasks:

- Task 1 - The contractor will identify the existing solid waste processing facilities that utilize fine trommels, evaluate their performance, and prepare a performance data base that can be used as initial guidance by solid waste facility designers.
- Task 2 - The contractor will determine if a suitable test site is available with a cooperative host or if a test facility should be designed for the performance tests.
- Task 3 - The contractor will prepare a test protocol that will include but not be limited to (1) source of waste, (2) test schedule, (3) sampling procedures and frequency, and (4) operating conditions and system configurations to be tested.
- Task 4 - The contractor will conduct a test program as outlined in the test protocol to collect the needed data. Requisite facility modifications shall be made with the sponsor's approval and the site owner/operator's concurrence.
- Task 5 - The contractor will conduct a detailed analysis and evaluation of the data. The data analysis shall fully and validly support all conclusions and recommendations.
- Task 6 - The contractor will prepare a written report detailing the test methodology, the test results, and the data analysis. The contractor will indicate suitable applications for trommels and will identify specific refuse processing systems (especially including active processing facilities) wherein such an application would be feasible. The report will address the probable impact of such application of trommels with respect to overall system performance and economics and will recommend performance criteria and specifications.

I. C.2 Identification and Evaluation of Low-Cost Materials Separation Equipment

Background--

Systems studied during the small systems analysis that are being applied to separate the various useful materials in mixed municipal waste streams (particularly the fuel fraction) have been observed to have high capital and operating costs and, consequently, have limited application to small systems. For example, air classifiers, which are currently used to achieve materials separation, have a cost ranging from \$2.50 to \$3 per ton processed in small-scale operations. Additional processing costs result from the operation of heavy shredders to prepare the waste for air classification. A reduction of the costs associated with this separation step would make materials separation systems far more attractive. This is particularly true for smaller systems where capital costs cannot be distributed over large throughput tonnages, and the resulting processing costs are, therefore, especially sensitive to this cost. The starting point for this study would be the data acquired during the small-scale system analysis.

The research and development effort outlined in this statement of work is aimed at developing a simple, low-cost piece of equipment to separate materials in a mixed municipal waste stream. The systems incorporating this item of equipment most likely would be those designed to produce a combustible fuel product from a mixed municipal waste stream.

A specific concept that appears to have a high probability of achieving this goal is one that accepts a reduced fuel product yield in order to reduce the processing cost for the system. Preliminary calculations performed in the small systems analysis indicate that this approach can reduce the net solid waste processing and disposal cost.

The development effort would consist of a study effort to review potential separation concepts and to select the most promising systems for demonstration. This would be followed by a demonstration phase to quantify performance in field applications. These two phases most likely would be pursued as completely independent studies rather than as one large effort. The concepts to be investigated should include but not be limited to the following: air knives, trommels, impact separators, ballistic separators, etc. This work should be coordinated with other efforts examining the performance of items of processing equipment both upstream and downstream of the separator to investigate the interaction in their performance. The level of effort for this project will be on the order of 5 or 6 man-years. The results of the study could be expected to impact the field of resource recovery in approximately 2 years. It may prove to be in the best interest of the DOE to contract for Phase I and Phase II separately.

Statement of Work--

This work will be directed at identifying and characterizing the performance of materials separation devices that are less costly than those items of equipment currently being employed for this function. The devices to be examined should be those that can be used to separate processed waste

(i.e., shredded or trommel) or as-received materials. The basic intent of the effort is to simplify the total processing system used to produce an acceptable fuel product.

The initial phase of the study will establish those concepts or mechanisms with the potential to reduce the cost of processing while maintaining the quality of separated fuel product. Subsequent project phases will determine the cost and efficiency of selected separation techniques through actual field testing. The ultimate goal of the project is to demonstrate improved separation techniques that will reduce the total cost of processing refuse derived fuel. The results of the study will present separation efficiency, reliability, cost of processing, and projections of these parameters for varying throughput rates. A location in the processing line for the application of the specific separation concept evaluated will be determined during the early phases of the study, but projection of performance at other locations or for other applications should be made based on the results of the field tests.

In order to accomplish the above objectives, the contractor shall perform the following tasks:

Phase I--

- Task 1 - Update and expand data supplied by the DOE on existing techniques for the production of refuse derived fuel.
- Task 2 - Identify potential new separation concepts capable of reducing the cost of producing refuse derived fuel and project their costs and potential effectiveness in separating the waste stream components. The concept of low-cost, low-yield combustible separation methods should specifically be considered in this task.
- Task 3 - Determine the potential benefits of each qualifying separation concept, and select one or more for testing. Selection criteria shall include but not be limited to the magnitude of savings potentially available from the application of the new equipment, the range of applicability of the concept, and the existence of facilities where tests may be performed.

Phase II--

- Task 1 - Select and/or design a test facility, and develop a test protocol for the system evaluation.
- Task 2 - Select a facility for the test unit based on the most favorable set of selection criteria.
- Task 3 - Prepare a detailed task, cost, manpower, and time schedule for the testing program.
- Task 4 - Monitor equipment performance to allow a determination of performance and cost of operation to be made.

Task 5 - Provide a detailed analysis of the results of the field test showing performance and cost estimates for the equipment studied under the test conditions and projected for other reasonable operating conditions.

Task 6 - Present a report describing those applications where the tested system may be most effectively applied indicating how performance and cost compare with those for commercially available separation equipment.

