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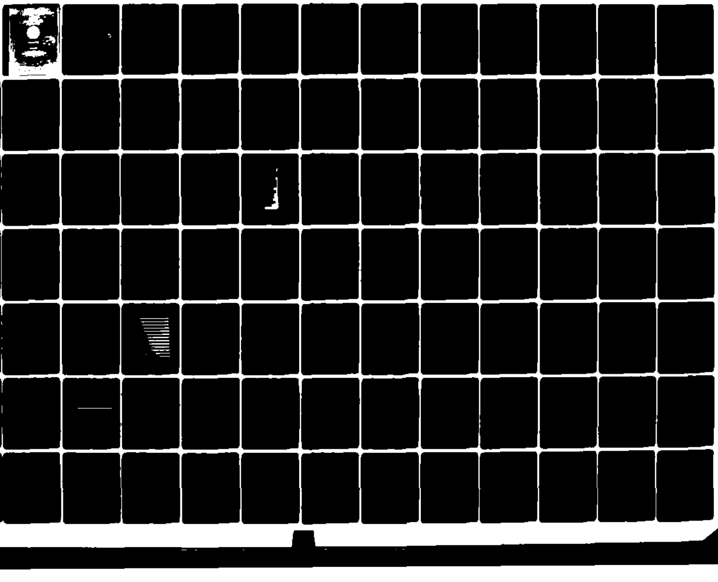

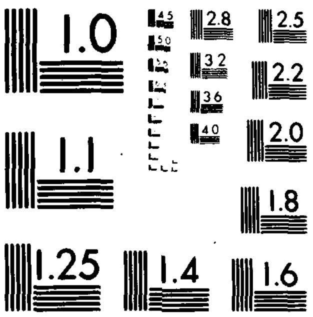

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Aerospace Report No.
ATR-80(8374)-1

MILITARY WASTES-TO-ENERGY APPLICATIONS

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FOREWORD

The research reported here was conducted as an Aerospace-Sponsored Research Project. The general objectives and emphasis of Aerospace-Sponsored Research are to (1) ensure that Aerospace remains in the forefront of critical scientific and engineering developments that will be important to future national security systems and (2) permit Aerospace to perform long-range technological projections and to develop planning and analysis techniques related to national security.

It is evidenced that the term "national security" connotes concepts in addition to the military factor of security. Energy and resource requirements greatly affect our national security posture and the quality of our lives as well. Initiatives to ensure energy supply, become more energy efficient, reduce dependency on critical fuels, and increase the use of alternative energy resources are important components incorporated into the defense energy management program.

This report provides a first-order assessment of the military waste material and byproduct stream and the affect on military installation energy supply and environmental protection goals. It identifies the status and information needs of this emerging conservation/waste utilization energy technology.

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ACKNOWLEDGMENTS

No research study comes to fruition through the efforts of the principal author alone, and this report is no exception. Many individuals have guided this effort and have lent support from the conceptual development of the study through its various stages of editorial revision and production. Although everyone cannot be acknowledged individually, the author would like to extend to all his sincere appreciation. At the same time, several persons have given so generously of their time and talent that specific recognition is necessary.

Thanks must be extended to R.L. Johnson, B.M. Bohi, and A.D. Abbott of the Environment and Conservation Directorate, for their technical supervision and guidance, and J. Meltzer, T. Iura, and D.R. Orozco of the Eastern Technical Division, for their assistance and support.

Deep appreciation is extended to the many representatives of agencies and offices within the U.S. Department of Defense: George Marienthal (Deputy Assistant Secretary of Defense for Energy, Environment, and Safety), Paul Haviland (ODASD-EES), Edward Dyckman (ODASD-EES), Steve Hathaway (U.S. Air Force Engineering Services). Invaluable information was provided by the U.S. Army (Office of the Chief of Engineers, Washington, D.C., and the Civil Engineering Research Laboratory (CERL), Champaign, Illinois); the U.S. Navy (Naval Facilities Engineering Command (NAVFAC), Alexandria, Virginia; Civil Engineering Laboratory, Port Hueneme, California; and the Naval Environmental Support Office, Port Hueneme, California); and the U.S. Air Force (Engineering Services Center, Tyndall Air Force Base, Florida).

Grateful thanks to M.C. Malloy, F.J. Collins, and Dr. C.A. Davos who reviewed and critically evaluated the draft report. Finally, a special commendation to Susan Hendrickson, Darlene Wilt, Dolores Michlik, Jan Proctor, Betty Viverette, and Diana Payne for their truly superb report production support.

ABSTRACT

The military is the largest Federal generator of solid and liquid waste. Therefore, the Department of Defense (DOD) management and individual military installations are required to comply with established regulations and guidelines not only for waste management but also for general environmental protection and energy conservation.

This analysis focuses on the military waste material and byproduct stream and the potential for energy recovery and utilization. Feedstock material includes municipal-type solid waste, selected installation hazardous waste, and biomass residue. The study objectives are to (1) analyze the characteristics of the military waste stream, (2) identify potential energy recovery options, and (3) examine and assess the technical and economic feasibility and environmental and institutional impacts of various energy recovery approaches.

Total energy recoverable from DOD solid waste could provide about 2 percent of DOD's facility energy demand. The energy potential available to DOD from biomass and hazardous waste was not available. Available waste-to-energy systems are thermal conversion processes such as incineration with heat recovery.

The significance of this recoverable energy from military wastes is put in proper perspective when the benefits and barriers in using waste-derived energy are considered. Some of the benefits of waste-to-energy conversion are as follows:

- Waste energy is a readily available and inexhaustible resource that greatly reduces dependence on imported energy;
- Nonrenewable domestic conventional fuels are conserved; and
- Waste is safely disposed, and waste volume is greatly reduced.

Among the barriers in using waste-to-energy, uncertainties and risks are very important. Several of them are identified and discussed, including technical, cost, energy utilization, waste stream, energy markets, and environmental uncertainties. Mitigation strategies and policies are suggested to reduce or eliminate the barriers to energy recovery.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF ACRONYMS

BOD	biochemical oxygen demand
BOE	barrels of oil equivalent
CERL	Civil Engineering Research Laboratory
COD	chemical oxygen demand
CONUS	contiguous United States
DO	dissolved oxygen
DOD	Department of Defense
DOE	Department of Energy
EPA	Environmental Protection Agency
FY	fiscal year
HC	hydrocarbon
HHV	higher heating value
LPG	liquid petroleum gas
MBOE	million barrels of oil equivalent
MSW	municipal solid waste
NAS	Naval Air Station
NO_x	nitrogen oxide
O&M	operating and maintenance
OTA	Office of Technology Assessment
PEP	pyrotechnics
POL	waste petroleum, oil, and lubricants
psia	pound-force per square inch absolute
RCRA	Resource Conservation and Recovery Act
RDF	refuse-derived fuel
scf	standard cubic feet
SMSA	Standard Metropolitan Statistical Area
SNG	synthetic natural gas
SO_2	sulfur dioxide
TPD	tons per day
TPD_5	tons per day (5-day average)
WESTNAVFAC	Western Division of the Naval Facilities Engineering Command

1.0 INTRODUCTION

1.1 Purpose and Scope

This analysis focuses on the military waste material and byproduct stream* and the potential for energy recovery and utilization. The study objectives are to (1) analyze the characteristics of the military waste stream, (2) identify potential energy recovery options, and (3) examine and assess the technical and economic feasibility and environmental and institutional impacts of various energy recovery approaches.

In addressing these three objectives, the scope is limited to acquiring available data on the waste characteristics of selected installations, technical characteristics of energy recovery systems, and the Department of Defense (DOD) waste management program.

1.2 Background and DOD Waste Management Objectives

The military is the largest Federal generator of solid and liquid waste.** Hence, for DOD management and individual military installation complexes, resource recovery from wastes and proper waste disposal practices are very important considerations. The era of energy shortfalls, conservation, increased environmental regulation, and diminishing (although costly) landfills has affected the military just as it has affected their civilian counterparts. The country is realizing that waste products should be *recognized as a resource instead of simply being disposed of and forgotten.* For energy and materials recovery systems to assume a prominent role in solid waste management practices, the following concepts must be considered: resource conservation and the elimination of wasteful practices, waste stream source separation, energy/materials recovery from the waste stream, and sound environmental residue disposal.

Various DOD directives and other governmental requirements*** serve as a background and motivation to DOD's objective to conserve materials and

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* For this study, the waste stream to be considered will be defined as municipal-type solid waste, selected installation hazardous waste, and biomass residue. In appropriate cases, waste or residue generated near a military installation will also be considered in the analysis. For further definition of selected terms, refer to the glossary.

** Department of Defense "strength" in U.S. territory is generally considered to be the sum of active duty military personnel and civilian personnel -- approximately 2.5 million persons at the end of March 1979, excluding indirect hire and reserve personnel (Ref 1).

*** Refer to Appendix A for a listing of relevant waste management requirements pertaining to military activities.

the environment and reduce the cost of its solid waste management program. In keeping with the above concepts, DOD seeks to (Ref. 2)

- Reduce the amount of material purchased and the amount of solid waste generated;
- Increase the service life and the potential recoverability of the materials purchased;
- Recover solid waste materials for sale or energy recovery, by source separation or the use of local or regional resource recovery facilities;
- Improve the operation of the collection, storage, transportation, and disposal functions of the solid waste system; and
- Comply with Federal, state, and local environmental laws.

Guided by these concepts and objectives, the command and facilities engineer at each installation is further stimulated by

- Potential opportunities to conserve costly and nonrenewable conventional fuels;
- Prospects of conducting solid waste management operations in a more environmentally acceptable manner;
- The challenge of reducing installation waste disposal costs; and
- The necessity to respond to a growing number of laws, regulations, and guidelines regarding facility waste disposal and recovery operations.

Along with increased interest in waste-to-energy systems, there are, however, divergent opinions on technical, economic, and other aspects of such systems. Although the focus in the recent past has been on large municipal systems (500 to 1000 tons per day (TPD)), small-scale (less than 200 TPD) energy recovery systems potentially applicable to military installations have also been the subject of considerable review. Those experienced in the equipment evaluation for project design and development continually point out the paucity of reliable long-term information on operational history necessary to precisely predict and ensure successful performance of both large- and small-scale energy recovery systems. Fuel savings, reduced waste disposal costs, greater environmental compatibility, and other benefits resulting from waste-to-energy systems must also be evaluated at the individual installation.

This report does not evaluate the potential of waste-to-energy systems for specific DOD facilities. Rather, it draws upon information from past individual installation evaluations and determines pertinent characteristics necessary for the further development of waste-to-energy systems.

1.3 Importance of DOD Waste Information

Information on waste stream characteristics are essential for proper waste management and disposal and for the design of effective waste-to-energy systems. Currently, there are no comprehensive and reliable data on DOD waste quality, composition, or emission factors.

Although there have been a number of specific waste surveys taken at various DOD installations, the reported results, in most cases, have been too aggregated or not comparable (Ref. 2). Waste information is also required for compliance actions to meet the U.S. Environmental Protection Agency's (EPA) guidelines for source separation (Ref. 3), beverage containers (Ref. 4), and resource recovery facilities (Ref. 5). Numerous attempts have been initiated by all three service branches to survey the solid waste stream (Refs. 2, 6, 7, 8, 9, 10, 11, 12, and 13). In addition, there have been over 30 solid waste surveys taken at specific DOD installations.

For the defense community to efficiently use resource recovery as a means of solid waste disposal, the magnitude of the solid wastes must be determined. In the past, landfill, incineration, and general salvage operations did not necessitate accurate, detailed estimates of solid waste parameters. However, as technology advanced and recovery of energy and materials became one of the objectives of solid waste management, the need for much more detailed information was apparent.

This study will not attempt to duplicate the data-gathering efforts previously taken but will use and analyze this information. However, it must be strongly emphasized that DOD should have at its disposal, detailed and accurate information on quantities and characteristics of solid waste generated at military installations prior to the initiation of any further studies aimed at improving solid waste management systems and implementing resource recovery systems.

1.4 Approach

The study approach has been to (1) complement and supplement the work of DOD agencies* engaged in energy and waste research and management in analyzing the waste stream and (2) concentrate on assisting decisionmakers at the installation and at higher levels of DOD management by providing an overall analysis and evaluation of military waste-to-energy options.

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* Information contacts were established with the U.S. Army (Office of the Chief of Engineers, Washington, D.C., and the Civil Engineering Research Laboratory (CERL), Champaign, Illinois); the U.S. Navy (Naval Facilities Engineering Command, Alexandria, Virginia, Civil Engineering Laboratory, Port Hueneme, California, and the Naval Environmental Support Office, Port Hueneme, California); and the U.S. Air Force (Engineering Services Center, Tyndall Air Force Base, Florida).

The analysis and evaluation of options are based on an intensive search of existing data bases and a state-of-the-art review of the applicable waste-related literature to determine the number and types of research studies that have been reported and would provide the necessary data for this report. The analysis of waste studies is based on information sources that include the Defense Documentation Center, Defense Logistics Agency (Alexandria, Virginia); Solid Waste Information Retrieval System, Office of Water and Waste Management, EPA (Washington, D.C.); Industrial Environmental Research Laboratory, EPA (Cincinnati, Ohio); and RECON, U.S. Department of Energy (Washington, D.C.); National Technical Information Service, U.S. Department of Commerce (Springfield, Virginia). Those research studies found to contain necessary solid waste and facility information were investigated further for use in this study. In addition, appropriate direct contact was made with planning and field managers involved in developments in waste management and energy recovery.

Chapter 2 of this report provides an overview of current DOD waste management practices and discusses pertinent characteristics of the waste stream. Relevant DOD waste information has been analyzed and evaluated in terms of energy recovery suitability. Chapter 3 describes the current DOD energy supply needs and the potential contribution of waste-demand energy.

Chapters 4-6 make up the major technical analysis of the report. The waste stream components studied include solid waste, selected hazardous wastes, and biomass. Chapter 7 presents an overall assessment of research findings in terms of various energy recovery options available for military application. This section also identifies first-order trade-offs and preferences for the competing approaches. Chapter 8 reviews the critical factors necessary for successful application and the implications for DOD waste management policy formation. This evaluation, in conjunction with other DOD and non-DOD energy recovery studies, should provide a firm basis for decisionmakers to analyze the potential for resource recovery on DOD installations. Chapter 9 presents policy recommendations.

2.0 PRESENT CONDITIONS

2.1 Military Waste Stream Identification: Solid Waste Information

Effective implementation of waste management and energy recovery systems requires acquisition of accurate data on the input waste stream. Information from waste surveys should provide the basis for the selection of the appropriate energy recovery facilities and their accompanying management systems. Identified waste stream problems can then be evaluated and corrected in the early planning and design stages.

One reason that acquiring reliable data on the military waste stream has been difficult is that it often requires expensive, time-consuming surveys. There is an urgent need for research in synthesizing existing data and developing accurate, workable models and methods that can be used to predict waste quantities and characteristics at military installations. If a relationship can be established between existing facility operation parameters and waste generation, this relationship would form the basis for various waste prediction models. The ability to accurately estimate the quantities of military wastes will provide DOD with part of the data base needed to develop improved waste disposal and energy recovery systems that meet current and future resource conservation and environmental protection requirements.

The waste stream characterization should basically describe and evaluate critical waste stream parameters, including waste sources, mass generation rate, waste composition, potential quantities, and other pertinent characteristics affecting the suitability of the waste stream for energy recovery. The resultant analysis and evaluation can then determine the appropriate disposal system for a specific installation.

Several plans and methods have been suggested for use by the service branches to characterize the solid waste stream and management practices for individual installations (for example, Refs. 9, 14, and 15). No attempt will be made here to review these methods or to select the best survey method to collect waste generation, recovery, and disposal information by individual installations, commands, service branches, and DOD as a whole. This important task is suggested for future research. The study will not try to duplicate these attempts to characterize the waste stream. Rather, it will identify and describe overall generic features of the military waste stream. Such a review will shed some light on the potential of energy recovery systems using military waste and, it is hoped, provide the impetus for DOD installations to assess their own potential for waste-to-energy recovery.

The reader should regard the validity of the data presented with caution. A variety of relevant DOD waste information has been consolidated and presented to illustrate the salient characteristics of the waste stream, provide DOD installations with a basis for making rough estimates of their waste quantities and composition, and indicate the types of useful data for decisionmakers. However, any waste stream is difficult to classify and measure. This is true on an overall national level as well as an installation or municipal level, and waste data reflect that difficulty.

The solid waste stream of the military is a good case in point. The following sections describe the solid waste characteristics as determined from recent studies. Descriptions of the biomass and hazardous wastes streams are found in Chapters 5 and 6, respectively.

2.2 Solid Waste Stream Characterization

Despite the notion that the solid waste stream is heterogeneous in its composition and thus variable in its properties, the potential of waste-to-energy systems can still be assessed. The information describing the waste stream exhibits variability; therefore, the design of energy recovery systems must provide for more operating flexibility, reserve capacity, and other design adjustments. Regardless of the difficulties in data gathering, characterizations of the average waste stream properties provide the starting point for planning and design. Another necessary input is a description of the deviation from these idealized characterizations.

Several properties of potential importance in waste characterization are shown in Table 1. Although the list is detailed, it is by no means complete. Such a checklist can be useful for the waste manager or decisionmaker in the assessment of waste-to-energy systems. In addition to estimating these emission factors and characteristics, a range of each of these parameters must be determined based on representative field sampling data. Any gross deviations or wide-range values should be questioned and explained prior to acceptance of such data for energy recovery calculations.

Potential sources of military solid wastes can be grouped into seven waste categories as defined by the Incinerator Institute of America (Ref. 17) and shown in Table 2. Military building types that may generate these types of waste are listed in Table 3.

Military solid wastes contain primarily Type 1 and 2 wastes. Hence, the typical characteristics of the waste stream will have (1) 20 to 30 percent incombustible material, (2) a lower heat value of about 5000 Btu/ton, and (3) a moisture content of about 30 percent.

Solid waste is generated at three primary types of functions within military facilities: family support, troop support, and industrial support. Military family support functions are quite analagous to the civilian residential sector. Housing is comprised of private residences, townhouses, duplexes, and other living quarters. Other waste sources are commissaries and exchanges, which produce shopping center type waste.