II. THERMAL SYSTEMS

II. A.2 Emission Levels from Solid/Waste/to/Energy Systems

Background--

Measurement and analysis of emissions has been performed in most solid waste processing facilities currently in operation. In general, this work has been concerned with regulated emissions (i.e., particulate matter), but the studies often have included an evaluation of the gaseous components in the discharged streams, the presence of trace organics in metals, hydrocarbons, and halogens such as chlorine.

Preliminary findings from these tests indicate significant increases in particulate mass flux with a shift toward much finer particle sizes in those cases where coal is blended with refuse derived fuel. The studies have also indicated that halogens (specifically chlorine) and certain trace metals (specifically lead) are present in significant quantities in the stack gases. Concern has arisen as a result of the indications that 50 percent by weight of the particulates emitted from some incinerators are smaller than 1 micrometer. This is in the respirable range, which suggests that a health hazard may exist. For this reason, the DOE feels that a specific evaluation should be made of the quantities and characteristics of chlorine and metals emitted from facilities burning refuse for energy.

The recommended procurement method for this program is a PRDA with multiple awards.

Statement of Work--

The objective of this program is to determine the environmental impact and potential health hazard posed by the burning of municipal refuse to produce energy on a wide scale. The results from this program should establish the level and character of emissions (particularly chlorine and trace metals) as a function of combustor configuration, plant load, and fuel blend. Since emissions from a combustion source are a function of reactor configuration, combustion conditions, method of feeding, and the composition of the fuel, an extensive program is desired in which a range of combustor and heat recovery configurations are evaluated. Selection of the test facilities will be based on the following criteria: (1) system type widely applied in a variety of existing installations, (2) ability to conduct tests with minimal equipment modification, (3) redundancy of equipment so as to preclude or minimize interruption of normal processing of the system, (4) flexibility of operation, and (5) a high degree of cooperation by the system owner/operator. Candidate systems include modular, starved-air

incinerators, waterwall incinerators, and excess-air incinerators because of their widespread application and advanced stage of development. This program should not repeat the emissions work already accomplished at the various functioning resource recovery facilities throughout the country but should build upon this work in developing a more complete data base of trace materials emitted from resource recovery combustion units. The level of effort of each test program is estimated to be 5 man-years with a period of performance required of 1 calendar year.

The scope of this contract can be divided into the following three phases:

- Phase I - Preparation of a Test Protocol
- Phase II - Collection and Analysis of Data
- Phase III - Final Report Preparation

Phase I - Test Preparation--

Task 1 - Survey of Past Work. In order to eliminate needless duplication of work in acquiring copies of past reports on emission tests on firing municipal refuse in various combustor configurations, the DOE project officer will supply to each contractor a list of appropriate references. The contractor will receive guidance from the DOE in: (1) determining which emission tests are most appropriate for the type of combustor under consideration; (2) determining what variables; i.e., plant load, combustor configuration, fuel type and blend, ash and fuel handling systems, etc., impact the emission levels; and (3) determining the sampling methodology that produces the most reliable results.

Task 2 - Preparation of a Test Protocol. The contractor shall prepare a detailed test protocol in which the following information will be established: (1) the types of emission tests to be conducted, (2) the test methodology for collecting and analyzing the stack discharge stream, (3) the location of various test ports in the combustion system, and (4) the number of replications for each test load and/or fuel blend fired. The contractor shall design a test protocol for both regulated and unregulated emissions. As a minimum, the emissions testing should include those pollutants shown in Table 1. Trace element analysis should be carried out as a function of particulate sizing.

Phase II - Collection and Analysis of Data--

Task 1 - Data Collection. The emission tests will be carried out at various boiler loads, refuse and coal blend (if appropriate), and under other varying process conditions as mutually agreed upon by the contract officer, the contractor, and the site owner/operator. Elaborative tests for gaseous emissions shall be carried out to verify both the sampling and analytical procedures. A side stream from the stack shall be piped

TABLE 1

Example Pollutants for Sampling and Analysis
of Solid Waste to Energy Combustion Systems

<u>Gases</u>	<u>Trace Elements</u>
SO _x	Arsenic
NO _x	Antimony
CO	Barium
CO ₂	Beryllium
O ₂	Boron
F	Chromium
HCN	Copper
Total HC as CH ₄	Cobalt
Total Acids	Lead
Total Aldehydes as Ketones (HCHO)	Manganese
	Mercury
	Selenium
<u>Organics</u>	
PCB	Tellurium
POM	Tin
	Titanium
	Vanadium
<u>Particulate</u>	
Mass Flux	Zinc
Sizing (to 0.01 micrometer)	
<u>Acid Dewpoint</u>	<u>Resistivity</u>

to ground level where it is delivered through a manifold to various collaborators (Cabin NDIR, luminescence, and other ion gas analyzers).

Task 2 - Data Analysis. The collected data will be subjected to such statistical treatment as to present a valid representation of the distribution of sample points and to provide an accurate indication of the trends which the tests indicate.

Phase III - Final Report Preparation--

The test results from this program will be presented in such a form that it can be readily usable by manufacturers of boilers and pollution control equipment. The contractor will prepare and submit the final report to the project officer within 90 days of completion of testing.

II. A.3 Determination of The Theoretical Efficiencies for Thermal Processing Systems

Background--

The recovery of energy from the hot gases released by solid waste combustion has been increasingly employed to reduce waste disposal costs for municipalities throughout the country. New processing systems developed to improve the efficiency of this energy recovery concept have resulted in widely varying claims by system developers. It is necessary to verify the reasonableness of these purported efficiencies before an accurate assessment can be made of the merits and viability of the system.