Troop support areas include barracks, mess halls, clubs, and other functional areas (e.g., classrooms, administrative offices, and routine and

Table 1. General, Physical, and Chemical Parameters of Possible Significance in the Characterization of Solid Waste

GENERAL PARAMETERS

- Compositional weight fractions
  - Domestic, commercial, and institutional
    - Paper (broken into subcategories)
    - Food waste
    - Textiles
    - Glass and other ceramics
    - Plastics
    - Rubber
    - Leather
    - Metals
    - Wood (limbs, sawdust)
    - *Bricks, stones, dirt, ashes*
  - Other municipal
    - Dead animals
    - Street sweepings
    - Catch-basin cleanings
  - Agricultural
    - Field
    - Processing
    - Animal raising
  - Industrial
  - Mining/metallurgical
  - Special
    - Radioactive
    - Munitions, etc.
    - Pathogenic
    - Moisture
- Process weight fractions
  - *Combustible*
  - Compostable
  - Processable by landfill
  - Salvageable
  - Having intrinsic value

PHYSICAL PARAMETERS

- Total wastes
  - Size
  - Shape
  - Volume
  - Weight
  - Density
  - Density stratification
  - Surface area
  - Compaction
  - Compactability
  - Temperature
  - Color
  - Odor
  - Age
  - Radioactivity
  - Physical state
    - Total solids
    - Liquid
    - Gas
- Solid wastes
  - Soluble (percent)
  - Suspendable (percent)
  - Combustible (percent)
  - Volatile (percent)
  - Ash (percent)
    - Soluble (percent)
    - Suspendable (percent)
  - Hardness
- Particle characteristics
  - Size distribution
    - Shape
    - Surface
    - Porosity
    - *Sorption*
    - Density
    - Aggregation
- Liquid wastes
  - Turbidity
  - Color
  - Taste
  - Odor
  - Temperature
  - Viscosity data
    - Specific gravity
    - Stratification
  - Total solids (percent)
    - Soluble (percent)
    - *Suspended (percent)*
    - Settlable (percent)
  - Dissolved oxygen
  - Vapor pressure
  - Effect of shear rate
  - Effect of temperature
  - Gel formation
- Gaseous wastes
  - Temperature
  - Pressure
  - Volume
  - Density
  - Particulate (percent)
  - Liquid (percent)

Table 1. General, Physical, and Chemical Parameters of Possible Significance in the Characterization of Solid Waste (Continued)

CHEMICAL PARAMETERS

General
- pH
- Alkalinity
- Hardness ($CaCO_3$)
- MBAS (methylene-blue-active substances)
- BOD (biochemical oxygen demand)
- COD (chemical oxygen demand)
- Rate of availability of nitrogen
- Rate of availability of phosphorus
- Crude fiber
- Organic (percent)
- Combustion parameters
  - Heat content
  - Oxygen requirment
  - Flame temperature
  - Combustion products (including ash)
  - Flash point
  - Ash-fusion characterization
  - Pyrolysis characterization
- Toxicity
- Corrosivity
- Explosivity
- Other safety factors
- Biological stability
- Attractiveness to vermin

Inorganic and elemental
- Moisture content
- Carbon

Hydrogen
- (P_2O_5 and phosphate)
- Sulfur content
- Alkali metals
- Alkaline-earth metals
- Precious metals

Heavy metals
- Especially Mercury
- Lead
- Cadmium
- Copper
- Nickel

Toxic materials
- Chromium
- Especially Arsenic
- Selenium
- Beryllium
- Asbestos

Eutrophic materials
- Nitrogen
- Potassium
- Phosphorus

Organic
- Soluble (percent)
- Protein nitrogen
- Phosphorus
- Lipids
- Starches
- Sugars
- Hemicelluloses
- Lignins
- Phenols
- *Benzene oil*
- ASB (alkyl benzene sulfonate)
- CCE (carbon chloroform extract)
- PCB (polychlorinated biphenyls)
- PNH (polynuclear hydrocarbons)
- Vitamins (e.g., B-12)
- Insecticides (e.g., Heptochlor, DDT, Dieldrin, etc.)

Source: Ref. 16

Table 2. Classification of Wastes

Type	Description
0	Trash (a mixture of highly combustible waste such as paper, cardboard, cartons, wood boxes, and combustible floor sweepings) from commercial and industrial activities. The mixtures contain up to 10 percent by weight of plastic bags, coated paper, laminated paper, treated corrugated cardboard, oily rags, and plastic or rubber scraps. This type of waste contains 10 percent moisture and 5 percent incombustible solids and has a heating value of 8500 Btu/pound as fired.
1	Rubbish (a mixture of combustible waste such as paper, cardboard cartons, wood scrap, foliage, and combustible floor sweepings) from domestic, commercial, and industrial activities. The mixture contains up to 20 percent by weight of restaurant or cafeteria waste, but contains little or no treated papers, plastic, or rubber wastes. This type of waste contains 25 percent moisture and 20 percent incombustible solids and has a heating value of 6500 Btu/pound as fired.
2	Refuse, consisting of an approximately even mixture of rubbish and garbage by weight. This type of waste is common to apartment and residential occupancy consisting of up to 50 percent moisture and 7 percent incombustible solids and has a heating value of 4300 Btu/pound as fired.
3	Garbage (consisting of animal and vegetable wastes) from restaurants, cafeterias, hotels, hospitals, markets, and similar installations. This type of waste contains up to 70 percent moisture, up to 5 percent incombustible solids, and has a heating value of 2500 Btu/pound as fired.
4	Human and animal remains (consisting of carcasses, organs, and solid organic wastes) from hospitals, laboratories, abattoirs, animal pounds, and similar sources; it consists of up to 85 percent moisture and 5 percent incombustible solids and has a heating value of 1000 Btu/pound as fired.
5	Byproduct waste (gaseous, liquid or semi-liquid, such as tar, paints, solvents, sludge, fumes, etc.) from industrial operations. Btu values must be determined by the individual materials to be destroyed.
6	Solid byproduct waste (such as rubber, plastics, wood waste, etc.) from industrial operations. Btu values must be determined by the individual materials to be destroyed.

Source: Ref. 17

Table 3. Classification of Waste Sources

IIA Classification	Building Types
Type 0	Offices, business establishments, classrooms, material storage, maintenance areas, community facilities, firing ranges
Type 1	Commissaries, hospitals, laundry and dry cleaning plants, barracks without mess, fire and police stations
Type 2	Family housing, barracks with mess, dependent schools, stockades
Type 3	Messhalls (including snack bars and cafeterias), clubs, meat cutting plants, bakeries
Type 4	Hospitals, kennels, biological laboratories
Type 5	Water treatment plants, sewage treatment plants, industrial waste treatment plants
Type 6	Power and heat generation plants, refuse incinerators

Source: Ref. 15

preventative maintenance facilities for vehicle and aviation repair). Military dispensaries and hospitals generate highly specialized wastes that are not included as part of the solid waste stream used to support an energy recovery system. This is due to the special handling and disposal practices to prevent the spread of disease.

Industrial support exhibits a wide range of activities including supply, rebuilding and modification, and munitions. Wastes emanating from activities such as fabrication, storage, and shipment of munitions and the overall refitting modification of tactical hardware (airplanes, tanks, ships, etc.) are generally not incuded as part of the refuse stream available for energy recovery. Unusable explosives and explosive-contaminated wastes require specialized handling. Old scrap or surplus materials are disposed of through the installation Property Disposal Office, which determines whether the article is fit for resale or for disposal.

Table 4 describes the overall characteristics of military refuse. Although all functions are not represented by all military service branches, this list is considered representative of the solid waste stream available for energy recovery.

Table 4. Characteristics of Military Refuse

Waste Type	Overall Generation Rate (pounds/capita/day)	Subcategory	Specific Characteristics/Remarks
Family Support*	3.2		Stable rate with fluctuations occuring at Christmas and late April. Annual harmonic accounts for variation. Contains 55 percent paper content compared to 40 percent paper in municipal-type waste. Average heating value is 5000 Btu/pound with an average of 22 percent inerts and 17 percent water.
		Commissaries and Exchanges	Large cardboard composition. Approximate heating value of 7000 Btu/pound and contains 5 percent ash and 5 percent water.
Troop Support*	0.3	Barracks	Lower rate than family housing areas due to less food preparation activity. Large paper fraction and beverage can composition.
	0.5	Berthing Piers	Includes food preparation wastes. Emission rate unreliable. Average heating value (for barracks and berthing piers) is about 6600 Btu/pound and contains 17 percent inerts and 9 percent water.
		Galleys and Messhals	Refuse is available relatively dry because garbage is generally disposed of through base sanitary sewer systems through garbage grinders; grease and meat trimmings are collected separately and sold. Average heating value is 6900 Btu/pound and contains 14 percent inerts and 12 percent water.
		Dispensaries and Hospitals	Highly specialized waste including infectious waste, contaminated dressing, pathological wastes, and drugs. Not included as part of recoverable solid waste stream.
	1.6	Offices and Administrative Facilities	Predominantly paper with average caloric value of 7000 Btu/pound and contains 13 percent inerts and 10 percent water.
		Routine Maintenance Facilities	Includes vehicular and aviation repair and maintenance. Generally contains paper, cardboard, and wood materials. Oils and grease are handled separately; scrap metals and broken parts are taken to the Property Disposal Yard for sale. Available refuse has an average caloric value of 6600 Btu/pound and contains 17 percent inerts and 9 percent water.
Industrial Activities		Supply	Typical warehousing functions generating carboard and wood solid waste. Caloric value of refuse is about 7500 Btu/pound and contains 8 percent inerts and 11 percent water.
		Rebuild and Modification	Many types of shops are represented. Salvageable materials are taken to the Property Disposal Yard. Refuse has an average heating value of 6600 Btu/pound and contains 17 percent inerts and 10 percent water.
		Munitions Production	Mainly off-spec explosives and explosive-contaminated waste requiring special handling. Not considered as part of normal solid waste stream. Paper, wood, and dunnage waste stream has a typical caloric heating value of 6300 Btu/pound and contains 16 percent inerts and 10 percent water.

*Based on a 5-day/week generation rate

Source: Ref. 10

The caloric heating value* of various material types is shown in Figure 1. Because paper is the primary component of the industrial and troop support military waste, the caloric values for these waste streams are, as expected, very similar to the higher heating value of paper. Overall, family and troop support solid waste have a caloric value range between 4200 and 5600 Btu/pound. Industrial waste has a heating value range between 6800 and 7500 Btu/pound.

Note that if the solid waste stream is processed to remove separable inerts (tin cans, bottles, engine blocks, glass, etc.) and dried to an average moisture content of 10 percent, the heating values in Figure 2 result. The increased heating value for refuse-derived fuel (RDF) for family and troop support solid waste can be significantly higher than the unprocessed feedstock. RDF is designated as a solid fuel obtained as a result of a mechanical process or sequence of operations that improve the physical, mechanical, or combustible characteristics of the unprocessed MSW (Ref. 86). Industrial waste is not expected to increase its caloric values significantly, for its contents are primarily dry paper and low garbage content but also may contain a higher content of hazardous pollutants and toxics. Industrial solid waste containing rubber may yield very high heating values. The latter value points out the need to rely on detailed onsite analyses rather than the use of average generation factors and associated heating values.

The previous discussion concentrated on specific properties of the military solid waste. While exhibiting similar qualities to municipal solid waste (MSW), such as family support wastes, there are certain unique qualities of military solid waste due to the very specialized and varied nature of military operations. The following section explores some of these characteristics and evaluates them in terms of their potential for energy recovery.

2.3 Salient Characteristics of the Military Waste Stream and Management Practices

The military installation solid waste stream exhibits several characteristics that are important for the overall consideration of potential energy recovery systems. These characteristics are particularly related to such factors as

(1) Military solid waste management practices

- Installation mission, size, location, etc.

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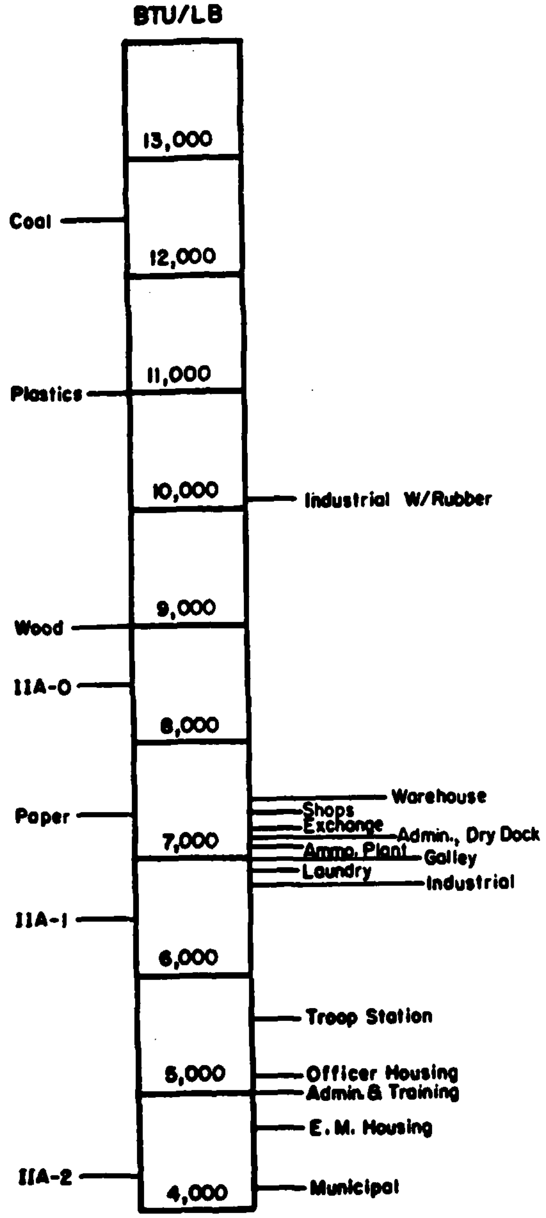
* Based on the energy (high-level Btu) liberated when a mass of solid waste is burned completely and the products of combustion are cooled to the initial temperature of the solid waste, as in a calorimeter. The lower heating value equals the higher heating value minus the latent heat of vaporization of water that is formed by the hydrogen in the solid waste fuel.



IIA-0,1,2: Incineration Institute of America Type 0,1,2 (see Table 3).

Figure 1. Comparison of Higher Heating Values (Btu/pound)

Source: Ref. 10

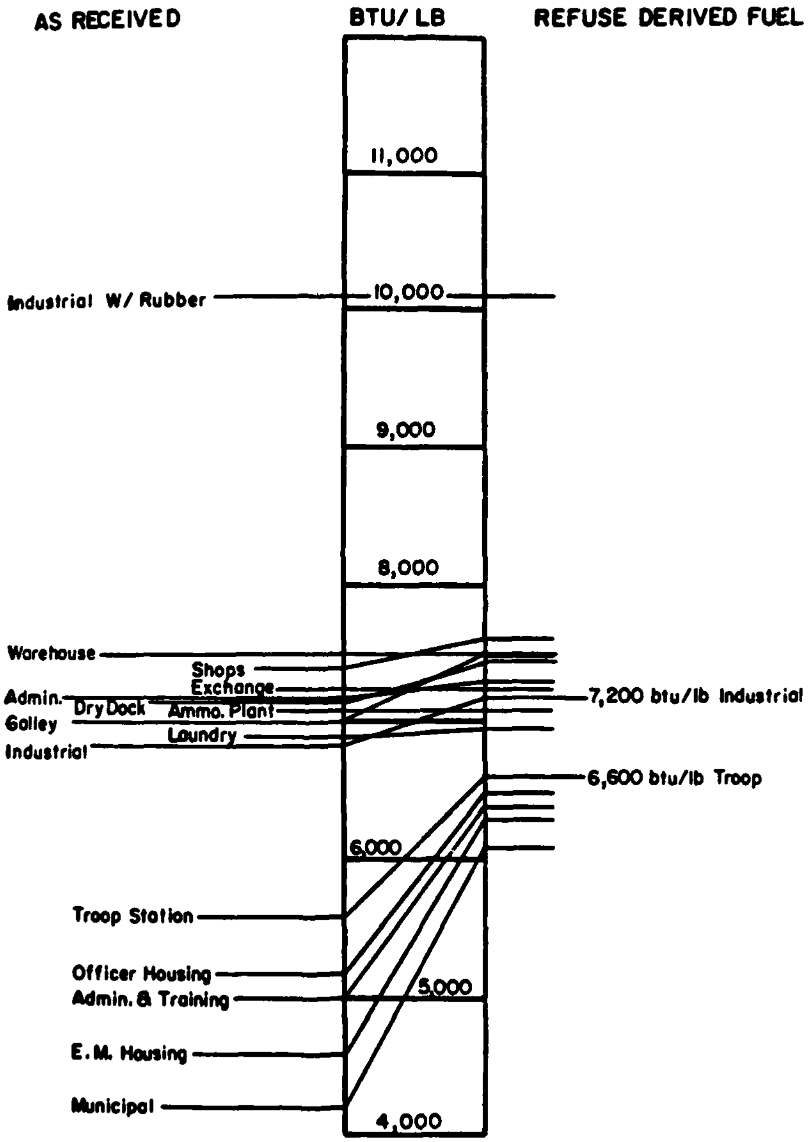


Figure 2. Comparison of As Received and Inert Free Refuse

Source: Ref. 10

- Installation comparisons with municipality
- Military waste characteristics (quantity, composition, quality)

(2) Variability within and among military services

- Quantity and composition

(3) Variability within and among installations

- Includes composition, density, chemical makeup, quality, and size

(4) Temporal variability of military solid waste factors

- Includes secular and random changes

2.3.1 Current Military Solid Waste Management Practices

Military installations can be generally regarded as self-contained enclaves similar in characteristics to small cities and towns with populations ranging from a few hundred to 50,000. Activities are mainly commercial and light industrial in nature. The residential areas of an installation vary in size but compare closely in makeup and configuration to housing developments in civilian communities.

Each installation is responsible for the ultimate disposal of its wastes. Thus, base commanders and their staffs (facilities engineering) are responsible for solid waste management. Certain guidelines and regulations regarding solid waste management have been developed by DOD and each service branch. Some of these requirements are listed in Appendix A. Such directives cover various phases of solid waste management and also reporting procedures.

The typical waste management operation at a military installation is performed by a contractor who collects and disposes of solid wastes. By far, the largest volume of collected solid wastes are disposed of in landfills either onsite or nearby. The Air Force disposes of more than 95 percent of its refuse in landfills (Ref. 18). The Army, likewise, disposes of the vast majority of its refuse in landfills either on or off Army installation locations (Ref. 7).

Scale characteristics are best realized in the mass volume comparison between a military installation and a municipality. Typically, a military installation will generate approximately 35 to 40 tons per day (TPD) of solid waste while a municipal system may be on the level of 600 TPD solid waste. Although there is less to be handled on a military complex compared to a municipality, this advantage is offset by difficulties in applying most available energy recovery technologies. Often, technology systems applicable for municipal systems cannot be easily scaled down to meet the requirements of an installation.

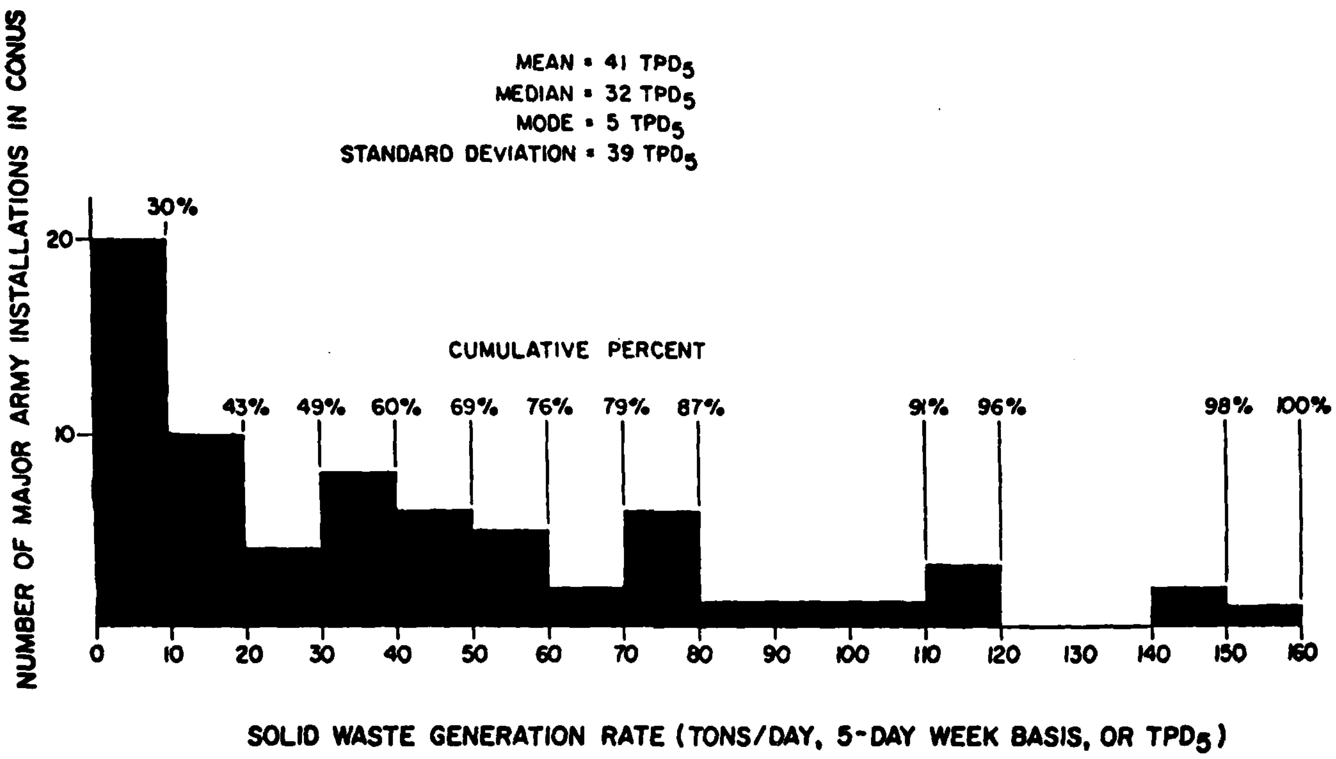
In addition, military installation solid waste is mainly industrial in nature (Refs. 10, 15, 19, 20, and 21) in comparison to the civilian input to energy recovery systems (Refs. 22 and 23). Military solid waste is typically less moist and contains higher caloric value materials than civilian municipal solid waste (Ref. 24). Hence, installation solid waste (on a per unit basis) contains a greater energy content than civilian municipal waste.

Service Branch Waste Characteristics -- Data available on the Army, Navy, and Air Force solid waste streams are insufficient both in terms of understanding the overall military situation and, except for specific cases, individual installations. Although each of the services has attempted to survey its own waste stream, the information collected is often admittedly incomplete and does not serve to accurately describe the military solid waste management system. The great diversity and number of military installations, the variability and budgetary constraints are primary reasons for this lack of adequate solid waste management characterization. However, data that have been gathered do give some indication of the overall military solid waste status and generic characteristics.

For example, in the Army installations of the contiguous United States (CONUS), approximately 15.3 million cubic yards of refuse were collected and disposed of in fiscal year (FY) 1978 (Ref. 7). On a person/year basis, 18.15 cubic yards were generated. Assuming a loose bulk density of approximately 100 pounds/cubic yard, a mass of 765,000 tons/year (or about 5 pounds/person/day) of solid waste were disposed of through Army operations. *Nearly all of this was disposed of in sanitary landfills within the installations'* boundaries.

Figure 3 depicts solid waste generation rate data for major Army Forces Command, Training and Doctrine Command, Development and Readiness Command, Health Services Command, and Communications Command installations in CONUS. Data are in tons per day, assuming a loose bulk density of 100 pounds/cubic yard. Note that, due to high variability, the general density conversion factor is imprecise and is used here only for illustrative purposes. Figure 3 also displays the scale of typical Army installations' solid waste generation rates. Although typical municipal-scale waste-to-energy systems may process waste up to and over 1000 TPD, about 40 TPD is the average output among fully active major Army installations in CONUS.

Economies of scale are thus far different for military installations than for municipal systems in considering the potential implementation of waste-to-energy systems. In addition, research and development of waste-to-energy systems have been geared toward municipal-scale processes. The scaling down of such systems for military installation purposes has therefore encountered many unknown problems, such as equipment selection and the development of small-scale hardware with an operational history of satisfactory performance.



FOR ILLUSTRATION ONLY; COMPUTED FROM CUBIC YARDAGE DATA USING LOOSE BULK DENSITY OF 100 LB./CUBIC YARD.

Figure 3. Scale of Army Installation Solid Waste Generation Rate. The Average Installation Generates About 35 Tons (32 mt) of Mixed Trash and Refuse Daily

Source: Ref. 25

Identification of the composition of the waste stream is one of the primary tasks necessary for accurate feasibility asessment of waste-to-energy systems. Many methods have been developed, such as manually sorting numerous load samples into their major constituents and then weighing each load. Table 5 describes a typical composition from an Army installation. Table 6 further describes the various constituents.

Table 5. Typical Waste Characterization From an Army Installation: Sample 1

Constituent	Percent by Weight	Generation Rate Tons/Year* (MT/Year)
Mixed Waste Stream		
Paper, corrugated board	48	3,245 (2,943)
Wood	14	946 (858)
Miscellaneous (inerts, sweepings, etc.)	10	676 (613)
Textiles	4	270 (245)
Plastics	4	270 (245)
Leather	1.5	102 (93)
Rubber	1.5	102 (93)
Food wastes	12	812 (736)
Yards and grounds waste	2	134 (121)
Metals	3	203 (184)
Total	100	6,760 (6,131)
Homogeneous Waste Stream		
Corrugated board		260 (236)
Mixed office paper stock		142 (129)
ADP cards		304 (276)
Waste motor pool oil		60,120 gal (2,186 m^3)

*Based on 7-day weigh survey

Source: Ref. 25

Examination of the sample military waste constituents reveals a higher fraction of combustibles, such as paper, cardboard, and wood, than typical civilian municipal waste streams (Table 7). However, what is not revealed in these tables is the condition of these materials for energy recovery. The generally poor condition of typical military waste significantly reduces both the energy and material recovery potential (Ref. 25). Conventional waste characterization and recycling guidelines do not adequately address this problem.

Table 6. Description of Waste Constituents in Table 5

Constituent	Description
Mixed Waste Stream	
Paper, corrugated board	Various types, some with fillers, mixed office waste; wet, dirty. Some ADP paper. Packaging.
Wood	Packaging, furniture, doors, desks, window frames, pallets, skids, toys, carpentry scraps, demolition and construction debris, dunnage; painted or stained, nails and bolts present, poor physical condition.
Miscellaneous	Glass (primarily bottles of all colors), inorganic ash, stones, dust and dirt, unidentifiable refuse, plaster, miscellaneous appliances, roofing materials, insulation.
Textiles	Cellulosic, protein, woven synthetics, rags, rugs, bedding materials; soiled and dirty.
Plastics	Film and rigid, polyvinyl chloride, polyethylene, styrene in packaging, housewares, furniture, toys, and nonwoven synthetics.
Leather, rubber	Shoes, tires, toys.
Food waste	Wet garbage, unidentifiable mixture.
Yards and grounds waste	Twigs and green branches, grass and leaves, logs, stumps.
Metals	Cans, wire, cable, foil, pipes, bicycle frames, strollers, eating utensils, carpentry shop waste, bedsprings, rusted sheet, demolition debris, shock absorbers, paint and oil cans, aerosol cans.
Homogeneous Waste Stream	
Corrugated board	Clean packaging from commissary, PX, warehouses, some staples, twine, metal stripping.
Mixed office paper stock	Ledger paper, ADP paper.
ADP cards	Clean, from ADP center.
Motor pool oil	Dirty sludge, contaminated with varnish, chlorinated solvents, miscellaneous degreasing and unidentifiable chemical compounds.

Source: Ref. 25

Table 7. Municipal Solid Waste Composition

Constituent	Percent of Weight
Paper	30
Yard wastes	20
Food wastes	17
Glass	10
Metals (ferrous, 8 1/2 percent; aluminum, 1 percent; other nonferrous, 1/2 percent)	10
Rubber, leather, textiles	5
Plastics	4
Wood	3
Miscellaneous inorganics	1

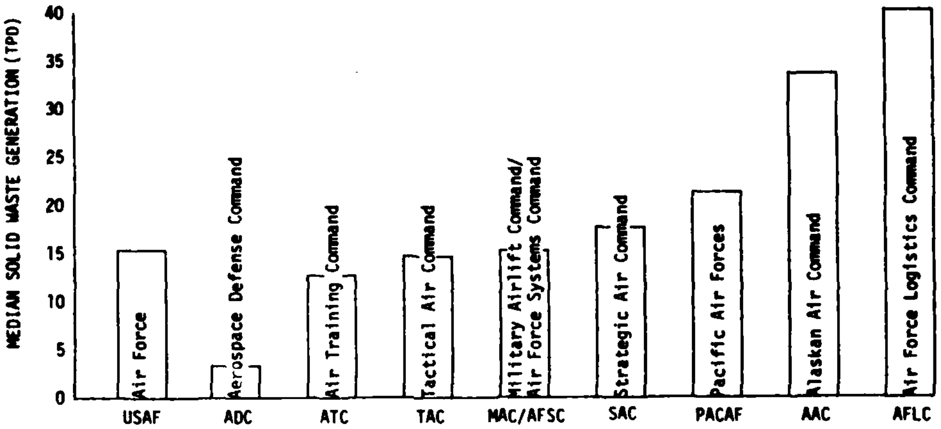
Based on EPA Estimates (1977), reprinted in Resource Recovery Briefs National Center for Resource Recovery, Washington, D.C., June 1979.

Source: Ref. 1

Analysis of waste mass data requires the use of a density factor, because quantities are normally reported in cubic yards. Volumetric waste data are gathered primarily to determine landfill life. However, directly measured weight data are critical in determining the heating value of a waste stream, i.e., in Btu/pound. In the absence of mass data, use of a density factor may lead to erroneous conclusions about the potential of an energy recovery program. Army studies have shown that the loose bulk density of typical military mixed solid waste is highly variable. One survey reported densities ranging from 57 to 372 pounds/cubic yard with an average density of 147 pounds/cubic yard (standard deviation of 70 pounds/cubic yard) (Ref. 21).

An Air Force survey (Ref. 6) of 160 installations further illustrates the rate generation fluctuations among military sites. The range was from 0.04 TPD (radar site) to 91.6 TPD (Hickam Air Force Base, Honolulu). The average rate for the survey was 17.8 TPD. Over 97 percent of the installations surveyed generated less than 50 TPD each. The annual generation total was about 500,000 tons for 107 nonradar sites. The total daily quantity amounted to 1901.5 tons. Of the installations reporting that they generated residential waste, 92.9 percent indicated a rate of 14.9 tons or less per day. The average among the 105 installations reporting was 5.7 TPD.

Figure 4 compares the daily generation rate quantities among various Air Force commands. The range of generation both within and among commands is extensive and requires that caution be applied in using average generation rates of commands to specific installations. It was suggested that the median generation rate be used for generic description purposes (Ref. 6).



	USAF	ADC	ATC	TAC	MAC/AFSC	SAC	PACAF	AAC	AFLC
Number of Bases	107	5	14	17	22	27	3	2	7
Average (TPD)	17.8	19.5	12.6	15.0	17.5	18.2	38.7	34.0	36.8
Range (TPD)	1.0- 91.6	1.4- 48.2	1.8- 30.5	6.2- 20.9	2.5- 57.0	8.8- 27.1	3.8- 91.6	15.5- 52.4	3.0- 40.0
Median (TPD)	15.7	3.3	12.2	15.7	15.8	18.1	20.8	34.0	40.0

Source: Ref. 6

Figure 4. Comparison of USAF-Command Waste Generation

Comparisons of Air Force and other per capita generation rate samples are presented in Table 8. The Air Force rate is higher than national and regional areas, except for California, for combined residential, commercial, and industrial solid wastes. Two possible explanations that have been forwarded are as follows (Ref. 6):

- Military activities tend to have more industrial activities (e.g., aircraft maintenance) that would produce heavier refuse.

- Military installations also collect a higher portion of their solid waste generation than do civilian communities. In civilian systems, wastes do not always reach disposal sites due to on-location incineration, burying, indiscriminate dumping, highway littering, inadequate collection services, collection rates, and selective source separation for recycling (Ref. 28).

Table 8. Per Capita Generation Rates--USAF, National, and Regional (Residential, Commercial, and Institutional Rates)

Source	Year	Pounds/Capita/Day	Reference
USAF	1975-1976	4.7	6
National (US EPA)	1975	3.2	26
California	1975	4.7	27
Ohio	1974	3.1	28
Denver, Colorado	1975	4.0	29

Source: Ref. 6

Navy solid wastes exhibit similar characteristics to Army and Air Force waste streams. About 77 percent of the total Navy solid waste is generated at bases that dispose of less than 75 TPD each (Ref. 30). A 1972 survey reported that 167 landfill sites were used by the Navy to dispose of waste from 147 shore facilites (Ref. 11). The survey also revealed that most of the sites were only marginally in compliance with Navy mandatory guidelines. In addition, the Navy's solid waste stream is about 70 to 90 percent (by volume) combustible (Ref. 31). This characteristic is significant for the Navy, because it uses steam networks in about 50 percent of its shore facilities to distribute heat energy (Ref. 32).

2.3.2 Variability Within and Among Military Services

In FY 1978, 850 military installations were located in the 50 states (Ref. 33). Of the total, DOD considers 376 (or 44 percent) to be major active military installations.* The Navy had 168 (45 percent**) of the installations, followed by the Air Force with 115 (31 percent), and the Army with 84 (22 percent). Nine (2 percent) DOD agencies round out the total.

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* Definition of major active military installations is subject to certain ambiguities, such as classification by personnel size, strategic operation, or strategic location.

** Includes 16 Marine Corps installations.

A comparative assessment of the total and per capita solid waste quantities generated by the military services was performed in 1972 (Ref. 34). Values were estimated based on the reported volumes of containers emptied (Table 9). The average reported density was 152 pounds/cubic yard, which would total 5.85 million tons of solid waste (Quantity A). Rigo (Ref. 10) asserts that the average solid waste density (based on reported container volumes) is only 82 pounds/cubic yard. Using this density, the 1972 estimated total quantity of DOD solid waste was 3.17 million tons.

Based on a 3.17-million-ton solid waste quantity, the estimated pounds per capita per day values are calculated using the reported 1972 population figures. Values for each of the military services show a wide variation. Differences could be attributed to the incompatibility of volume reports and populations, or there may be real differences in the solid waste generation rates of the services or combinations thereof. Table 9 indicates solid waste generation differences between military services; information was developed from selected installations. Although these differences may exist, they could also be attributed both to methods in measuring the volume of waste generated and the selection of installations.

Table 10 data also indicate that a small percentage of the larger installations generate most of the solid waste. Extrapolation to major CONUS active installations reveals that at least 25 percent of each service's waste is generated by 7 percent of the installations that have the largest population (Ref. 2). At least 50 percent of each service's waste is generated by 17 percent of the installations having the largest population. In other words, DOD management can focus on the energy recovery potential of over 50 percent of the U.S. territory military waste by examining only 17 percent of the installations.

2.3.3 Variability Within and Among Installations

Variability within an installation's solid waste classification exists among several characteristics. Factors that greatly influence this variability include installation, mission, activity readiness level, geographic location, climate, and local habits (Ref. 25). Waste characteristics in which variability are most prevalent and have the most significance for energy recovery are waste generation rates and composition.

Studies have indicated that an Army depot may generate up to 10 TPD of rubber waste, with approximately the same quantities of paper, cardboard, and wood (Ref. 19), and another Army installation with a total solid waste generation rate three times greater may not necessarily generate as much of those constituents (Ref. 20). Hence, a military site with a substantially smaller generation rate may have a greater potential for energy recovery than an installation with a higher generation rate (Ref. 25). This characteristic is due simply to the different makeup of the waste stream.

Critical variables in determining energy recovery potential, besides the daily generation rate, are waste composition factors such as density, chemi-

Table 9. Comparative Summary of 1972 Military Solid Waste Quantities[1]

	Army	Navy	Air Force	Total
Volume of Containers Emptied, 10^6 cubic yards/year	22	28	27	77
Reported Density, pounds/cubic yard	136	178	137	152
Estimated Quantity (A), 10^6 tons/year	1.5	2.5	1.85	5.85
Estimated Quantity (B), (at 82 pounds/cubic yard), 10^6 tons/year[2]	0.91	1.51	1.11	3.17
Population, millions				
Civilian	0.40	0.34	0.28	1.02
Military	1.12	0.59	0.72	2.43
Subtotal (P1)	1.52	0.93	1.00	3.45
Reported (P2)*	1.44	1.40	0.90	3.74
Estimated pounds/capita/day				
Quantity A/Population P1	5.4	14.7	10.1	9.3
Quantity A/Population P2	5.7	9.8	11.3	8.6
Quantity B/Population P1	3.3	6.8	6.1	5.0
Quantity B/Population P2	3.5	4.5	6.8	4.6
EPA 1971 Municipal Solid Waste[3]				3.3

*Note: Reported population (P2) is defined as resident population plus one-third nonresident population for the Army and Air Force; Navy P2 consists of resident and nonresident populations minus personnel living aboard ships.