Maximum system operation efficiencies can be determined from physical laws that apply to all processing systems. One such verification approach would be to use the efficiencies analogous to the Carnot cycle or other theoretical maxima. Comparison of reported efficiencies can then be made with these maxima.

This research and development effort is aimed at determining the theoretical efficiency of each of three generic types of thermal processing systems: pyrolytic, starved-air combustion, and excess-air combustion. *Theoretical efficiency* is defined as that efficiency that would occur if all losses from a system were minimized and the thermal reaction were continued to completion. This efficiency would exceed that of all actual processes and would, therefore, define the maximum attainable system thermal efficiency. This data would provide a basis for determining the maximum energy revenues obtainable from a given system, thereby indicating potential system viability.

Individual efforts studying specific processes are currently being executed at a number of universities throughout the country (Arizona State, Georgia Tech, Princeton, etc.). These individuals and facilities should be considered for the ongoing studies. The level of effort for this study is estimated to be 4 to 5 man-years spanning a 2-year period.

Statement of Work--

This work will determine the maximum theoretical thermal efficiencies for various types of solid waste thermal processing systems. The processes to be evaluated should include excess-air incineration, starved-air incineration, and pyrolysis reactions. The initial stages of the study will establish the mathematical formulations that represent the physical and chemical processes occurring in each of the above systems. The useful ranges over which the physical parameters need to be studied will be provided by the DOE from previous systems analyses. Verification of the theoretical analyses will be accomplished through lab scale tests performed under optimal process conditions. The results of this work will provide the theoretical limit on process thermal efficiencies and a consistent format for reporting these process efficiencies. This information can be used in determining optimal system economic performance. Using this knowledge, entities considering implementation of energy recovery systems will be able to recognize unrealistic claims of system thermal efficiencies and unfair marketing practices.

To accomplish the above objectives, the contractor shall perform the following tasks:

- Task 1 - Develop the mathematical representation of thermal processes applied to energy recovery from solid waste systems.
- Task 2 - Adapt the developed characteristics to a computerized format that can be used to "simulate" a variety of operating conditions.
- Task 3 - Exercise models using operating parameters of actual system operating parameters supplied by the DOE representative.
- Task 4 - Design test facilities to investigate "ideal" process performance.
- Task 5 - Perform laboratory tests to verify the theoretical model, and perform model modification to reflect test results.
- Task 6 - Estimate the order of magnitude of realistic radiative and conductive losses from ideal systems employing the above processes.
- Task 7 - Report results of the study including theoretical and maximum reasonable system efficiencies, and provide a model and format that can be readily utilized by the DOE or other interested parties.

II. A.5 Boiler Erosion/Corrosion Evaluation for Systems Firing Refuse Derived Fuel

Background--

Recently, the concept of burning unprocessed and processed urban waste in incinerators and boilers has been applied to waste heat recovery boilers. Each RDF fuel form has chemical properties and feeding and combustion characteristics that make it attractive to particular combustor configurations. Private industry and public utilities both have recognized the potential of RDF as a fuel. However, one of the reasons that they have not readily responded to this fuel source is the question of the long-term effects of corrosion, erosion, and fouling on boiler performance. Corrosion studies carried out at the Union Electric Power Company in St. Louis; at the Ames, Iowa, demonstration; and at the Wisconsin Electric Company in Milwaukee have provided valuable data in this area, but additional work needs to be carried out. Specifically, long-term corrosion, erosion, and fouling studies need to be carried out at actual field boiler installations for a minimum of 1 year. The use of probes and coupons do not duplicate either the external or the internal environments of boiler and superheater tubes. Therefore, the preferred method of monitoring corrosion and erosion is on-site exposure of actual boiler tubes and other components within the system.

The effort envisioned herein would consist of multiple projects funded through contracts or PRDA procurement methods. Preferred test facilities would include waterwall incinerators, modular incinerators with waste recovery, and coal-fired boilers co-firing densified or fluff RDF.

Statement of Work--

The objective of this program is to investigate corrosion, erosion, and fouling in conventional boilers with regard to such specifics as identifying the various types, mechanisms, amounts, and likely locations of these occurrences when burning municipal refuse. The municipal refuse may range from unprocessed to highly processed densified refuse and may be fired alone or blended with coal of varying sulfur contents. The results of the project should indicate what appropriate adjustments can be made in present equipment and operating procedures to avoid problems and, thus, to permit general industry/utility acceptance of RDF as an acceptable alternate fuel. In addition, the results of this program should provide data that can be used for the design of new systems and equipment.

Since corrosion, erosion, and fouling in a boiler is a function of the furnace sizing and design, the arrangement and design of the heat transfer surfaces, the method of introducing fuel and air into the furnace, the selection of materials, and the type and method of boiler cleaning equipment employed, a multiple program is desired in which a range of boiler, furnace, and incinerator configurations will be evaluated. Those installations that will be considered as acceptable sites are: (1) spreader stoker-fired, traveling-grate boilers with superheat (air swept or densified refuse fed); (2) small modular incinerators with heat recovery; (3) fluidized bed reactors with heat recovery; (4) pyrolysis reactors; and (5) mass burning traveling grate boilers.