Sources:
1. Ref. 34
2. Ref. 10
3. Ref. 35

Table 10. Solid Waste Generation at Selected and CONUS Military Installations

	ARMY[1]					NAVY[2]					AIR FORCE[3]				
	Tons Per Inst. Per Cal. Day	No. of Inst.	Cum. % of Inst.	Total Tons Per Cal. Day Each Class	Cum. % of Total Daily Wts.	Tons Per Inst. Per Cal. Day	No. of Inst.	Cum. % of Inst.	Total Tons Per Cal. Day Each Class	Cum. % of Total Daily Wts.	Tons Per Inst. Per Cal Day	No. of Inst.	Cum. % of Inst.	Total Tons Per Cal. Day Each Class	Cum.% of Total Daily Wts.
	0-6	56	43	157	6	0-10	48	41	240	8	0-10	12	48	60	15
	6-11	16	55	134	11	10-20	16	55	240	17	10-20	8	80	120	43
	11-22	22	72	370	26	20-30	19	71	475	33	20-30	3	92	75	62
	22-34	17	85	476	46	30-40	7	78	245	41	30-40	0	92	0	62
	34-45	5	89	196	53	40-50	9	85	405	55	40-50	0	92	0	62
	45-56	3	91	151	59	50-60	5	90	275	65	50-60	0	92	0	62
	56-67	5	95	308	72	60-70	4	93	260	77	60-70	0	92	0	62
	67-78	2	96	146	78	70-80	2	95	150	79	70-80	1	96	75	80
	78-89	1	97	84	81	80-90	3	97	255	88	80-90	1	100	85	100
	89-101	2	99	179	88	90-100	1	98	95	91					
	101-112	1	99	106	92	100-120	0	98	0	91					
	112-256	1	100	184	100	120-130	1	99	125	95					
						130-140	1	100	135	100					
Totals		131		2491			116		2900			25		415	
Mean	19					25					17				
Median	9					16					11				
SELECTED INSTALLATION DATA EXTRAPOLATED TO CONUS MAJOR ACTIVE INSTALLATIONS[4]															
	0-21	90	71		25	0-25	112	63		25	0-14	93	61		25
	21-40	21	87		50	25-46	35	83		50	14-24	36	84		50
	40-72	10	95		75	46-68	18	93		75	24-77	16	95		75
	72-256	6	100		100	68-140	12	100		100	77-90	8	100		100
Total CONUS		127					177					153			

Note: For those installations without measured weight data, waste volume was converted to weight using the factor 82 pounds per cubic yard (Ref. 10)

Sources: 1. Ref. 36
2. Ref. 10
3. Ref. 18
4. Ref. 2

cal makeup (as measured by heating value and proximate, ultimate, and mineral analyses), waste component condition, and size distribution. Examples of chemical variability in Army solid waste are shown in Tables 11, 12, and 13.

Comparisons between municipal solid waste and military waste also illustrate significant differences. Table 14 shows relative commercial-industrial waste to residential waste ratios for various waste streams. These

Table 11. Chemical Variability of Installation Waste Is Reflected in Range of Values for Proximate Analysis

	Solid Waste (%)	Absolute Variation (%)
Moisture	16.69 - 31.33	14.64
Ash	9.43 - 26.83	17.40
Volatile	25.75 - 38.90	13.15
Fixed Carbon	0.61 - 14.64	14.03
As-Fired Heating Value	3900 - 5505 Btu/lb	1605 Btu/lb

Source: Ref. 25

Table 12. Chemical Variability of Installation Waste Is Reflected in Range of Values for Ultimate Analysis

	Solid Waste (%)	Absolute Variation (%)
Moisture	16.69 - 31.33	14.64
Carbon	23.45 - 33.47	10.02
Hydrogen	3.38 - 4.72	1.34
Nitrogen	0.19 - 0.37	0.18
Chlorides	0.13 - 0.32	0.19
Sulfur	0.19 - 0.33	0.14
Ash	9.43 - 26.83	17.40
Oxygen	15.37 - 31.90	16.53

Source: Ref. 25

Table 13. Chemical Variability of Installation Waste Is Reflected in Range of Values for Mineral Analysis

	Solid Waste (%)	Absolute Variation (%)
Phosphorus pentoxide	1.02 - 4.69	3.67
Silica	48.93 - 60.07	11.14
Ferric oxide	3.50 - 5.92	2.42
Alumina	5.02 - 13.72	8.70
Titania	0.74 - 1.60	0.86
Lime	7.54 - 18.19	10.64
Magnesia	1.14 - 1.91	0.77
Sulfur trioxide	1.84 - 12.54	10.70
Potassium oxide	1.57 - 2.70	1.13
Sodium oxide	3.62 - 5.95	2.33
Undetermined	0.08 - 0.69	0.61

Source: Ref. 24

Table 14. Commercial-Industrial Waste to Residential Waste Ratios

Waste Stream	Commercial-Industrial to Residential Ratio
MSW	20/80
Air Force	66/34
Navy	90/10
Total DOD	80/20

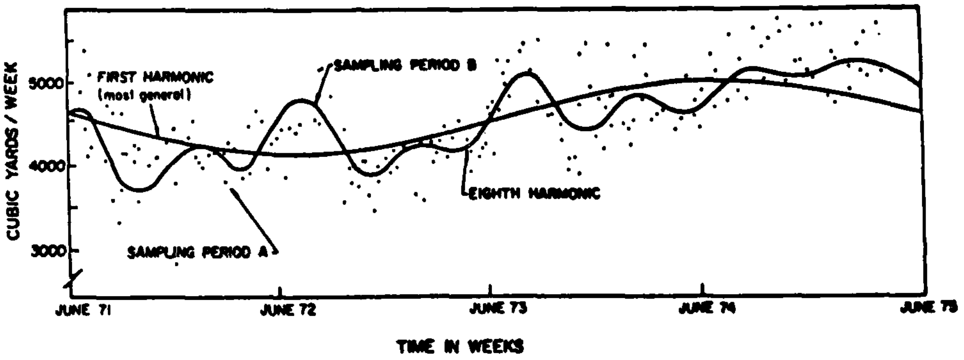
Source: Ref. 2

ratios, however, show wide variations in generation rates between various types of installation facilities even within the same service. For example, the average total pounds per 1000 square feet per day for a Naval office building is about 7.3; for a storehouse, 23.7; and for a commissary, 63 (Ref. 10). An important energy recovery component, paper, also exhibits variation in installation solid waste; its percentage by weight can vary from 27 percent for clubs to 85 percent for commissaries (Ref. 15).

2.3.4 Temporal Variability of Military Solid Waste Factors

Military solid waste factors are dynamic because of secular and random changes in product composition and demand, installation activity level changes, and seasonal climatic changes. Difficulties are often encountered when these temporal variations are not accounted for in the energy recovery feasibility analysis.

Figure 5 shows weekly cubic yardage data for four calendar years at an Army military installation in CONUS. Statistical analyses revealed both random and nonrandom components in the time series analysis. Nonrandom components were annual and seasonal periodicities. Random components were evident in the generation rate. The analysis demonstrated that data gathered at Period A on Figure 5 would have resulted in dramatically different conclusions about the generation rate than a survey at Period B.



Source: Ref. 37

Figure 5. Time-Variability of Installation Solid Waste Generation Rate. A Resource Recovery Facility Sized on the Basis of Data From Sampling Period A Would be Different From One Sized According to Data From Period B

Another analysis performed at an Army depot focused on wet garbage and incombustibles, cardboard, and wood waste (Figure 6). Based on this study, a survey made in weeks 31 to 33 will lead to far different conclusions about the energy recovery potential than a survey performed during weeks 23 to 25.

The dynamic nature of military solid waste characteristics is also illustrated in Tables 15 and 16. Data for both tables were recorded at the same installation using the same methods, but taken 90 days apart. Each set of data represents 1 day during which at least 10 randomly selected truckloads were sorted and weighed by constituent. The total generation

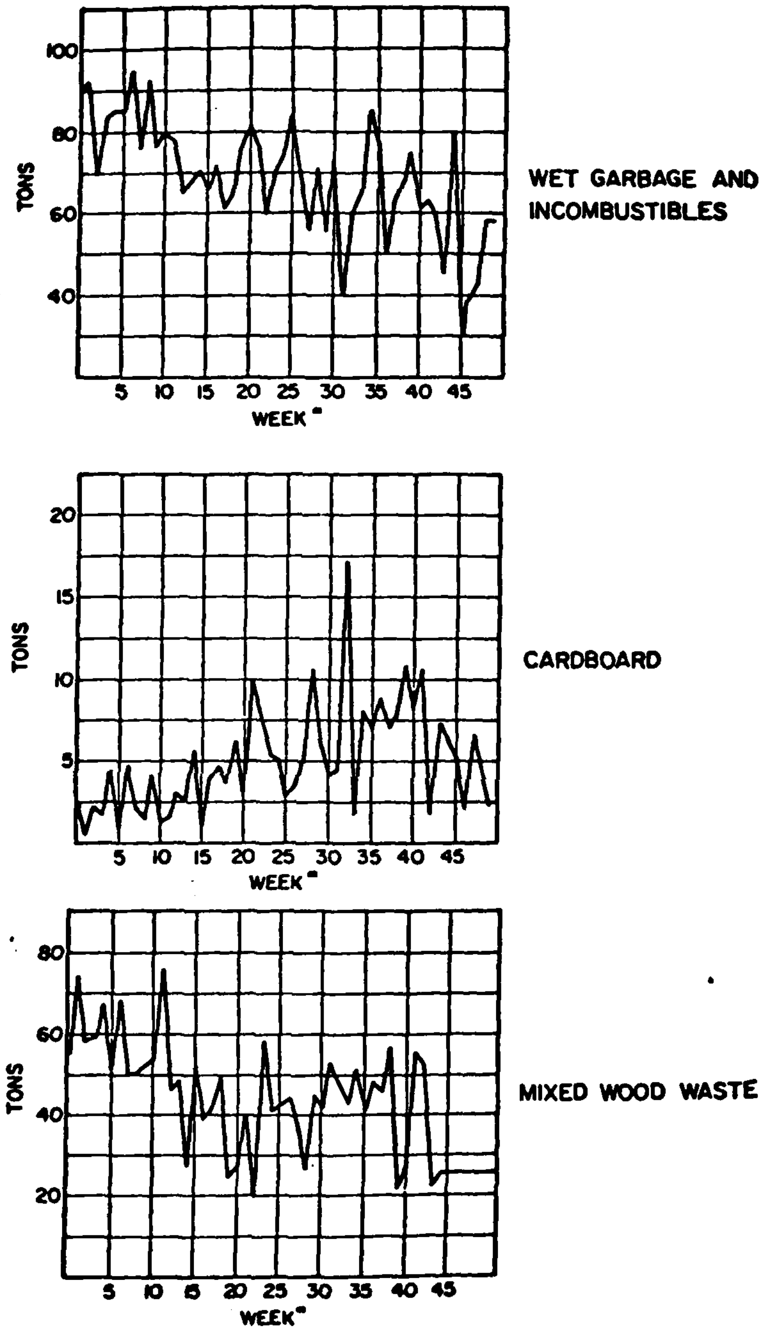


Figure 6. Time-Variability of Solid Waste Composition at an Army Installation. A Waste Survey During Week 15 Would Yield Different Conclusions About Resource Recovery Than Would a Survey in Week 32.

Source: Ref. 25

Table 15. Typical Waste Characterization From an Army Installation: Sample 1

Constituent	Percent by Weight	Generation Rate Tons/Year* (MT/Year)
Mixed Waste Stream		
Paper, corrugated board	48	3,245 (2,943)
Wood	14	946 (858)
Miscellaneous (inerts, sweepings, etc.)	10	676 (613)
Textiles	4	270 (245)
Plastics	4	270 (245)
Leather	1.5	102 (93)
Rubber	1.5	102 (93)
Food wastes	12	812 (736)
Yards and grounds waste	2	134 (121)
Metals	3	203 (184)
Total	100	6,760 (6,131)
Homogeneous Waste Stream		
Corrugated board		260 (236)
Mixed office paper stock		142 (129)
ADP cards		304 (276)
Waste motor pool oil		60,120 gal (2,186 m^3)

*Based on 7-day weigh survey

Source: Ref. 25

rate in Sample 2 (Table 16) is 46 percent greater than for Sample 1 (Table 15) (Ref. 25). Hence, depending on the sample selected, the generation rate could be 26 TPD (5-day average) (TPD_5) or 38 TPD_5. There are no comprehensive, practical procedures for the facilities engineer to use in developing a reliable waste inventory (Refs. 38, 39, and 40). Large-scale recovery technologies may not be proven for small-scale applications. Indeed, caution should be applied in comparing one installation with another because intangibles, such as mission, location, climate, and other factors, can all influence waste generation, collection, processing, and disposal practices.

Table 16. Typical Waste Characterization From an Army Installation: Sample 2

Constituent	Percent by Weight	Generation Rate Tons/Year* (MT/Year)
<u>Mixed Waste Stream</u>		
Paper, corrugated board	49	4841 (4391)
Wood	5	494 (448)
Miscellaneous (inerts, sweepings, etc.)	8	790 (717)
Textiles	2	198 (179)
Plastics	2	198 (179)
Leather	-	- -
Rubber	-	- -
Food wastes	20	1976 (1792)
Yards and grounds waste	12	1186 (1076)
Metals	2	197 (179)
Total	100	9880 (8961)
<u>Homogeneous Waste Stream</u>		
(No change from Table 15)		

*Based on 7-day weigh survey

Source: Ref. 25

2.4 Impact of Variability and Current Practices on Design of Military Waste-to-Energy Systems

Concept design selection of an energy recovery system is based on essential characteristics of the installation waste. The military waste characteristics that are critical for the selection of energy recovery systems are largely determined by onsite sampling and laboratory analysis. Currently, sample characteristics often fluctuate with time and greatly influence the selection of energy recovery systems. Variations in waste characteristics were described previously and presented in Tables 15 and 16. Table 17 lists some of the properties determined from two samples obtained at different times from the same military installation. Based on this information and that contained in Tables 15 and 16, different preliminary design concepts could be developed. Table 17 presents the results based on the two samples.

Sample 1 had a generation rate that was less than that of the Sample 2 generation rate (26 TPD_5 versus 38 TPD_5) generation rate. In addition, the Sample 1 lower heating value of 6592 Btu/pound produced a daily quantity of 342.8 MBtu of waste energy. The Sample 2 lower heating value of 5783 Btu/pound was over 12 percent less than that of Sample 1; however, because Sample 2 had a greater generation rate, it actually produced a 28 percent higher daily quantity of waste energy than that of Sample 1 (439.5 MBtu versus 342.8 MBtu).

Table 17. Computation of Fuel Properties of Wastes From Tables 15 and 16

Constituent	Percent by Weight	Moisture Content, Percent	Volatile Matter, Percent	Fixed Carbon, Percent	Ash, Percent	Lower Heating Value, Btu/lb (kJ/kg)	
Table 15 Data							
Paper, corrugated	48	4.93	71.77	9.29	14.01	6,200	(14,421)
Wood	14	12.00	67.00	18.00	3.00	8,300	(19,305)
Miscellaneous	10	25.00	54.00	1.00	20.00	6,000	(13,955)
Textiles	4	10.00	80.00	7.00	3.00	8,000	(18,607)
Plastics	4	1.00	95.00	2.50	1.50	14,600	(33,958)
Leather	1.5	4.31	62.08	8.12	25.45	9,071	(21,098)
Rubber	1.5	2.00	83.00	-	15.00	11,300	(26,283)
Food wastes	12	58.52	36.71	2.68	2.09	4,709	(10,953)
Yards and grounds waste	2	56.50	33.42	8.20	1.88	3,779	(8,790)
Metals	3	2.00	1.50	1.50	95.00	120	(279)
Composite	100.0	15.29	63.53	8.11	13.07	6,592	(15,332)
Table 16 Data							
Paper, corrugated	49	4.93	71.77	9.29	14.01	6,200	(14,421)
Wood	5	12.00	67.00	18.00	3.00	8,300	(19,305)
Miscellaneous	8	25.00	54.00	1.00	20.00	6,000	(13,955)
Textiles	2	10.00	80.00	7.00	3.00	8,000	(18,607)
Plastics	2	1.00	95.00	2.50	1.50	14,600	(33,958)
Leather	-	4.31	62.08	8.12	25.45	9,071	(21,098)
Rubber	-	2.00	83.00	-	15.00	11,300	(26,283)
Food wastes	20	58.52	36.71	2.68	2.98	4,709	(10,953)
Yards and grounds waste	12	56.60	33.42	8.20	1.88	3,779	(8,790)
Metals	2	2.00	1.50	1.50	95.00	120	(279)
Composite	100.0	23.76	57.72	7.27	11.25	5,783	(13,451)

Source: Ref. 25

Table 18 shows the variation range of some chemical constituents in the waste stream of the installation sampled. Determination of an accurate, representative sample will also determine the system hardware requirements. Table 19 describes the appropriate design concept based on each sample's characteristic along with associated capital costs.

Table 18. Variability of Chemical Composition of Military Installation Solid Waste

Constituent	Mass Percent
<u>Proximate Analysis</u>	
Moisture	14.70 - 32.50
Ash	9.25 - 30.63
Volatiles	25.04 - 64.55
Fixed carbon	0.59 - 14.90
Lower heating value	3900 - 6970 Btu/lb (9071 - 16,211 kJ/kg)
<u>Ultimate Analysis</u>	
Moisture	12.72 - 32.50
Carbon	22.40 - 34.04
Hydrogen	3.70 - 4.86
Nitrogen	0.20 - 0.40
Chloride	0.11 - 0.46
Sulfur	0.18 - 0.51
Ash	9.25 - 30.63
Oxygen	14.68 - 33.10
<u>Mineral Analyses</u>	
Silica	47.60 - 61.28
Alumina	5.10 - 12.44
Titania	0.80 - 1.45
Magnesia	1.02 - 1.60
Lime	6.29 - 19.00
Phosphorus pentoxide	0.95 - 5.20
Ferric oxide	3.44 - 4.87
Sulfur trioxide	1.75 - 14.66
Potassium oxide	1.50 - 3.01
Sodium oxide	4.44 - 6.30
Undetermined	0.05 - 0.80

Source: Ref. 25

Table 19. Concept Design Selection of Waste-to-Energy Systems Based on Sampling Characteristics of Wastes

Sample	Waste Generation Rate (TPD$_5$)	Heating Value (Btu/lb)	Daily Quantity of Waste Energy (MBtu)	Design Concept Supported	Capital Required Rate (1977 dollars)
1	26	6592	342.8	One package incinerator/ heat-recovery boiler system operating 3 shifts/day, 5 days/week (also low-horsepower shredder for bulky combustibles)	$1.4 million
2	38	5783	439.5	Two package incinerator/heat-recovery boilers	$2.2 million

Source: Reference 25.