The level of effort for each program is 5 man-years with the expected length of the program being 18 months. The minimal acceptable length of a corrosion/erosion test is 6 months, with 12 months preferred. The program can be divided into three phases:

- Phase I - Preparation of a Test Protocol
- Phase II - Collection and Analysis of Data
- Phase III - Final Report Preparation

Phase I - Preparation of a Test Protocol--

- Task 1 - Survey of Past Work. In order to eliminate needless duplication of work in acquiring copies of past reports of emission tests on firing municipal refuse in various combustor configurations, the DOE project officer will supply to each contractor a list of appropriate references. The contractor will receive guidance from the DOE in: (1) determining which emission tests are most appropriate for the type of combustor under consideration; (2) determining what variables, i.e., plant load, combustor configuration, fuel type and blend, ash and fuel handling system, etc., impact the emission levels; and (3) determining the sampling methodology that produces the most reliable results.
- Task 2 - Identification and Selection of Test Facilities. Selection of the test facilities will be made based on the following criteria: boiler type widely applied in a variety of installations; ease of conducting tests with minimal equipment modifications; and multiple boiler operation providing system redundancy, flexibility of operation, and a high degree of commitment by the boiler owner/operators.
- Task 3 - Preparation of a Test Protocol. The contractor will prepare a detailed test protocol. This protocol will establish: (1) the location of various test areas within the combustion system; (2) the number of test samples; (3) the test methodology for monitoring corrosion, erosion, and fouling; (4) the degree to which such factors as fuel properties, combustion conditions, and other parameters will be varied or controlled; (5) the schedule for removing samples for analysis from the combustion system; (6) the diagnostic procedures required to quantify the corrosion, erosion, and fouling of the test specimen; and (7) the approach to be used in analyzing and identifying the corrosion mechanism.

Phase II - Collection and Analysis of Data--

- Task 1 - Installation/Removal of Test Specimen. After the contractor has installed the prescribed number of test specimens within the combustion system, the test shall be initiated. It is expected that tube scrapings and test specimens will be periodically removed from the combustion system to permit quantification of corrosion, erosion, and fouling as a function of time and fuel blend changes.

Task 2 - Analysis of Test Specimen. The analysis procedures shall be sufficient to measure any loss in the strength or serviceability of tubes and other components, especially as contrasted to the comparable loss of identical parts exposed only to the combustion products of other fuels such as coal. Such loss of serviceability should be expressed in: (1) cracking (stress-corrosive cracking and thermal stress cracking), (2) microstructural changes, (3) local loss of metal thickness (pitting), (4) uniform loss of metal thickness, and (5) amount and type of scale and deposits.

Task 3 - Definition of the Corrosion Mechanism. The test specimens shall be subjected to metallographic, X-ray diffraction, microprobe analysis, and other laboratory techniques as required to identify and quantify the various chemical constituents of the scale, base metal, fouling material, etc. Based upon this rigorous analysis, the mechanism of metal attack shall be hypothesized.

Phase III - Final Report Preparation--

The test results from this program shall be presented in such a form that the locations; type; quantity (as a function of time, fuel type, and combustion conditions); and corrosion/erosion mechanism can be readily understood by boiler manufacturers and operators. It is the object of the program to provide a study report that can be used as guidance to minimize the occurrence of corrosion, erosion, and fouling when firing municipal refuse in conventional fuel firing equipment.

II. A.6 Optimization of Feed and Ash Handling Systems

Background--

Several different types of material handling systems are currently in use throughout the resource recovery industry. In many cases, these have been the cause of severe operating problems and have required extensive rework and redesign efforts. This has resulted because of an insufficiency of information about the handling characteristics of municipal solid wastes and its ash residue as well as a certain tendency within the resource recovery field to "reinvent the wheel." Many of the combustion systems investigated during the small-systems analysis did not include specific feed systems or ash removal systems, yet it will be necessary that well designed, reliable feed and ash handling systems be available for such combustion systems to become commercially acceptable.

The proposed effort envisions a developmental program aimed at performance characterization of equipment to transfer feed material into thermal processing vessels and to remove ash and residue from those vessels. Initially, the program will gather and evaluate all available data on existing and proposed materials handling equipment on the basis of generic system type. This data, upon evaluation for validity, will be used to generate extensive design guidance suitable for purchasers, users, and system

designers. Documentation of the performance of existing equipment to be studied will offer the resource recovery industry in the United States significant assistance in the development and design of new systems and will minimize problems and redundancy of effort in specifying material feed and discharge systems.

Statement of Work--

This work will be aimed at investigating the equipment currently used to transport solid waste into thermal processing vessels and equipment used to remove ash and residue from processing vessels. This study will establish reliability, relative cost, capacity, and ability to provide a gas-tight seal and will consider other functional performance characteristics of the various equipment designs applied to or proposed for solid waste systems. Types of systems to be investigated should include but not be limited to excess-air incinerators, starved-air processes, and pyrolysis systems. Feed systems investigated will include those handling unprocessed solid waste as well as those handling separated waste streams. Ash removal systems should include wet and dry systems and slagging as well as nonslagging systems. Specific equipment items to be investigated should include but not be limited to pan conveyors, drag conveyors, rams, rotary valves, multiple slide gates, stoker systems, pneumatic systems, and any other equipment items identified during the study.

The project will provide a data bank to be used in performing comparisons of the various available equipment items in order to assist systems vendors and designers in selecting the optimum systems for specific applications. The desired results will be design data leading to a reduction in the total cost of construction, start-up, and/or operation and maintenance of solid waste processing systems.