The described analysis typifies the initial problem of determining feasibility of an appropriate waste-to-energy system. The development of reliable waste characterization and management survey methodologies is essential in determining proper waste system design. Critical factors, such as time variability of solid waste characteristics, must be determined accurately for initial project development purposes and subsequent design stages.

2.5 Potential Solid Waste Quantities

The exact quantity of military and municipal solid waste generated in the United States is unknown. Therefore, estimates were made for each waste stream based on (1) a rate of solid waste generation that is expressed in terms of pounds per person per day and (2) national and military populations as estimated by the United States Census Bureau and DOD, respectively. Table 20 presents military personnel and their dependents by service. Table 21 lists estimated solid waste quantities for the military and the Nation as a whole. The military solid waste volume is about 1 percent of the national total. Although the military solid waste volume may be small in relationship to the national solid waste volume, regional and individual DOD installations may exhibit characteristics that would make energy recovery from such installations highly feasible.

2.5.1 Regional Solid Waste Management and Military Activities

On January 15, 1976, notice was published in the Federal Register (41 FR 2359) proposing regulations as required by the Resource Recovery Act of 1970 (Public Law 91-512). Section 209 of the Act required the Administrator of the U.S. Environmental Protection Agency (EPA) to "recommend to appropriate agencies and publish in the Federal Register guidelines for solid waste recovery, collection, separation, and disposal systems . . . ." In addition, Section 211 mandated that Federal agencies having jurisdiction over solid waste disposal activities "shall insure compliance with the guidelines recommended under Section 209 and the purposes of (the Solid Waste Disposal Act) . . . ."

Table 20. Estimated Active Duty Military and Civilian Strengths and Their Dependents (CONUS, Alaska, and Hawaii)*

Type of Personnel	Army	Navy	Marine Corps	Air Force	Total
Total Active Duty Military	473,644	254,114	147,979	435,775	1,311,512
Total Civilian					849,679
Total Dependents	1,021,429	546,938	152,077	756,346	2,477,007

*DOD "strength" is generally considered to be the sum of active duty military personnel and civilian personnel as of March 31, 1979.

Source: Ref. 41

Table 21. Estimated Overall Solid Waste Quantities

Community	Population	Estimated Solid Waste (tons/year)
National	213.5×10^6*	172.8×10^6**
Military	2.3×10^6+	1×10^6++

* As of 1975, U.S. Bureau of the Census, Current Population Reports.

**J.G. Gordon, "Assessment to the Impact of Resource Recovery on the Environment," The Mitre Corporation, Metrek Division, MTR-8033, prepared for the Environmental Protection Agency, Municipal Environmental Research Laboratory, December 1978.

+ For the military community, it is arbitarily estimated that 60 percent of the active military and civilian personnel and 40 percent of their dependents live on DOD installations.

++Based on an average of 3.3 pounds per person per day (Ref 42).

The proposed guidelines published by EPA on January 15, 1976 (41 FR 2359), were intended to provide requirements and recommended procedures for the establishment and use (by Federal agencies) of facilities to recover resources from residential, commercial, and institutional solid waste, and to recommend the establishment and use of such facilities to state, interstate, regional, and local governments. Use of resource recovery facilities result in conservation of resources and in a reduction in the amount of solid waste that requires disposal.

These requirements and recommended procedures were applicable to any Federal facility that generated, collected, or disposed of 100 tons or more per day (equivalent to 26,000 tons or more annually) of residential, commercial, and institutional solid waste and shall establish or utilize resource recovery facilities to separate and recover materials or energy or both from such solid waste. Additionally,

> If any one Federal facility within a Standard Metropolitan Statistical Area (SMSA) generated 50 tons or more of residential, commercial, and institutional solid waste per day (equivalent to 13,000 tons or more annually), and if the combined total of this solid waste for all Federal facilities within the SMSA is 100 tons or more per day (equivalent to 26,000 tons or more annually), all Federal facilities within that SMSA shall establish or utilize one or more resource recovery facilities to separate and recover materials or energy or both from this solid waste. The agency that generates the largest quantity of residential, commercial, and institutional solid waste in the SMSA shall be designated the lead agency in the resource recovery facility planning process. The lead agency shall be responsible for planning, organizing, and managing the joint resource recovery activities of the agencies in the SMSA, and shall report the compliance decision of the agencies in the SMSA in accordance with subparagraph 245.100 (f) or (g), as appropriate, in a consolidated report. All other agencies in the SMSA shall assist in planning such resource recovery activities (Ref. 12).

Pursuant to these regulations, DOD service branches tried to determine how many regional or independent resource recovery systems were likely to be under DOD jurisdiction. In subsequent work, DOD studied the possible kinds of systems available to comply with the proposed resource recovery provisions.

As an example of DOD efforts, the approach employed by the Navy to carry out this study proceeded in six major stages (Ref. 12):

1. A review of all the Standard Metropolitan Statistical Areas was undertaken to determine which SMSAs contained Navy installations.

2. When the SMSAs with Navy installations were determined, a list was compiled of all DOD installations in the same SMSAs.

3. Solid waste emissions were estimated for all large DOD intallations in the SMSA. Estimates were based on past surveys or historical emissions by population or total cubic yards of solid waste generated.

4. On the basis of these solid waste emission estimates, lead agency status was determined for those selected SMSAs that met EPA's requirements. Collection and transport of the solid waste to central locations within the region was assessed.

5. The energy potential of the solid waste generated in the selected SMSAs was determined.

6. Energy consumption (boiler heat loads) in the selected SMSAs was evaluated to identify installations in which refuse-derived fuel could be used.

Table 22 gives the waste generation rates by region for DOD installations within those regions. The regions are those with major Navy installations, where the waste generation rates reach or come close to the levels specified in the EPA guidelines. TPD is based on 260 days/year (5 days a week). The table lists eight regions in which the Navy is the largest generator of solid waste (of the three services). Three regions are listed in which the Army or Air Force is the largest generator of waste or, in the case of Washington, where the largest waste generator was not determined. Four other regions are listed in which the estimates of waste generation rates are close enough to the levels specified by EPA that more accurate measurements or increases in waste generation might place them within the guideline limits. The Navy is the largest waste generator in these four regions.

The waste generation rates for the regions are very uncertain. More reliable estimates will soon be available from surveys at the major installations. However, it appears likely that at least 7 regions with major Navy installations fall within the waste generation rates specified in the EPA guidelines, and possibly as many as 15.

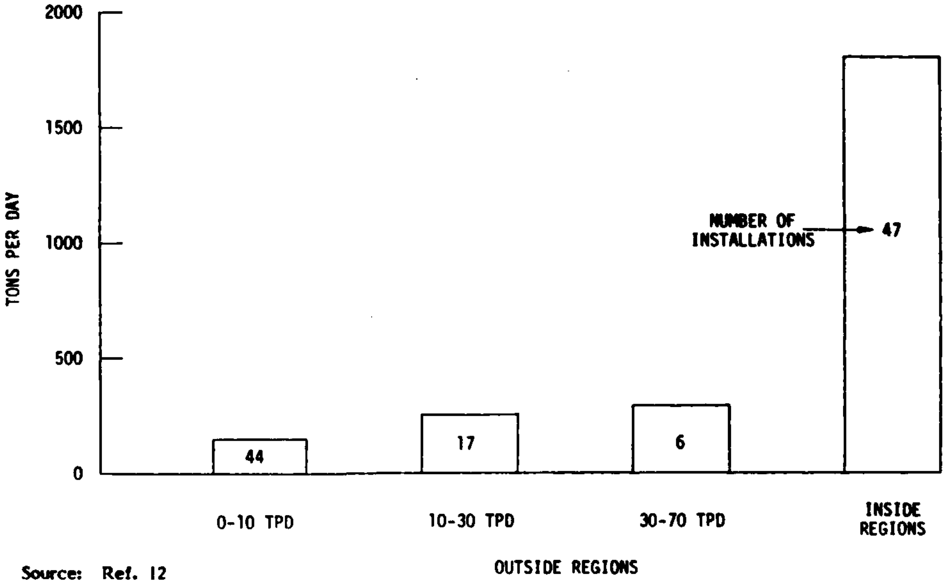
The total daily waste generation by Navy installations within the 11 regions identified in Table 22 as falling within the guidelines is shown in Figure 7. The figure also shows the total daily waste generation by the other Navy installations outside those regions by the size ranges of daily waste generation rates (for example, there are 17 installations outside those regions that generate 10 to 30 TPD for a total of 260 TPD). Approximately 75 percent of the Navy solid waste is generated by installations within the areas where regional systems would be required by the EPA guidelines. Only 10 percent of the Navy solid waste is generated by installations outside those regions will be in areas where municipal regional solid waste systems may be established and may be able to turn over their waste to the municipal systems.

Table 22. DOD Waste Generation Rates by Regions

	Tons Per Day (TPD)[5]	
	Navy	Total (DOD)
<u>Navy Lead</u>		
San Francisco	163.4	237.8
Los Angeles	81.8	90.5
San Diego	605.1	605.1
Honolulu	125.4	172.0
Chicago	89.6	102.4
Philadelphia	138.7	226.6
Norfolk	135.0	215.0
Camp Lejeune	210.0	210.0
<u>Other Lead</u>		
Riverside (AF)	37.2	113.1
Baltimore (Army)	30.3	126.3
Washington* (Undetermined)	217.4	589.3
TOTAL	1833.9	2688.1
<u>Possible Requirement for Resource Recovery Facilities (Navy Lead)</u>		
Charleston	60.0	85.0
Bremerton	70.0	70.0
Jacksonville	90.0	90.0
Pensacola	55.0	55.0

*Incomplete

Source: Ref. 12



Source: Ref. 12

Figure 7. Distribution of Solid Waste Generation Rates by Navy Installations

The number of Navy installations indicated in Figure 7 is much less than the number of activities identified on the map of "Major Army, Navy, and Air Force Installations in the United States." The installations referred to in Figure 7 generally include several activities on a single base. Table 23 gives estimates of the waste generation rates for the DOD installations in the regions identified in Table 22.

Presently, EPA has not issued any guidelines with regard to the further implementation of Section 209 of the Resource Conservation and Recovery Act. Reports have been issued to EPA by DOD for those SMSAs in which DOD activities constituted the largest generator of solid waste. Regional management of solid waste could prove to be an appropriate scale on which to implement resource recovery options and would also involve DOD installations as primary participants in regional waste-to-energy systems.

Table 23. Solid Waste Quantification by Regions

	Region	Waste Generation TPD$_5$	Heating Value* MBtu/day
San Francisco Bay	A	237.8	2378
Los Angeles Metropolitan	B	90.5	1528
San Diego	C	605.1	6051
Riverside	D	113.1	1131
Honolulu	E	172.0	1720
Chicago	F	102.4	1024
Philadelphia	G	226.6	2266
Baltimore	H	126.3	1263
Washington, D.C.	I	589.3	5893
Norfolk	J	213.7	2137
North Carolina	K	209.4	2094
Jacksonville		90.4	904
TOTAL		2776.6	28,389

*Assuming 5000 Btu/pound solid waste

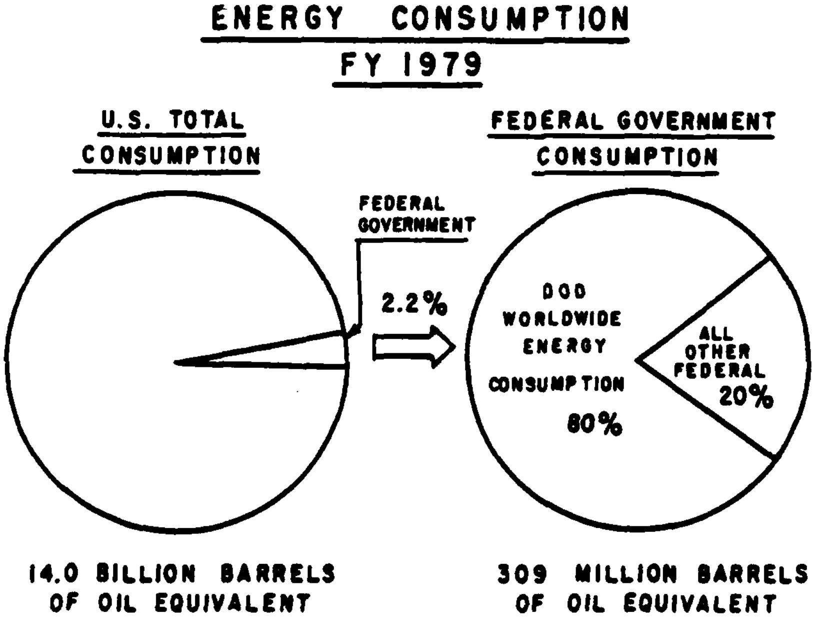
Source: Ref. 12

3.0 MILITARY ENERGY REQUIREMENTS

3.1 Overall DOD Supply and Demand Requirements

The shortfalls of DOD energy supplies are the most serious and pervasive threat to long-term national security. The deterrence of armed conflict, production of modern weapons systems, and maintenance of the overall readiness of the U.S. military are all keyed to uninterrupted and diversified energy supplies.

DOD is the Government's largest energy consumer (Refs. 43 and 44). It used about 247 million barrels of oil equivalent (MBOE), or approximately 80 percent of the Federal Government's consumption requirements for direct use in FY 1979 (Figure 8) (Ref. 41). This total is about 2 percent of the total U.S. national consumption. Therefore, DOD is vitally concerned with the increasing reliance on foreign oil imports to meet domestic demands. The threat of foreign oil import disruptions and the severe national security problems associated with such action demand that measures be taken to decrease the Nation's (and DOD's) vulnerability to any action taken by a foreign country to interrupt U.S. oil imports. Hence, the long-term impact of dwindling natural petroleum supply is extremely important to DOD.



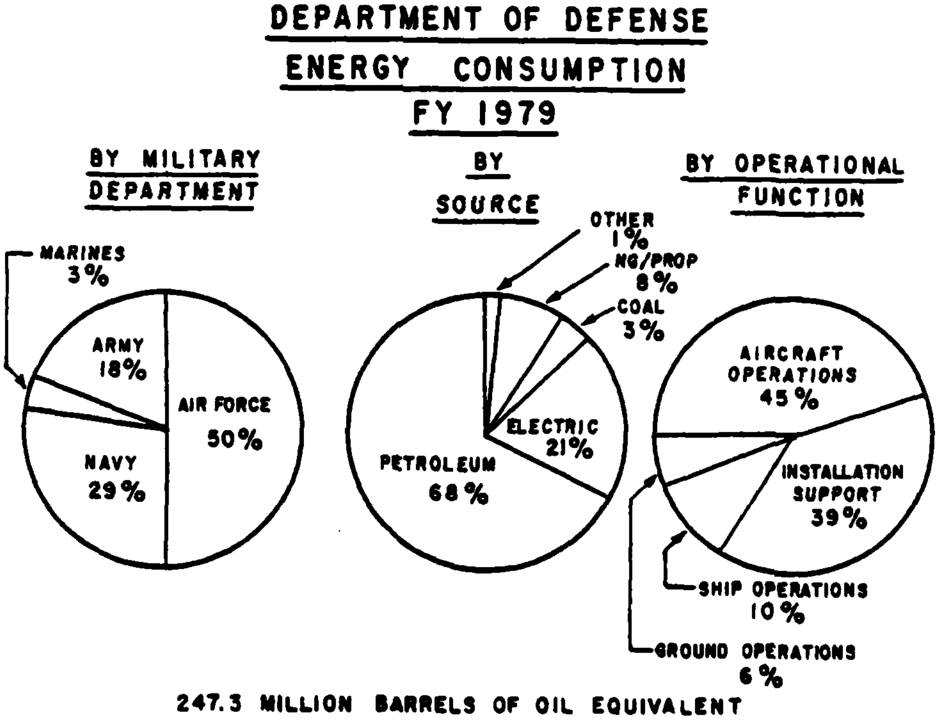
Source: Ref. 41

Figure 8. Energy Consumption FY 1979

The costs of energy consumption and the reliance on petroleum best describe the military energy predicament. Petroleum accounts for about 70 percent of defense energy consumption (Figure 9). However, although there has been a decrease in consumption patterns, the costs of energy have continued to escalate (Figure 10). In FY 1978, DOD consumed about 247 MBOE at a cost of over $4 billion (Ref. 41). Petroleum products accounted for 170 million barrels.

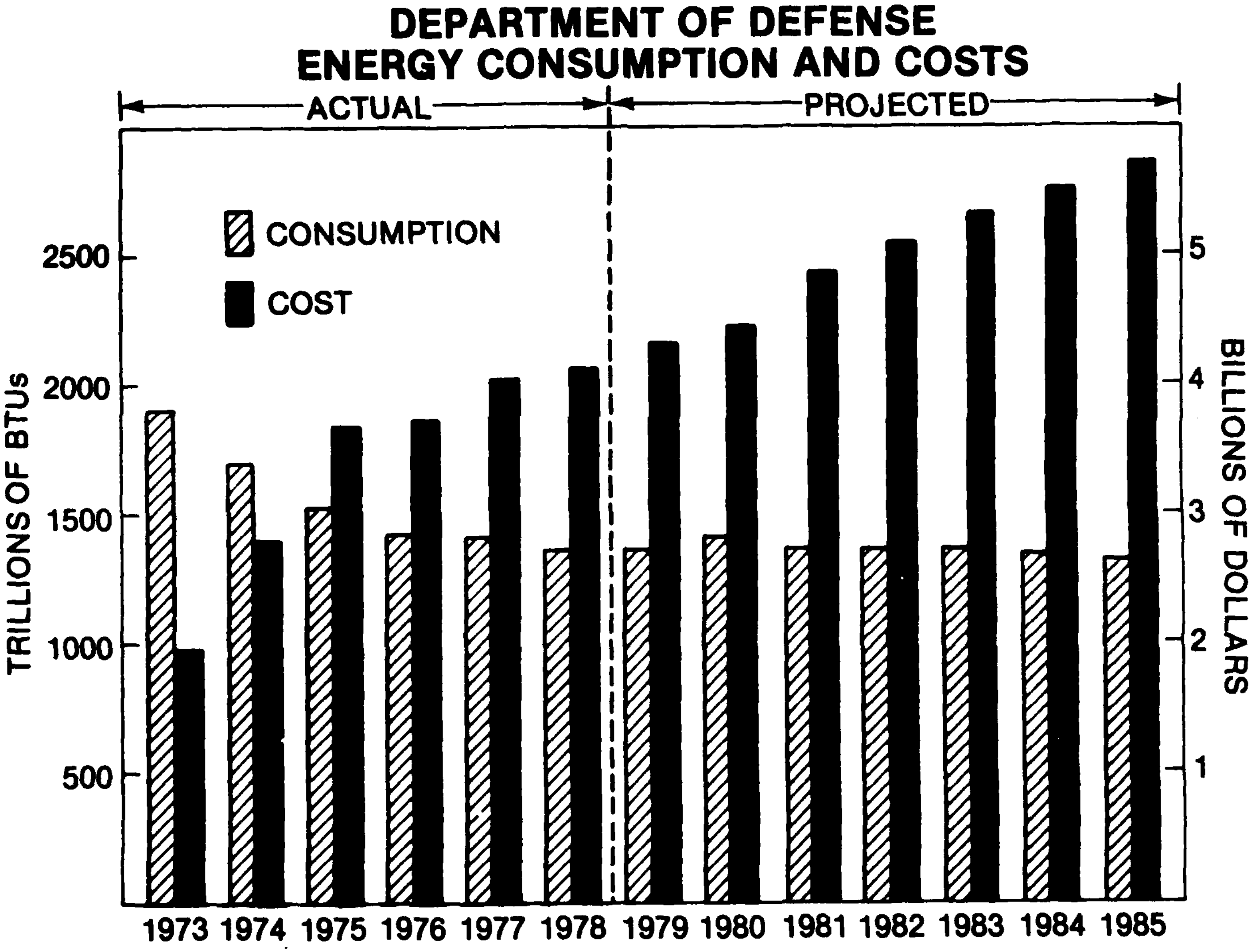
Table 24 quantifies costs and consumption, in barrels of oil equivalent, for the major service and defense activities. FY 1975 was used as a baseline year to assist in program management review of changes in consumption. The percent change of energy consumption from FY 1975 is tabulated for DOD-wide operations. Figure 11 shows a breakdown of petroleum allocation by service for FY 1976.

The Air Force is the largest single user of petroleum within DOD. More than 50 percent of the energy purchased by DOD, the equivalent of 125 million barrels of oil a year, is used by the Air Force (Ref. 45), and more than 55 percent of DOD petroleum purchases are for the Air Force.



Source: Ref. 41

Figure 9. DOD Energy Demand (Excluding Nuclear)



Source: Ref. 41

Figure 10. Department of Defense Energy Consumption and Costs

Table 24. DOD Energy Consumption and Costs

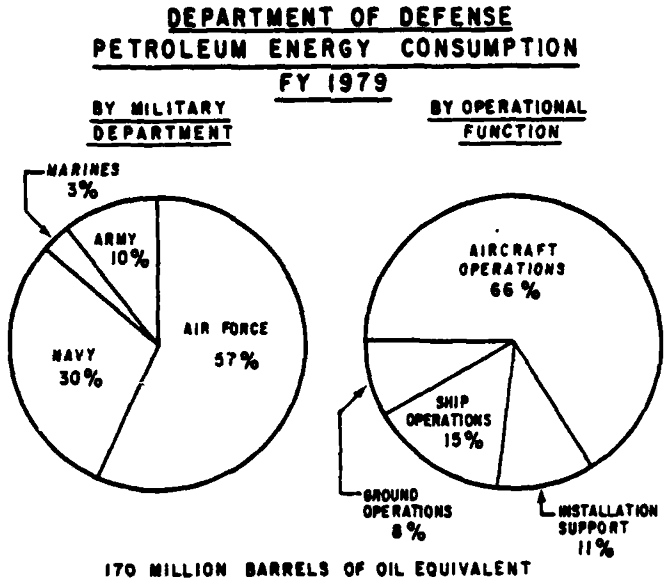
	FY 1975		FY 1978		FY 1985	
$-Millions	Mobility	Facility	Mobility	Facility	Mobility	Facility
Army						
BOE* (x10^6)	7.7	38.4	7.2	35.5	6.9	28.3
$-Millions	106.6	438.4	158.7	622.9	165.6	805.7
Navy						
BOE* (x10^6)	53.05	27.13	44.99	26.6	41.5	22.58
$-Millions	807.1	324.4	821.9	416.4	888.6	409.3
Marine Corps						
BOE* (x10^6)	4.05	3.87	3.91	4.0	3.9	3.82
$-Millions	51.6	46.2	71.4	62.6	83.5	69.2
Air Force						
BOE* (x10^6)	100.6	34.1	90.8	34.4	91.5	28.0
$-Millions	1508.0	414.5	1770.0	510.0	2239.0	487.7
DLA						
BOE* (x10^6)	0.031	0.576	0.025	0.573	0.031	0.467
$-Millions	0.483	4.052	0.554	7.742	0.761	10.671
Total						
BOE* (x10^6)	165.431	104.076	146.925	101.073	143.831	83.167
$-Millions	2483.783	1227.552	2822.554	1619.642	3377.461	1782.571
% Change						
(From FY 1975)			-11.2	-2.9	-13.1	-20.1

*BOE: Barrels of oil equivalent x 10^6 (BOE = 5.6 x 10^6 BTU)

Source: Ref. 41

Most of this energy is in the form of fuel for Air Force aircraft operations. The Air Force consumes about 91 percent of the 95 million barrels of petroleum purchased in a year as aviation fuel. Of the remainder, about 7 percent is used for heating and other installation support and 2 percent is for automobile, truck, and other vehicle fuel.

As an example of DOD energy conservation efforts, the Air Force reduced fuel consumption by 35 percent in a 5-year period (Ref. 45). This was accomplished through many conservation measures, but it was mainly from reducing flight hours from 4.9 million hours/year before the 1973 oil embargo, to 3.2 million hours/year in 1978.



Source: Ref. 41

Figure 11. DOD Petroleum Demand, FY 1979

However during that period, fuel costs increased more than 120 percent, in spite of the fuel consumption reduction (Ref. 45). Cost comparisons are quite alarming for jet fuel: in 1973 it was 11 cents/gallon and in 1979 it was 44 cents/gallon. There are indications that the cost will be about 55 cents/gallon in 1980 (Ref. 45).

Hence, for the Air Force as well as the Army and Navy, an intensive research and development effort is underway to find new methods of reducing energy consumption and providing additional energy supplies. Research programs intended to meet both needs include using waste-heat recovery systems, burning alternative fuels, using waste lubricants and contaminated fuel, and using refuse-derived energy.

3.2 DOD Energy Planning and Management: Its Implications for Energy Recovery

The military energy problem is essentially a microcosm of the national energy situation. In DOD's Energy Management Plan (Ref. 41), the overall thrust of dealing with the energy problems was described in the following paragraphs:

> United States national security objectives can be achieved only if we are thoroughly prepared to meet essential military energy requirements. The continuation of our ability to deter armed conflict, to produce modern weapon systems, to maintain the readiness of our military forces, and to support worldwide commitments on the seas, in the air, and on the ground, depends on energy, most importantly liquid hydrocarbon fuels.

Assured supplies of energy, particularly mobility fuels, is essential to ensure our national defense. This is true whether we are at peace, in a time of crisis, or at war. To meet this goal has become more difficult as our energy supplies becomes less subject to our control and more vulnerable to disruption. Our military capabilities in any event and in any given part of the world totally depend on the mobility of our weapons and support systems. As a result, we are increasingly concerned that our reliance on liquid hydrocarbon fuels, for now and in the foreseeable future, is based on the availability of natural crude oil. The challenge of the Defense energy management program in the near and mid term is to assure adequate fuels through supply and conservation initiatives. For the longer term, we need to avail ourselves of more secure, plentiful energy resources through technological advances.

To meet energy management and conservation goals, DOD has developed three distinct but interrelated areas in its energy management program. These are as follows:

- Energy supply to ensure DOD energy requirements to support mobility operations and installations.
- Energy conservation to reduce energy consumption in mobility fuels and utility energy sources that support installations, and
- Energy technology applications to better utilize depletable energy resources and demonstrate the feasibility of new energy technologies.

Each area has its own set of goals and programs designed to meet them. Appendix C lists the goals and objectives for energy supply and conservation for DOD installations.

These DOD energy planning and management actions are designed to meet military readiness requirements of responding to emergencies under any condition of energy supply. In accomplishing this broad objective, the DOD energy management program covers a wide variety of energy supply, conservation, and technology efforts. Hopefully, these priority item areas will

- Provide for essential fuel supply during national emergencies and in times of fuel shortages,
- Broaden the range of fuels that military equipment can use,
- Promote energy self-sufficiency on military installations, and
- Reduce fuel consumption and utility costs.

3.3 Installation Energy Needs

DOD energy use can be categorized in three classes:

- For direct mission activities, aircraft, ship, and ground operations;
- For fixed-base operations; and
- By industrial suppliers to DOD.

The first two classes are considered direct energy usage in that DOD purchases the fuel or energy needed for these activities, and the last is considered indirect because the fuel/energy used is purchased by the supplier. This report is primarily concerned only with the second of these classes, i.e., energy use for fixed-base operations. However, applications for waste-derived energy to the other two classes will be discussed where appropriate.

Decisions to implement waste-to-energy systems will be made at the installation level. Faced with DOD energy management directives, each facility command must investigate every feasible option available to use base energy more efficiently.

Because DOD is the largest energy consumer in the Federal Government, DOD's energy management activities at individual installations will reduce the Federal Government's energy consumption and demonstrate a clear committment to better energy management and conservation.

Normal peacetime energy products of permanent military installations include electricity generated both onsite and from a utility; thermal waste heat recovered from electric generation for hot water, space heating, air conditioning, and other purposes; and steam energy systems.

The steam output holds primary significance in military installation energy systems, such as in a supplemental fuel boiler or a direct-fired boiler. Of all the resources available from refuse, steam energy is probably the most valuable resource that can be obtained (Ref. 46). Steam is useful if nearby users are available, as in the case of an installation (Ref. 47). Steam can be used for such purposes as heating, cooling, equipment testing, and electric power generation.

Military installation complexes will typically have several major heating and industrial boiler plants per installation providing saturated steam for heating, cooling, and processes. These plants are designed to accept coal, natural gas, fuel oil, and other fuels. The nature of a military installation's mission is such that individual activities are highly vulnerable to unpredictable temporary or permanent shutdowns. With no guaranteed long-term steam user on the installation, an energy recovery system at any location on the facility could be a high-risk venture (Ref. 21).

Feasibility studies for waste-to-energy systems should therefore focus on the more reliable continuous steam demand areas at an installation. For example, at the Naval Weapons Support Center (Crane, Indiana), the plant supplying steam to administrative functions was determined to be the site where waste-derived fuel could be used (Ref. 21). On a larger scale, the Naval Shipyard Complex within the Charleston, South Carolina, SMSA was found to have a sufficient load to be able to accept energy input from solid waste (Ref. 48).

Evaluation of heating plant characteristics should be from three basic standpoints (Ref. 50):

- Potential for adjacent siting of a solid waste thermal processing facility,
- Compatability of the energy demand with the available waste energy, and
- Potential for the existing combustion hardware to fire supplementary waste-derived fuel.

3.4 Potential Energy Recovery Contribution

As described previously, overall DOD-wide solid waste generation data were unavailable. Until more accurate methods are available, present values are based on arbitary per capita values or regional surveys. This section will present solid waste characteristics as on energy resource. It will also provide, as a general estimate, the magnitude of contribution that solid-waste-derived energy could have to military requirements.

Energy recovery from solid waste can offer some favorable energy and cost equivalencies in comparison to fossil-type fuels, such as coal and oil. Table 25 displays the equivalencies that may vary according to the extent of solid waste processing involved, type of coal mined, and other variable factors. Other considerations should also be included in the calculation. For example, use of solid waste as an energy resource by combustion will reduce about 80 to 95 percent of the original volume (Ref. 16). This would significantly lower transfer and hauling costs and reduce the environmental impact of landfilling.

The magnitude of energy recovery from military solid waste is shown in Table 26. Because reliable overall generation estimates were not available, the calculations and values shown can be regarded as a first-order approximation. A more accurate computation would necessitate a comprehensive inventory of all military installations.

Depending on the current price/barrel set by th Organization of Petroleum Exporting Countries, the value of energy derived from DOD solid waste could be worth approximately $44 to $51 million (based on the current price range of $26 to $30/barrel of light crude) (Ref. 52). This total is still a

Table 25. Approximate Energy Equivalencies of Solid Waste

Energy Source*	Heating Value (Btu/lb)
Municipal Solid Waste	4,600
Refuse-Derived Fuel	6,000
Coal	10,000 - 12,000
Oil	18,300 (7.8 lb/gallon)

*One ton of RDF = 1/2 ton of coal
= 2 barrels or 84 gallons of No. 6 oil

If coal costs $55/ton, RDF would be worth $27.50/ton
If oil costs $0.50/gal, RDF would be worth $42/ton

Resource	Unit Cost ($)	Cost per 10^6 Btu ($)
RDF	25/ton	2.08
Coal	55/ton	2.29
Oil	0.50/gallon	3.50

(All of the above is based on one-to-one substitution of fuels. In actual cases, other factors must be considered before any new fuel can be used or its selling price determined.)

Source Ref. 51

Table 26. Potential Availability of Waste-Derived Energy

Solid Waste Category	Estimated Quantity[1] (tons/year)	Energy Equivalent Btu/year[2]	BOE[3]	Quad[4]
National	172.8×10^6	1.7×10^{15}	2.9×10^8	1.7
DOD	1×10^6	1×10^{13}	1.7×10^6	0.01

1. Based on Table 21
2. Assumes 5000 Btu/pound of solid waste
3. BOE = barrels of oil equivalent
   1 barrel crude = 5.8×10^6 Btu
4. Quad = 10^{15} Btu

small fraction of the DOD allocation for petroleum procurement. However, use of waste-derived energy may provide a feasible alternative energy source on a regional and installation level.

Table 27 presents the available energy derived from solid waste for selected regions in which DOD is a significant Federal waste generator. For example, the southern California region generates significant municipal and Federal waste rates to justify energy recovery studies in the past. The four SMSAs include (1) Los Angeles-Long Beach, (2) Anaheim-Santa Ana-Garden Grove, (3) Riverside-San Bernardino-Ontario, and (4) San Diego.

Major DOD facilities in this region are shown in Table 28. DOD installations in the first three SMSAs individually do not reach the 100-TPD rate set forth by EPA as a major Federal facility (Ref. 5), but combined in each SMSA came close to that rate. Major DOD installations in the San Diego SMSA provide a significant waste generation quantity.

Several proposals for energy recovery have already been attempted in the southern California region involving DOD. For example, in Los Angeles County, a preliminary proposal to undertake construction of a 1000-TPD mass burning, water wall combustion unit was suggested. The project would use refuse primarily from the Long Beach and Los Angeles harbor areas as fuel to produce steam. The steam would be marketed to several customers, including the Long Beach Naval Shipyard. The Sanitation Districts of Los Angeles County later suggested that the Shipyard be considered the only user of the refuse-derived energy. However, the steam demand at the Shipyard was insufficient to support a 1000-TPD facility. Further, issues such as the technical feasibility of meeting current air pollution standards with the pro-

Table 27. Potential Availability of Selected DOD Solid-Waste-Derived Energy by Region

Region	Estimated Quantity[1] (tons/year)	Energy Equivalent Btu/year[2]	BOE[3]
San Francisco Bay	61,828	6.2×10^{11}	1.0×10^{5}
Los Angeles Metropolitan	23,530	2.4×10^{11}	4.0×10^{4}
San Diego	157,326	1.6×10^{12}	2.7×10^{5}
Riverside	29,406	2.9×10^{11}	4.9×10^{4}
Honolulu	44,720	4.5×10^{11}	7.5×10^{4}
Chicago	26,624	2.7×10^{11}	4.4×10^{4}
Philadelphia	58,916	5.9×10^{11}	9.8×10^{4}
Baltimore	32,838	3.3×10^{11}	5.5×10^{4}
Washington, D.C.	153,218	1.5×10^{12}	2.6×10^{5}
Norfolk	55,562	5.6×10^{11}	9.3×10^{4}
North Carolina	54,444	5.4×10^{11}	9.1×10^{4}
Charleston	22,100	2.2×10^{11}	3.7×10^{4}
Jacksonville	23,504	2.4×10^{11}	3.9×10^{4}
	744,016	7.5×10^{12}	1.3×10^{6}

1. Based on 5-day average daily generation rate (see Table 23).

2. 1 ton solid waste $\cong 10^{7}$ Btu

3. BOE $\cong 6 \times 10^{6}$ Btu

posed energy conversion system brought about more uncertainties. Market analysis and technical evaluation are currently being studied. In San Diego County, a 1200-TPD refuse-derived fuel-fired steam generating water wall combustion unit was proposed (Ref. 53). The site of the facility was to be on land owned by the city of San Diego surrounded by the Naval Station, San Diego. The Naval Station proposed two alternative sites. The State of California and the Western Division of the Naval Facilities Engineering Command (WESTNAVFAC) participated in a study that concluded that resource recovery was feasible on any of the three sites and that the Naval Station electric demand was also a viable market, technically, for refuse-derived energy (Ref. 53). Other markets for the energy were also reported.

Investigation by WESTNAVFAC defined the dynamic economic and physical condition under which the Naval Station could also be a steam market. The county of San Diego is continuing its planning process to try to accommodate the Navy desire for alternate siting. The Naval Station has begun conditional excessing of its prefered alternate site, which would be conveyed to the city of San Diego in exchange for the originally proposed city-owned site. Many technical, institutional, and marketing questions that pervade resource recovery still remain to be answered.