Phase I--

- Task 1 - Identify feed and ash handling systems applicable to small solid waste resource recovery systems from those at existing waste processing facilities for systems currently being tested. Concepts should also be identified which are not currently being utilized but which appear to hold promise in reducing the cost of waste processing or improving the efficiency of system operation.
- Task 2 - Investigate equipment performance versus specifications for existing facilities. Parameters to be studied should include capacity, cost, reliability, flexibility to handling off-design material, and ability to maintain an air seal.
- Task 3 - Document particular problems associated with specific equipment items and types of systems. Determine whether these problems are unique to the material being handled or to the system being studied or if they are a function of solid waste processing in general.

- Task 4 - Determine critical parameters and design criteria that should be considered by system designers, purchasers, vendors, etc., and indicate the relative importance of each in overall system cost, operation, and efficiency.
- Task 5 - Identify equipment items holding most promise to enhance the capability of waste processing systems by effectively handling solid waste and incinerator residue.
- Task 6 - Identify facilities where controlled tests of feed and ash handling systems can be accomplished and recommend specific test procedures and data needs for determining concrete guidance in the design of materials handling systems.

Phase II--

- Task 1 - Select specific site (two sites) from the candidates identified in Phase I, Task 6, for performance of a test and analysis program leading to optimization of material handling systems.
- Task 2 - Develop test protocol for sites to be evaluated.
- Task 3 - Perform facility modifications as required to effectively complete the requisite test program.
- Task 4 - Collect, reduce, and evaluate data on feed and ash handling systems according to the finalized test protocol of Phase II, Task 2. Test program will be designed to allow determination of equipment or hardware modifications, process design changes, and control requirements for optimal design of conveyor systems applied to this purpose. A final report will be prepared presenting the results of this study and offering the basis of a design procedure for achieving optimum or "state of the art" in feed and ash handling systems.

II. A.8 Refractory Life and Maintenance Requirements

Background--

The small-scale systems analysis revealed that refractory problems can add significantly to the operating and maintenance costs of combusting solid waste. This results in increased maintenance costs and, more importantly, in increased downtime. Small-scale system vendors and designers have indicated that selection of refractory material for their systems is not based upon testing program results but rather upon empirical results obtained at field installations. Although this may result in an acceptable materials selection, variations in process conditions and methods of operation at specific facilities preclude the controlled test conditions required to select optimal refractory materials and operational procedures for maximum refractory life.

This research and development effort is aimed at reducing the cost to dispose of solid waste in thermal processing systems by improving the performance and the life of the refractory lining in these units. This research

study is important because of its potential to reduce processing costs and to improve system reliability. A specific case of a technology requiring analysis of total life cycle refractory costs is the small modular incinerator. The emphasis in developing these systems has been on minimizing the capital cost of the systems rather than on the total cost.

This research and developmental effort would consist of a study requiring manpower on the order of 3 man-years applied over a 12-month period. The evaluation of the results of recommended design and operational changes will continue for several years and will require approximately 1 to 2 man-years. Thus, initial recommendations and investigation results will be available in about 1 year while the results of controlled field tests will be available after a period of several years.

Statement of Work--

This work will examine the potential for reducing the cost of processing the solid waste in thermal processing systems by improving the performance of the refractory lining. The systems to be evaluated should include excess-air incinerators, starved-air incinerators, pyrolysis systems, and any other thermal processing system having refractory materials for insulating purposes.

The initial stages of the study will establish the costs associated with the installation and maintenance of the refractory lining in existing processing systems. The installation techniques, material selection, and operational modes will be evaluated to determine the ability to reduce processing costs by modifying these items. If it is determined that significant savings can be realized through changes in procedures, estimates of the magnitude of these savings will be made, and specific recommendations will be formulated and presented to system vendors and owners/operators.

The results of these recommendations applied to field installations shall be monitored and compared to "base case" systems evaluated during this study. In this way, the study will provide a demonstration of the advantage of analyzing refractory costs through a total life cycle analysis rather than on a first cost basis.

To accomplish the above objective, the contractor shall perform the following tasks:

- Task 1 - Identify thermal processing systems used to dispose of municipal solid waste that have been operational for more than 2 years and have an operational history of greater than 2 years.
- Task 2 - Prepare a format to be used in acquiring data regarding refractory life and maintenance, refractory types, service, etc. This format will be utilized by the contractor in documenting current refractory service conditions and performance and by system vendors and operators over the long-term field service test (Task 6). This document shall be submitted to the DOE for approval prior to initiation of the field survey (Task 3).

- Task 3 - Expert review of service data to determine the applicability of materials and the method of installation to process conditions. Review operating and shutdown cycles, refractory cure, etc., to determine alterations and procedures that might improve refractory life.
- Task 4 - Make an estimate of changes in cost resulting from recommended changes in materials or operational procedures, and determine net change in cost of operation.
- Task 5 - Develop strategy to achieve participation of system vendors or owners/operators in a study of the effect of the changes recommended in Task 4 on refractory life, and solicit participation of system vendors or owners/operators (not limited to those surveyed).
- Task 6 - Encourage documentation of resultant performance and "base case" performance by system operators/owners by providing data collection forms and guidance in their use, emphasizing the value to the operators of the information gathered to assist in the optimization of their operation.
- Task 7 - Analyze results of implemented changes and compare to base case performance.