Table 28. Southern California Region DOD Waste Generation Rates

Standard Metropolitan Statistical Area	DOD Activity	Service	Waste Generation Rate (TPD_5)
Los Angeles-Long Beach, California	Los Alamitos NAS	Navy	1.0
	Los Angeles AFS	Air Force	8.7
	Long Beach Shipyard	Navy	39.7
Anaheim-Santa Ana-Garden Grove, California	Seal Beach Weapons Station	Navy	8.0
	El Toro Marine Corps Air Station	Navy	33.1
	Santa Ana Marine Corps Air Station (Helicopter)	Navy	
Riverside-San Bernardino-Ontario, California	Norton AFB, San Bernardino	Air Force	32.8
	March AFB, Riverside	Air Force	21.5
	George AFB, Victorville	Air Force	21.0
	Twenty-nine Palms MCAS	Navy	25.3
	MC Supply Center, Barstow	Navy	11.9
	Ft. Irwin, Barstow	Army	0.6
San Diego, California	Camp Pendleton MCB/Region Medical Center	Navy	288.5
	Miramar NAS	Navy	38.5
	San Diego NB	Navy	197.9
	North Island NAS	Navy	56.3
	Coronado NAB	Navy	23.9
		Total	808.7

Abbreviations:
NAS - Naval Air Station
AFS - Air Force Station
AFB - Air Force Base
MCAS - Marine Corps Air Station
NAB - Naval Air Base
MCB - Marine Corps Base

Source: Ref. 12

The possibility remains strong that the Naval Station could use refuse-derived energy, conceivably at a cost savings over alternate procurement. However, it is incumbent on San Diego County to establish its intentions toward Navy energy possibilities. Although over 600 TPD of DOD-generated refuse in the metropolitan San Diego area borders on enough to conduct serious independent Federal resource recovery investigation, the current low cost and availability of landfill disposal render this proposal economically impracticable. Additionally, the only possible energy use could be in conflict with local planning, and Federal directives clearly indicate that Federal facilities are not to compete but should participate in local community resource recovery plans.

Table 29 shows the energy potential for solid wastes for a small selection of military installations. As shown in the table, waste-derived energy could make significant contributions to the fuel requirements of an installation's basic energy needs. The fuel consumption figures are for the fuel used on base, and exclude fuel used by the utilities to produce electricity consumed on the base.

Table 29. Solid Waste-Derived Energy From Selected DOD Installations

Base	Population Served	Annual Fuel Consumption Billion Btu (excludes electricity)	Cu. Yd/ Person	Annual Solid Wastes			Solid Waste Energy as a Percent of Fuel Requirement
				Thousands of Cu Yd	Thousands of tons	Billions of Btu	
Ft. Bragg[1] (Fayetteville, North Carolina)	43,723	2,927	16.3	713	35.7	357	12
Ft. Hood[1] (Killeen, Texas)	68,230	1,834	10.5	713	35.7	357	19
Ft. Dix[1] (Trenton, New Jersey)	19,528	1,562	21.4	418	20.9	209	13
Ft. Knox[1] (Louisville, Kentucky)	41,287	2,510	14.5	600	30	300	12
Ft. Ord[1] (Seaside, California)	34,016	10,549	14.0	477	23.9	239	2
Naval Shipyard Complex[2] (Charleston, South Carolina	38,825[3]	1,190[4]	-	-	24.7	298	25
Quantico Marine Base[5] (Fredericksburg, Virginia)	9,781	372[6]	-	-	34.07[7]	192[8]	52
Naval Submarine Base[9] (New London, Connecticut)	15,934	2,084[10]	-	-	32.8[11]	362[12]	17
Travis, AFB[13] (Fairfield, California)	15,860	1,020	14	153	27	214	32
Offutt AFB[13] (Omaha, Nebraska)	13,922	1,262	9	141	25	197	16
Loring AFB[13] (Limestone, Maine)	4,106	1,457	9	101	18	141	10

Notes:

1. Based on Ref. 7.
2. Based on Ref. 48.
3. Includes Naval Station, Naval Supply Center, Submarine Training Center, and Fleet and Mine Warfare Training Center (Ref. 33).
4. Includes only Naval Shipyard Complex Boiler Plants 32, 123, NS2, and 44.
5. Based on Ref. 54.
6. Average base load quantity from central heating plant, based on 3-year average steam production of 33.5 Klb/hr, efficiency of 0.80, and vapor enthalpy of 1,018 Btu/lb.
7. Includes main base and family housing total of 9,984 tons/year plus base forest region (slash) of 24,000 tons/year.
8. Represents lower heating value of composite base waste and 60 percent availability of slash. If the surrounding civilian waste is included, the total energy available is 798,817 MBtu/year.
9. Ref. 55.
10. Based on Central Powerplant steam production (FY 1977) of 1.05 x 10^9 lbs, efficiency of 0.6, and vapor enthalpy of 1,195 Btu/pounds of mass at 150 pound-force per square inch gauge.
11. Includes mixed solid waste from base and surrounding community.
12. Assumes 5,523 Btu/lb of waste.
13. Ref. 56. The cubic yards of waste are converted to tons, assuming 350 lb/cubic yard based on the average of 450 lb/cubic yard for compactor-truck waste and 250 lb/cubic yard for loose waste. The figures for energy content of the waste assume a heating value of 4,000 Btu/lb, which is based on 20 to 30 percent moisture content and 95 to 99 percent burn of the combustible wastes, using fluid-bed technology.

The calculations represent only first-order estimates. Although energy recovery of wastes is technically justified at these installations, other factors might cause such an attempt to become infeasible. For example, the nature of steam production for installation use may require that individual activities be widely separated and that steam must be supplied by relatively small boiler plants located at the centers of the dispersed clusters of buildings. If a base does not have a large-scale central boiler plant continually producing large quantities of steam, there will be no suitable location for an energy recovery plant to feed large quantities of supplementary fuel for steam. In addition, the nature of an installation's mission may be such that individual activities could be highly prone to unpredictable temporary shutdowns. Hence, if there is no guaranteed long-term user on the installation, implementation of any energy recovery system could be a high-risk venture.

Other considerations such as environmental and economic concerns must also be analyzed in the energy recovery proposal. These factors will be discussed in the following section.

4.0 IDENTIFICATION AND DESCRIPTION OF POTENTIAL ENERGY RECOVERY SYSTEMS FROM SOLID WASTE FEEDSTOCK SYSTEMS

This chapter will operate on the assumption that implementation of soundly engineered, practicable waste-to-energy systems could perform reliably and could benefit DOD through fuel savings, reduced waste disposal costs, and greater environmental compatibility in waste disposal operations. It will focus on back-end technologies for energy recovery (Figure 12). Potential advantages and conflicting technical-economic opinions regarding energy recovery from solid waste feedstocks, and in later chapters biomass and hazardous waste feedstocks, will be examined.

The purpose of this chapter is not to present the final decision on whether or not waste-to-energy systems are appropriate for DOD installations. Nor will it determine the optimum recovery system or feedstock to use. Rather, this analysis is only intended to provide guidance to DOD and installation managers on the potential and technical status of current and emerging waste-to-energy technologies that might have application on DOD fixed facilities and installations.

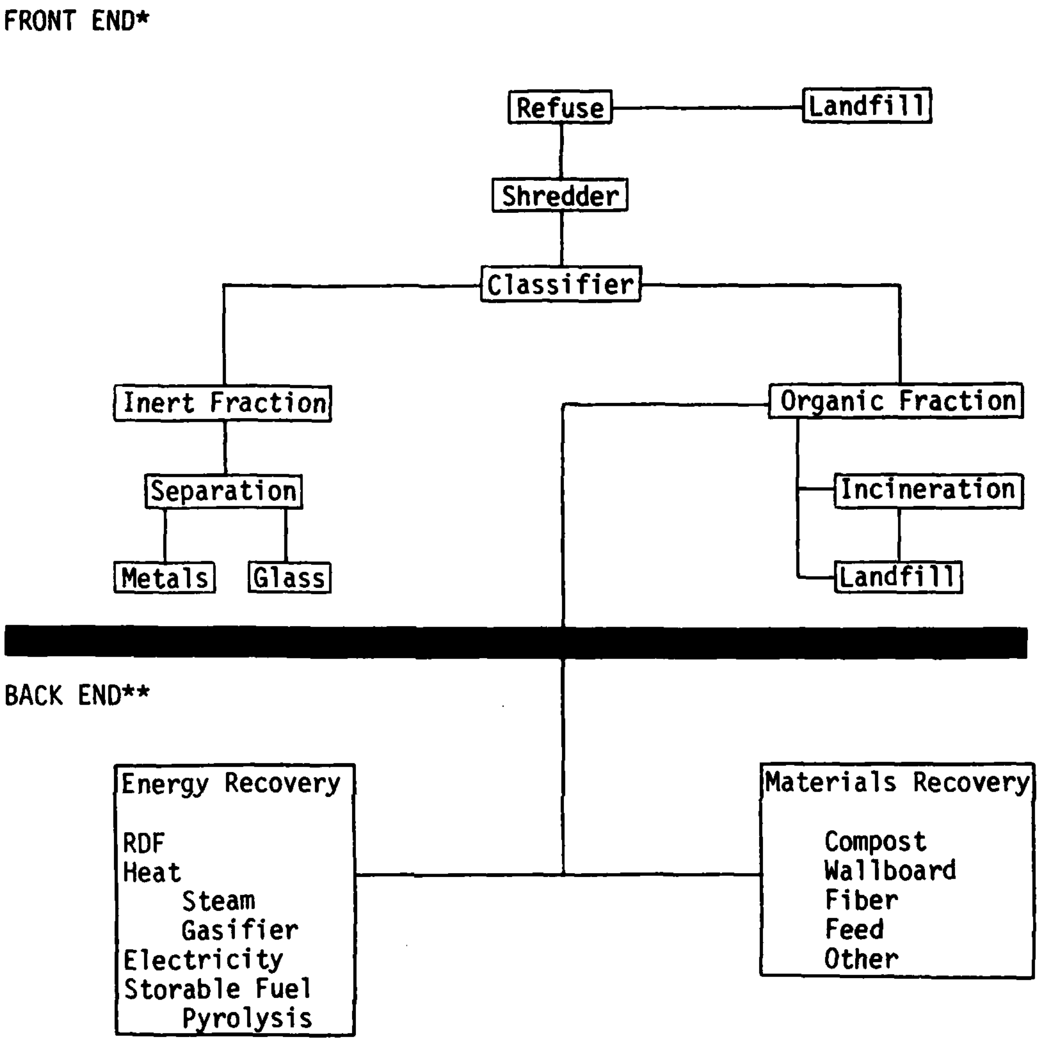
4.1 Scope and State-of-the-Art Review

The military solid waste feedstock stream was described in Chapter 2. Among the notable features for military solid waste was the apparent variability of quantity, spatial, and temporal characteristics. Concept design and equipment selection of energy recovery systems are based on these essential properties of the waste and, thus, are highly dependent on an accurate waste input characterization.

As presented previously, back-end recovery systems are most applicable to large numbers of DOD installations and smaller municipalities. Front-end systems (Figure 12) are associated with high capital and operating costs and depend largely on the sales revenue of recovered materials (Ref. 58, 59, and 60). A back-end system, typically for heat recovery, will fire raw refuse for the production of stream and other end-use products. Figure 13 presents a number of possible waste-to-energy conversion methods. Although some system options are commercially unavailable for installation use within the near term (less than 7 years), systems such as package and site-erected heat-recovery incinerators and supplementary use of solid and pyrolytic gaseous refuse-derived fuel in existing boilers are potentially available now (Ref. 61).

The following conversion process categories will be described and analyzed: combustion, pyrolysis, and bioconversion. Appropriate systems within each category will be described in accordance with military installation application.

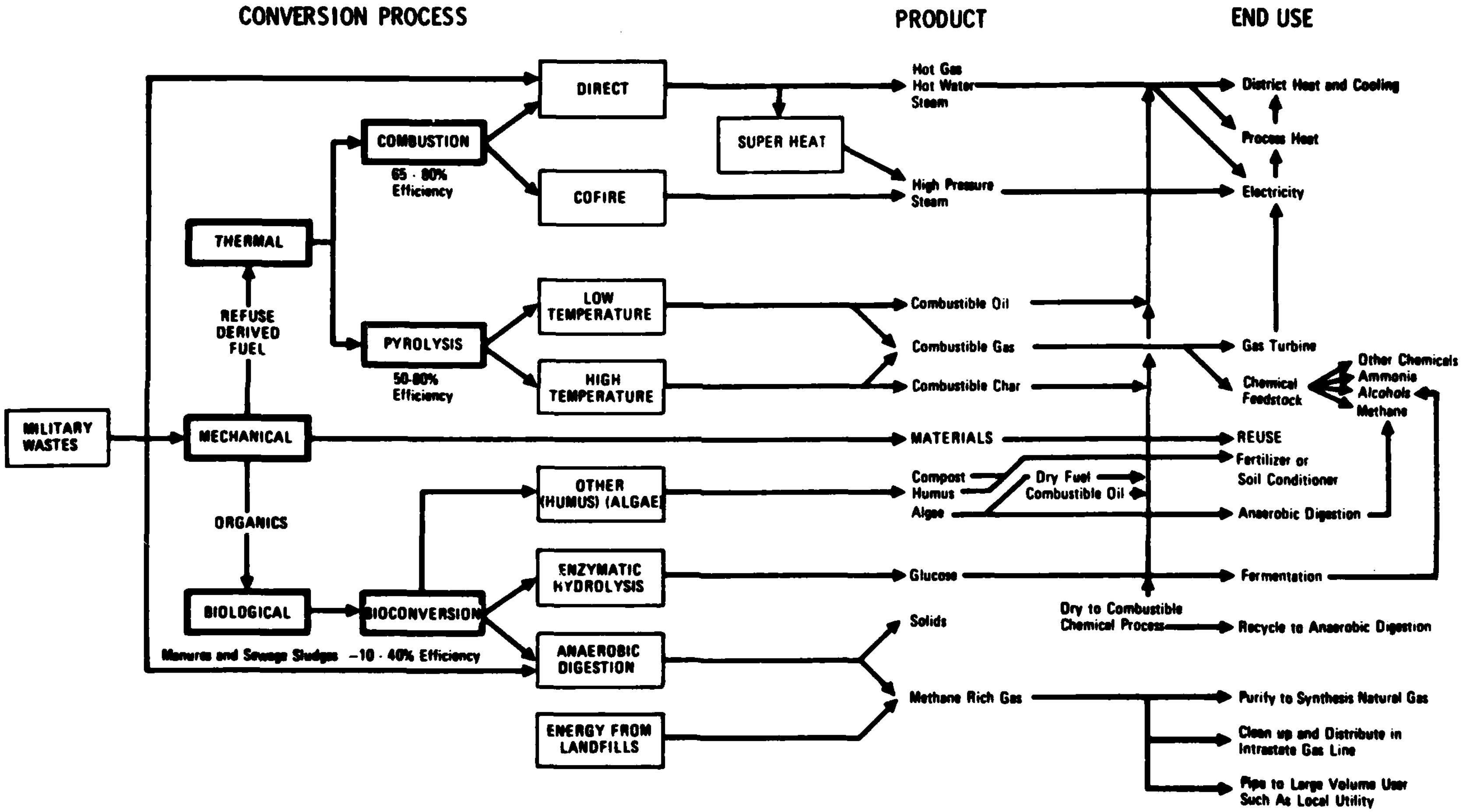
The design of energy recovery systems is more of an art than a science. No comprehensive, practicable procedures exist by which military



*Refers to material recovery.
**Refers to direct utilization or conversion of the organic portion of the waste.

Source: Ref. 57

Figure 12. Resource Recovery Systems



Source: Adapted from U.S. Department of Energy

Figure 13. Military Waste-to-Energy Options

installation managers can develop a reliable waste inventory for energy recovery feasibility assessment. Design of energy recovery systems based on unreliable input characterization is doomed to failure. In addition, developmental large-scale recovery technologies cannot be assumed for small-scale applications. With these potential pitfalls, DOD facilities managers and engineers must keep abreast of the most current information available on waste management and energy recovery.

Information needs include (1) availability status of near-term energy recovery technologies; (2) comparative performance levels of various applicable technologies; (3) potential environmental, health, and safety concerns; (4) economics of systems, and (5) assessment of scale affecting system design.

The technologies described here are further detailed in Appendix B. Energy recovery feasibility requires indepth consideration of local installation and surrounding region conditions, as well as a thorough knowledge of technological capabilities. This chapter will not provide adequate detail to make such local installation decisions but, rather, will assist in making the policy decisions associated with energy recovery programs.

4.2 Availability Status of Energy Recovery Systems for Military Application

Table 30 describes the technical status and availability to military facilities of general energy recovery systems. The difficulty encountered in determining the military applicability was that many of these systems were in the experimental or demonstration mode. Hence, while many were "operational," a significant portion of these were not "commercial" or had no previous application to military installations.

The types of systems represented in Table 30 indicate that a possible shift is underway in producing more commercially available small-scale energy recovery systems. Industrial and institutional interest is also strong and increasing as noted in the small modular combustion units at Blytheville, Arkansas; Groveton, New Hampshire; and Siloam, Arkansas (Ref. 71).

4.3 Comparative Analysis of Various Technologies

The Office of Technology Assessment (OTA) developed three performance measures in comparing systems (Ref. 72): degree of proven commercialization, waste reduction efficiency, and energy recovery efficiency. Note that due to the rapid development of the energy recovery technology area recently, accurate data were difficult to obtain.

Table 31 lists the various system technologies according to the degree of proven commercialization (Ref. 73). The classification is judgmental and is intended only as a general guide to commercialization status. Technology status is for both large- (1000 TPD) and small-scale (25-600 TPD) applications.

Table 30. Status of Energy Recovery Systems

System Type	Conversion Process	Technical Status	Availability to Military Application
Modular (package or "off-shelf") Small-Scale Systems	Direct Combustion		
1. Starved or controlled air incinerator		Commercially available but only about 5 1/2 years experience in energy recovery. Energy recovery efficiencies average 40 to 60 percent. Operation in both municipal and industrial applications with heat recovery. Uncertainties result from the short operational history, for example air pollution (particulate).	Unknown, but looks promising. Requires longer field testing and thorough evaluation.
2. Rotary-Kiln Incinerator		Commercially available over 15 years, but little performance data available. Energy recovery efficiencies average 60 to 75 percent.	Yes, but many uncertainties exist; i.e., reliability, air pollution, costs, etc.
3. Augered-Bed Incinerator		Relatively new development and little data on operating performance. Computed energy efficiency is 65 percent.	Unknown, requires further operational testing.
4. Basket-Grate Incinerator		Commercially available but not a reliable mass burning method. Grate can sometimes be a problem.	No, requires further development.
Field Erected Systems (onsite assembly) 1. Refractory Wall Furnace 2. Water Wall Furnace 3. Slag-Forming Furnace	Direct Combustion	History of successful operations in U.S. and Europe. For example, water wall incinerator with heat recovery has operated at Norfolk, Virginia, since 1967. Adaptable to large-scale utilization. Problems with preprocessing and stoking requirements.	Yes, but many not be applicable to small-scale use.
Refuse-Derived Fuels 1. Types: coarse, fluff and dust, densified 2. RDF combustion systems: package, new field-erected, existing steam generators, fluidized bed combustion	Direct Combustion	Testing by Army at more than a dozen military installations indicates RDF may be economically attractive in relatively small-scale applications (20 to 60 TPD). Further investigation needed on the cofiring of RDF with coal in existing military central steam generators and other combustion systems.	Unknown, but no long-term information available on RDF as a cofiring supplementary fuel.
Pyrolytic Conversion (system may be down or in developmental stage) 1. Andco-Torrax Slagging Process 2. Pyro-Sol Process 3. Purox System 4. Garrett (Occidental) 5. Monsanto-Languard Process	Pyrolysis	Research basically focused on developing pyrolytic conversion systems aimed at producing a gaseous fuel from destructive distillation of organic constitution of solid waste. Problems are encountered where a substantial portion of solid waste fuel value is not recovered and fixed carbon remains in char and undergoes only incomplete combustion, liberating less heat than required to drive distillation process.	Unknown, pyrolysis still in pilot or demonstration phase. Requires evaluation of pyrolysis process with existing facility heating systems.
Anaerobic Digestion 1. Methane From Landfills 2. Controlled Anaerobic Digestion	Bioconversion	Development has been using primarily sewage sludge and landfill systems to produce methane. For methane recovery from landfills, there may not be any suitable military controlled sites with sufficient volume. No adequate demonstration of a controlled anaerobic digestion system other than at sewage treatment plants.	Unknown, probably very little application using solid waste only. However, if solid and liqud waste is used, potential exists for some methane recovery. More analysis required.