II. A.9 Development of 5- to 20-TPD Systems

Research and Development Needs--

This research and development program is designed to further develop technology for converting solid waste to energy for communities generating 5 to 20 TPDs.

The program would provide funding for feasibility and implementation efforts specifically for intermediate sized facilities. The procurement mechanism for this effort would be in the form of a Program Announcement for cost shared demonstrations. Awards would go to projects judged to have the greatest probability for success.

A major problem affecting the implementation of solid waste to energy systems for the smaller communities is the lack of technologies available for these communities. The major effort of this research and development need will be to bring technologies to the forefront that will be capable of servicing the needs of smaller communities. Developing technologies that can serve these communities would make a major impact on converting solid waste to energy. By developing modules that can process 5 to 20 TPD, multiple modules would be able to service communities generating wastes up to 100 TPD. Candidate technologies identified in this size range identified in the small systems analysis were limited to small modular, starved-air incinerators.

Statement of Work--

The Office of Conservation, Division of Buildings and Community Systems, is empowered to conduct research and development to speed the implementation of converting solid waste to energy. Of major concern to most of the smaller

communities is the lack of technologies available for converting solid waste to energy. These communities face the same problems as large communities, i.e., unavailability of acceptable landfill sites and increased landfill disposal costs. By sponsoring research and development for technologies to assist the smaller communities, a major positive impact on the recovery of energy from solid waste could be obtained. It is the intent of this work effort to provide the necessary funds to further develop technologies so that solid waste to energy can be achieved.

The major objective of this research program is to support demonstrations of technologies with municipalities, owners of technologies, and industry.

Scope of Work--

This program would allow owners of technologies or municipalities or industries to propose cost-shared efforts for the design, demonstration, and testing of systems capable of converting solid waste to energy for communities generating 5 to 100 TPD_s of solid waste. The respondents to this RFP will identify the technology, the further developments needing to be accomplished, the parties involved in the proposed program, and the testing to be performed. They will also discuss economics of the proposed system concept and how the economics would impact on smaller communities. More specifically, the respondent will provide the following data:

1. Technology to be Employed--The respondent will identify the technology to be proposed for the program and will provide narratives, descriptions, pictures, and other documentation that may be appropriate for describing the technology. This information should also describe the status of the technology; document whether the proposed technology is a scale up, scale down, or identical to an existing system; and determine if the proposed system concept is new and innovative and requires further laboratory and/or pilot demonstration.
2. Technology Development Requirements--The respondent will identify and describe the research and development needs for the proposed technology. The respondent must remember that the DOE does not propose to support technology development directly. However, DOE will encourage development by others by supporting implementation and planning efforts for specific projects under this program. Engineering, testing, evaluations, etc., can be supported by this program; and respondents to this request shall identify by tasks the engineering needs required for the project and any required technology development.
3. Parties Involved in Proposed Program--The respondent shall identify all parties involved in the proposed program and specify their involvement; their financial commitment, if any; and the tasks to be accomplished by each party. Included shall be a discussion on how the proposed program will be managed and organized.

4. Proposed System Economics--Keeping in mind the main objective of the proposed effort, the respondent will develop a presentation of how the economics of the proposed system will help to develop the small-scale, solid waste to energy market area. The respondent will make projections of capital costs, operating and maintenance costs, and energy and/or material credit. They will present a scenario as to why smaller communities would pursue the development of a waste to energy project using this technology. The result of this project would be the installation and demonstration of the selected technologies. The physical product of this specific work will be a feasibility report on the specific installation. This report should be of such a nature that it could be used to secure financing for similar installations elsewhere via a normal municipal or industrial bonding mechanism.

II. A.11 Optimization Studies of Control Systems for Small Modular Incinerators

Background--

Small modular incinerators provide the most attractive alternative for small-scale energy recovery since the process and hardware for these systems has already been developed. Advances improving the efficiency and economic performance of these energy recovery systems will have a major impact on advancing the status of small-scale resource recovery. Investigations performed under the small systems analysis have revealed that the majority of companies providing modular incinerators are quite small and do not have the resources to develop sophisticated control components for their existing systems. Additionally, the emphasis in the marketplace has been to minimize "first cost" rather than optimize system performance. Recent studies have indicated that system performance is erratic and is mainly a function of the quality of the maintenance and operational attention given to the unit. This is a strong indicator of the need for better control systems to minimize the variability of performance.

The DOE feels that a specific development effort should be aimed at selecting optimum control systems for various modular incinerators used to recover energy from solid waste. Although the specific geometry of the various modular incinerators differs by vendor, the basic process is essentially the same. This should facilitate the optimization of a common control system for starved-air processes.

The rapid development and increasing complexity of process control equipment makes it difficult for small companies to incorporate the most highly developed control systems into their products. The study effort is necessary because the results could have a major impact on system performance and, consequently, on system economics.

This effort would consist of two phases: Phase I - Investigation of Needs and Determination of Optimal Control Systems and Phase II - Implementation and Testing of Control System in Field Installations. Phase I is estimated to require 2 to 3 man-years of effort expended over a 1-year period.

Phase II is estimated to be a 3 man-year effort expended over 12 months. Phase I results should have a substantial impact on small modular incinerator technology and may suffice to motivate vendors to adopt the recommended system without executing Phase II. For this reason, Phases I and II will be funded separately.

Statement of Work--

This work will be directed at developing an improved control system to be employed on modular starved-air incinerators applied to recover energy from the incineration of solid waste materials. The goal of this project will be to develop a process control system that is cost effective in providing improved economic performance as well as improved energy recovery efficiency of small, starved-air, modular incinerators. To achieve this goal, it will be necessary to coordinate closely with the system vendors to ensure that consideration is given to their needs, to encourage their utilization of the system developed, and to take advantage of their experience and knowledge concerning the systems. The project will establish those parameters that should be monitored and controlled to most efficiently control the incinerator process, the proportional relationships and time factors that should be incorporated in the control hardware, the hardware items that can most effectively be applied in the control system, and a conceptual design of the control loop for a "typical" starved-air modular incinerator. The system will then be demonstrated on an actual field application. As is the policy of the DOE, no hardware will be purchased under this program. The active involvement of vendors will be necessary, and it will be the contractor's responsibility to solicit the participation of all interested parties.

By accomplishing these goals, the project will provide an effective concept for controlling the starved-air incineration process and, consequently, for improving the efficiency and economics of systems based on this concept. A demonstration project will be developed during this program to provide information concerning variations in the efficiency and economics of the system operation resulting from the improved control system.

A report of the results of the evaluation will be generated by the contractor comparing the performance of the plants with and without the improved controls and drawing conclusions concerning the performance of the units with the improved control systems. These conclusions will be supported with data obtained during the system field tests.

Phase I - Investigation of Needs and Determination of Optimal Control--

Task 1 - The DOE will supply information from previous evaluations to allow the contractor to characterize the thermal process employed in starved-air incinerators. The contractor shall use this data to identify the major factors affecting system economics and their relationship to process control.

Task 2 - Develop a conceptual design of a control scheme to optimize system performance and submit to system vendors for review. Design should include specifications of the control elements, the total system, the proportional and time factors relating various process parameters, and a projection of likely improvements in system performance and costs.

- Task 3 - Finalize control system design and document Phase I effort.
Submit the resultant design to the DOE for review and approval.

Phase II - Implementation and Testing of Control System in Field Installations--

- Task 1 - Selection of units to be utilized for demonstrations. Selection criteria should include: systems that are representative of state-of-the-art technology, facilities that dispose of solid waste and recover waste heat on a regular basis, and presence of cooperative vendor and operating entities.
- Task 2 - Design specific control systems for the selected units and construct these control systems in field installations. (Cost of equipment and installation paid by system vendor).
- Task 3 - Develop a data collection protocol for characterizing system performance.
- Task 4 - Shakedown of demonstration control system in field installation.
- Task 5 - Finalize protocol, secure equipment for testing, and develop a testing schedule. Data will include but not be limited to waste loads, charging rates, burning rates, analysis of incoming refuse and discharged refuse, auxiliary fuel and the utility consumption, heat recovery efficiency, emission testing, and such data as is necessary to perform an economic analysis.
- Task 6 - The contractor will monitor the designated plant and will be responsible for the completeness of the data collection scheme.
- Task 7 - The contractor will provide a detailed analysis of the operation of the systems to determine their performance on a technical, economic, and environmental basis.

III. BIOLOGICAL PROCESSING SYSTEMS

III. C.2 Optimum Design and Operation to Maximize Gas Recovery Rates

Background--

Most municipal solid waste in the United States is landfilled. This disposal method can be expected to continue to be the ultimate disposal method for the majority of MSW. Within any landfill, microbial processes are taking place that over a period of several years will convert the organic portion of the solid waste to stable nondegradable forms. During this conversion, the microbial cultures will produce methane as a waste product of their feeding and growth. This energy conversion process, which is naturally occurring and uncontrolled, is taking place in all of the municipal solid waste disposed of in landfills.

Since methane is being produced in municipal landfills and, in some cases, is readily capturable, it is logical that we use it as a fuel product for our country's ever increasing energy needs. The purposes of this study are to determine optimum methods of capturing and using fuel gas produced in

landfills, to identify methods of enhancement of the rate of gas production, and to identify probable levels of gas recovery that could be achieved in different landfill configurations and climates.

The biological decomposition process taking place in a landfill throughout most of its life is analogous to the anaerobic decomposition utilized in wastewater treatment. The product gas in a healthy anaerobic digestion condition will be composed of approximately 50 percent methane and 50 percent carbon dioxide. This product gas composition is also typical of that measured at well established landfills. Considering that a wastewater treatment digester is operating at near optimum conditions of homogeneity, temperature, and other controls, landfills fall short of the optimum conditions for maintaining microbial cultures. The most important impact of the "non ideal" conditions existing in landfills is that microbial decomposition of landfilled MSW requires several years to complete, compared with the several days typical of wastewater treatment plant digesters. It is commonly assumed that anywhere from 20 to 50 years is required for complete stabilization of a municipal landfill.

There have been several laboratory scale studies of the digestion of municipal solid waste in simulated landfill conditions. These studies disagree regarding the rapidity of establishment of stable microbial cultures in municipal solid waste and of the rate at which methane gas can be produced. Several ongoing studies of gas capture and recovery from existing landfills at Mountain View, Industry, and Palos Verdes, California, indicate that the technology of landfill gas recovery and use is achievable. Accomplishing the proposed study will require 3 man-years over a 2-year period.

Statement of Work--

The intent of the present study is to define levels of optimum and probable gas production as a function of landfill design, material composition in the landfill (determined by the operating history), and local weather conditions (especially moisture infiltration and local temperature history). From this information, the contractor will determine optimum gas withdrawal rates consistent with gas production rates in the field. He will then determine the specific "best" withdrawal well design for particular landfills dependent upon their depth, area, and local weather conditions.

In order to accomplish the goals of this program, the contractor will accomplish the following specific tasks:

- Task 1 - Perform a literature search of reported rates of microbial destruction of the organic constituents in municipal solid waste, probable gas production rates, and levels of success achieved in other landfill gas collection and use studies. The contractor will make direct contact with other government-sponsored research and development efforts to obtain their most recent and most up-to-date information to prevent any duplication of effort.

- Task 2 - Generate a mathematical simulation of methane generation in landfills utilizing the available information on the decomposition rates for different environmental conditions. The purpose of this simulation will be to estimate gas generation rates as a function of landfill size, geometric configuration (e.g., waste depth, waste area, nature of cover soil, etc.), landfill life, density of landfill contents, and local climate factors.
- Task 3 - Use the simulation generated in Task 2 to estimate the ranges of gas production rates from minimum through probable to maximum for specific conditions and types of landfill configurations.
- Task 4 - Estimate what areas of the United States and what type and size landfills in those regions would be amenable to the landfill gas recovery concept as an energy recovery technology. This estimate would be made from the results obtained in Task 3.
- Task 5 - Determine optimum recovery rates and landfill gas capture well designs for the specific representative landfill configurations deemed suitable in the previous task. In addition to recovery rates under varying conditions, the projected economics of each concept will be determined on a relative basis.
- Task 6 - Identify, in at least four regions of the United States with significantly different weather conditions, specific landfill sites and their landfill gas withdrawal strategies. These sites will be utilized to demonstrate the concept of landfill gas recovery. Since so much work has already been done in the State of California, it is likely that further study in that locale is unnecessary at this time. Thus, the potential sites identified as demonstration sites shall exclude those possessing characteristics and weather conditions exhibited in previously funded demonstration sites. The final report for this effort will fully identify the hypotheses and logic on which the landfill gas recovery wells are based and shall fully justify the nature and location of the chosen candidate demonstration sites.

III. D. Investigate Process Configuration Alternatives for Anaerobic Digesters

Background--

Anaerobic digestion has a long history of application to treatment of sewage sludges for volume reduction, waste stabilization, and methane production. With the development of waste management philosophies that emphasize reclamation of energy and resources rather than simple disposal, this technology has also been applied more recently to municipal solid waste,

agricultural wastes, and manures. This is a desirable trend both from a disposal standpoint and an energy outlook. However, the economics and some of the technology still require improvement before the anaerobic digestion of MSW fractions becomes attractive enough for development to commercial application.

While digestion of MSW is similar in theory to the anaerobic degradation of municipal wastewater sludges, there are several factors that make the process much more difficult in practice. Most of these problems have been documented in lab scale research. Results from laboratory studies have shown that hydrolysis of cellulose fibers is the rate-limiting step in anaerobic digestion of cellulose. In addition, normal wastewater treatment operation does not provide adequate mixing of municipal solid waste slurries. Scum layer formation occurs readily, resulting in decreased efficiency due to loss of effective volume. Grit and glass in the waste abrade plumbing and cause excessive wear on pumps and mixing equipment.

It would be the goal of this effort to compare and evaluate, on a consistent basis, several of the more important concepts in existence for the improvement and optimization of anaerobic digestion of MSW. It is expected that an initial "lab scale" study would be performed, occurring over a 2-year time period and requiring a 4-man-year effort.

Scope of Work--

The purpose of the proposed research is to investigate and to compare, on a laboratory scale, several methods of improving the efficiency of anaerobic digestion. Hydrolysis of MSW fractions, both by acid and enzymes, followed by mesophilic anaerobic digestion of MSW fractions in a conventional stirred reactor and in an unstirred, plug-flow reactor and a two-phase system consisting of an acid digester followed by a methane digester will be studied. While each of the ideas mentioned has been studied on a laboratory scale separately, there has not yet been any research combining or comparing these methods.

The light organic fraction of MSW will be used as process feedstock. Feedstock preparation (size reduction, separation, and cleaning) may be either dry process or wet process, but must be representative of commercially available technology for MSW processing. All tests, evaluations, and experimentations will be properly replicated to assure statistical validity of the program's results and conclusions. Performance data to be obtained for each unit operation will include but not be limited to (1) optimum operating conditions, (2) process efficiency, (3) input energy requirements, (4) nutrient and other additive requirements, and (5) operational problems.

In order to successfully fulfill the needs of this program, the contractors will perform the following tasks:

- Task 1 - Perform a literature search to determine existing information on methods of operation, process requirements, and advantages of each process operation to be evaluated.

- Task 2 - Determine equipment requirement for realistic evaluation of each process during "in-lab" evaluation program.
- Task 3 - In concert with the DOE's technical project officer, determine those specific processes to be evaluated. These will include but not be limited to acid hydrolysis, enzyme hydrolysis, plug-flow digestion, two-stage digestion, and all appropriate combinations of these.
- Task 4 - Develop a test protocol for the full and realistic comparative evaluation of the processes of interest.
- Task 5 - Perform the test program as defined. All results, conclusions, and recommendations resulting from this study will be fully documented in the final report of the program. This report will also include specific recommendations as to which, if any, of the studied processes holds sufficient promise to deserve further development and/or pilot- and full-scale demonstration.