Sources: Refs. 17, 24, 25, 61, 62, 63, 64, 65, 66, 67, 68, 69, and 70

Table 31. Development Status of Waste-to-Energy Technologies

System Acquisition Phase	Phase Definition	Energy Recovery Technology
Commercial	These are existing full-scale commercial plants that operate continuously. Consequently, there are some operating data available from communities and engineers already involved in the use of the process. Although such systems are being commercially utilized, they may be technically complex. To operate properly, they will require maximum use of available information leading to careful design and operation by knowledgeable professionals. There may be only limited operating experience with some parts of these plants. Thus, technological uncertainties may still exist.	● Waterwall combustion ● Small-scale modular incineration with heat recovery ● Solid fuel RDF (wet and dry processes)
Developmental	These are technologies that have been proven in pilot operations or in related but different applications (for example, using raw materials other than mixed MSW). There is sufficient experience to predict full-scale system performance, but such performance has been confirmed. System design requires considerable engineering judgment about scale-up parameters and performance projections; consequently, the level of technical and economic uncertainty is generally greater than with commercially operational technologies.	● Low-Btu gas pyrolysis ● Medium-Btu gas pyrolysis ● Liquid pyrolysis ● Biological methane from landfill conversion
Experimental	These include new technologies still being tested in laboratories and pilot plants. Because there is not sufficient information to predict technical or economic feasibility, such technologies should not be considered by cities contemplating immediate construction.	● Biological anaerobic digestion ● Waste-fired gas turbine
Research	These technologies, which are only in the laboratory testing stages with no pilot plant activity underway, are most technologically and commercially uncertain.	● Hydrolysis systems

Source: Ref. 72

Reducing the amount of waste being disposed of in rapidly diminishing landfill sites is another major concern of DOD installation managers. Overall, incineration systems have a higher waste reduction efficiency than pyrolysis or bioconversion. However, residue products of combustion and pyrolysis should be studied to determine whether additional toxic effluents are being landfilled. Table 32 shows estimates of the residual fraction of solid waste that must be disposed of in landfills or by other methods.

Energy efficiencies of recovery processes are subject to a wide range of estimates. Because there is no currently accepted standard method to determine energy recovery efficiency, the calculation is highly dependent on such variables as (1) choosing the system boundaries for which the calculation is made, (2) choosing higher or lower heating value of the waste, and (3) including or excluding the energy content of nonfuel materials (Ref. 72).

Table 33 presents various system energy efficiencies based on the energy content of the fuel produced and on the output energy as steam. The figures in Table 33 are based on calculations using data in literature and not from actual working systems; therefore, inferences from this table should be approached with caution.

Although the performance measures in Table 33 suggest some optimism for the future, actual energy potential will be less than the maximum anticipated. Barriers such as environmental and economic considerations will place certain limits on the solid waste contribution to the Nation's energy pool.

Table 32. Estimated Waste Reduction Efficiencies of Selected Energy Recovery Technologies

Technology	Residue as percent of input waste: Weight percent	Residue as percent of input waste: Volume Percent	Reference
Waterwall combustion	25-30[a]	10	30
	20-35[a]	5-15	74
	25-30[a]	-	75
Small-scale incineration	30[a]	10	64
Dry fluff RDF	10-15[b]	-	75
	20[c]	-	76
Low-Btu pyrolysis	15-20[a]	3-5	76
Medium-Btu pyrolysis	17[c]	2	76
Liquid pyrolysis	27[b]	-	76
	7[b,d]	1-2	77
Anaerobic digestion	17[b]	-	77

[a] With metals not recovered.
[b] With metal recovery.
[c] With ferrous recovery.
[d] Assumes the char would have economic value and would not be landfilled.

Source: Ref. 72

4.4 Environmental, Health, and Safety Concerns

The environmental, health, and safety aspects of energy recovery examined in this section should require the attention of DOD, installation managers, regulatory agencies, and the research and development community. The areas addressed include air, water, and solid emissions from energy recovery facilities and impacts on workplace conditions. Although there are no forseeable environmental barriers facing the further development of waste-to-energy technologies, significant environmental requirements must be identified and resolved (Refs. 78, 79, 80, and 81). However, although the identified problems appear to be solvable, the solutions could add significantly to the cost of the program and constrain the potential range of practical technologies.

Despite the fact that there have been environmental analyses performed on a variety of waste-to-energy systems, there remain no conclusive data available to adequately assess the environmental and health concerns. This is partially due to the wide array of recovery alternatives and the relatively

Table 33. Energy Recovery Efficiencies of Energy Recovery Processes

Process	Efficiency basis Energy in fuel produced[a]	Energy available as steam[b]
Fluff RDF	70[c]	49[c]
Dust RDF	80	63
Wet RDF	76	48
Waterwall combustion furnace	--	59
Modular incinerators	--	25-50
Purox gasifier	64	58
Monsanto gasifier	78	42
Torrax gasifier	84[c]	58[c]
Occidental Petroleum Co. pyrolysis	26	23
Biological gasification[d]	33[c]	29[c]

[a] Higher heating value of the fuel product, less the heating value of the energy used to operate the system expressed as a percent of the heating value of the input solid waste. It was assumed that electricity is produced onsite using the system's fuel product.

[b] To compare all the processes on an equivalent thermodynamic basis, the energy available as steam was calculated using an appropriate boiler efficiency for each fuel product.

[c] Corrected figures are based on communications with EPA and an EPA contractor.

[d] Includes energy recovered from sewage sludge that also goes into the digester. This calculation also assumes that the filter cake residue from the digester is burned to recover heat.

Source: Ref. 72, based on the EPA Fourth Report to Congress, p. 59, with corrections by OTA as noted. All calculations are based on higher heating value of input solid waste 5000 Btu/pound, with some inorganic materials removed.

short operating history of many systems. Although there are obvious environmental benefits from resource recovery, such as volume reduction and energy conservation; these benefits should not be used as trade-offs for potentially significant but yet undetermined impacts from waste recovery.

The following areas describe significant concerns based on recent research. A detailed analysis of concerns was not possible for every waste-to-energy system. The reader is urged to refer to environmental evaluations of specific systems for more detailed data. Concern characteristics presented are discussed particularly as they relate to the potential impact on military installations.

4.4.1 Air Emissions

Typically, a military installation using its own wastes to produce its own energy through incineration will not be subject the New Source Performance Standards for incinerators since such systems will be less than 50 TPD.* However, if DOD becomes involved in a larger regional effort, Federal and local regulations may apply.

Air emissions data are available for various waste-to-energy combustion systems. These systems include direct incineration and combined RDF/fossil-fuel-fired systems. Pollutants from pyrolysis and bioconversion systems have not been characterized to the same extent as combustion units.

An EPA report on small modular incinerator systems stated that gaseous emissions were related directly to the size load fed into the incinerator (Ref. 64). Sulfur and nitrogen oxide levels were reported negligible, and 90 percent of the stack particulates were less than 7 micrometers in diameter. Overall stack emissions contained a wide variety of metals and halogens in small quantities; the residue had high pH and traces of metals such as zinc, tin, lead, and cadmium.

Co-firing of RDF and coal was analyzed by the Air Force (Ref. 82). In a 1:1 mix with coal, sulfur dioxide (SO_2), hydrocarbon (HC), and nitrogen oxide (NO_x) emission levels were significantly lower than when burning coal only in a utility-sized boiler (80,000 pounds of steam/hour). Particulate emissions were unchanged, but lead, chloride, and fluoride emissions increased. The 2:1 mix had a lower SO_2 and HC level but a higher NO_x level than emissions from coal burning only. Lead, chloride, and fluoride levels were significantly increased, and particulate emissions were erratic. The study recommended the use of RDF in a 1:1 mix with coal; however, the increased lead emissions were a serious concern.

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* 40 CFR, subpart E, 60.50, 1977: Incinerators of less than 50 TPD are exluded from Federal air quality standards. State requirements may differ.

Considerations in using RDF instead of raw unprocessed refuse include the following benefits:

- There is less variability in the fuel characteristics, making combustion control and optimization easier to implement in a given device of economical design (Ref. 83).
- In many cases, existing boilers can use low to moderate amounts of RDF in the fuel input, which would result in low or no add-on cost of retrofits or supplemental hardware (Ref. 84).
- The fuel is relatively low in sulfur (typically 0.2 to 0.5 percent, ranking with low-sulfur western coals) (Ref. 85).

Possible disadvantages of using RDF include the following:

- The unit may be derated due to the lower heating value of the fuel (Ref. 86).
- RDF has a higher ash content than oil, gas, and many coals; a retrofit or additions for ash removal capability may be required (Ref. 87).
- Higher chlorine content than conventional fuels, observed in some instances, might be a potential source of corrosion on metal surfaces exposed to combustion gases (Ref. 83).

Available technology should be able to control such emissions as SO_2, NO_x, CO, and HC (Ref. 88). The lower sulfur content of solid waste compared to most coals is an especially attractive characteristic in producing energy. Other emissions, such as hydrogen chloride gas (produced by burning plastics), could combine with water to form hydrochloric acid and could cause potential health and corrosion problems, although available scrubber technology is expected to control such emissions (Ref. 72).

There are few data concerning air pollution from pyrolysis, particularly in smaller scale systems. Hopefully, future systems will reveal a better characterization of air emissions. For example, the Andco-Torrax system will be pilot tested in 1981 at Walt Disney World (Lake Buena Vista, Florida). The system will process 100 TPD of coal, bark, wood, and MSW, involving high temperature pyrolysis to create a combustible gas, which in turn is burned in a second chamber to power a boiler (Ref. 68). The plant will be used to test the design for later application at the U.S. Department of Energy's Idaho National Engineering Laboratory for incineration of transuranic waste and residue immobilization (Ref. 89).

Pyro Sol's Pyrolysis System has been operating in Redwood City, California, using an automobile fluff waste to produce marketable gas to the Pacific Gas and Electric Company (Ref. 67). The Bay Area Air Quality Management District has issued an operating permit for the 125-TPD design plant. It is conceivable that the design could be applicable to using municipal or military solid waste.

Processing and waste conversion plants may also emit dust, odor, and noise in the plant vicinity. Proper design of the plant's facility would alleviate many of these fugitive emissions.

4.4.2 Liquid Emissions

Important parameters of wastewater control from energy recovery systems include high temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), hydrogen ion concentration (pH), alkalinity, hardness, total solids, total dissolved solids, suspended solids, settleable solids, phosphates, nitrates, chlorides, flourides, heavy metals, odor, and color (Ref. 75).

From a small modular incinerator plant, the daily discharge of process water varied from 10,000 to 30,000 gallons (Ref. 64). The tipping floor water had a BOD of 1780 milligrams/liter (mg/l), a COD of 2710 mg/l, an arsenic level of 9 mg/l, and residue removal sump water had a pH of 12 and a temperature of 39°C. The tipping floor water is treated by a municipal treatment plant, which is currently sufficient to treat the added load.

Water pollutants from incineration processes are limited to ash sluice water (Ref. 88). Bottom ash from a coal/RDF firing system is sluiced from the boiler into an ash pond, which is another pollution control problem. Aeration of the ash pond may be necessary to improve BOD and DO. Flocculation techniques may also be necessary to meet guidelines for suspended solids and other contaminants in the effluent.

4.4.3 Solid Residuals

Leachate is produced from combustion ash, pyrolysis residues, and particulate matter recovered by air pollution control equipment. Laboratory tested residues from small modular incinerator systems contained unburned hydrocarbons and traces of a variety of heavy metals (Ref. 64). Although overall anlaysis revealed insignificant amounts of pollutants, the residue could be a potential source of pollution if its pH level dropped enough (< pH 6) to allow solubility of the residue heavy metals during surface drainage at the local site or the leachate formation at the disposal site (Ref. 64).

4.4.4 Health and Safety Factors

Persons working in or near energy recovery facilities are most susceptible to potential health and safety hazards including pathogens, noise, dust, toxic substances, and accidents. Little is presently known about the characteristics or magnitude these hazards pose.

Pathogens -- Exposure to bacterial, fungal, and virological pathogens can occur at any point within the waste-to-energy recovery facility, such as unloading, storage, classification, conversion, and disposal. Unfortunately, there are no applicable health standards for microbiological contaminants in the workplace for energy recovery facilities, nor is reliable data available on worker health.

Negligible epidemiological data exist on refuse collection, transport operations, and other long-term exposure areas (Refs. 72 and 81). Potential transfer of bacteria and virus can occur to operators continually exposed to raw municipal refuse. However, a study of New York City sanitation workers has produced inconclusive results on the association of disease to solid waste exposure (Ref. 90). Additional assessments are needed to determine the health and safety problems in resource recovery facilities. DOD has undertaken bacteriological and virological research. Many researchers indicate that research on resource recovery facilities would be expedited if these experiments could be declassified and distributed (Ref. 72).

Dust -- Concern for the microbiological aspects of dusts at refuse disposal/resource recovery plants can be traced to the potential for pathogens to be present in such waste. This results from the fact that the bacteria found in solid waste are similar to those found in sewage. The bacteria detected in aerosols from solid waste include fecal streptococci, staphylococcus, salmonella, shigella, total coliforms, and fecal coliforms (Ref. 91). Additional concerns are asbestos fibers, aluminum, cadmium, and other toxic substances.

Dust particle inhalation can infect lungs and also mucous membranes and the digestive tract. The infectious potential and etiology of such invasion are currently unknown. Studies at Ames (Ref. 85) and the National Center for Resource Recovery (Ref. 92) indicate that dust particles may be 4 microns or less.

The need for dust control measures at an energy recovery facility is considerable in light of current uncertainties. Long-term needs are to characterize the dust problem in energy recovery plants and to assess its health effects.

Noise -- Noise surveys of a 3-ton/hour resource recovery system reported noise levels in excess of 90dBA* near the system processes (Ref. 92). Control methods include engineering design and worker protection. Proper design and operation of shredders, air classifiers, trommels, cyclones, and other processes should minimize noise levels. Providing worker protection equipment and limiting the exposure time in high noise areas may also be required.

Explosions, Fires, and Accidents -- Potential safety concerns relate to the accident potential that exists in any plant with moving machinery. However, this accident potential is controllable with existing safety standards. The safety aspects of explosions from dust in processing plants are minimal if proper design control systems are employed.

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* Ninety decibels on the A scale (90dBA) is the maximum noise level permitted for an 8-hour day by present Occupational Safety and Health Administration standards. This level is thought to be too high by some organizations who prefer an 85dBA standard (Ref. 72).

Solid waste may contain explosives; flammable liquids and gases; aerosol cans; propane, butane, and gasoline fuel containers; and other volatile substances. When these substances are shredded, an explosion could occur. A study of explosions in refuse shredders in 1976 revealed 95 explosions in the 45 MSW shredding plants surveyed (Ref. 93). Shredders are designed to withstand only mild explosions; hence, damage is also done to peripheral equipment, such as ducts and conveyors.

Some protection methods against shredder explosions include manual or automated surveillance of input material, explosion venting, explosion suppression/extinguishing systems, water spray, rotary drum air classifiers, or equipment isolation (Ref. 72). None of these methods are failsafe. Some, like the continuous water sprays, reduce the heating value of the shredded refuse.

Dust produced from refuse shredding does not appear to be a significant explosion hazard (Ref. 92). Dust in combination with flammable gas or vapor could be explosive. Further, dust can be a contributing factor in fires caused by explosions, which are usually associated with fine powder RDF production.

Accidents to plant workers will also occur from operating diverse mechanical and electrical systems contained within an energy recovery facility. Assuming that the facility is properly designed for safety and occupational safety regulations are enforced, control of these hazards may be adequate.

4.5 Economic Considerations of Military Waste-to-Energy Systems

Due to factors such as site specificity requirements and technology performance uncertainties, energy recovery facilities can require high capital investment and can be costly to operate and maintain. However, factors like the rising cost of conventional energy supplies and technological improvements will also influence the economics of energy recovery. This section examines the factors affecting the economic viability of waste-to-energy systems on military installations and the implications of these considerations for DOD policy on resource recovery.

4.5.1 Costs and Benefits of Energy Recovery Systems

Table 34 lists some of the costs and benefits associated with an energy recovery facility. The economics of a system for a military installation or a region include both direct and indirect costs and benefits. Direct costs and benefit values are available and appear on the balance sheet. Indirect costs and benefits are not readily apparent, but should be considered by DOD management. For municipal systems and for contract waste management operations handling military waste, a "tipping fee"* is charged if direct costs exceed direct benefits. Tipping fee revenues could also be used to adjust perceived imbalance in indirect costs and benefits.

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* A tipping fee is a charge for dumping waste at a landfill or energy recovery plant, expressed as dollars per ton.

Table 34. Costs and Benefits Derived From Waste-to-Energy Systems

	Direct	Indirect
Costs	Planning and design Investment in plant and equipment Site purchase and preparation Transporation and transfer Operating labor, maintenance, supervision Residue disposal Auxiliary fuels	Interjurisdictional coordination Loss of flexibility to respond to changed waste characteristics Air and water pollution from facility operation including residue disposal Health and safety hazards to workers and adjacent population
Benefits	Revenues from sale of materials and energy	Avoided cost of landfill or other disposal costs Avoided water pollution from landfills or dumps Reduced health and safety hazards to workers and population adjacent to landfills or dumps Reduced costs to collectors of dumping in controlled surroundings Public relations benefits for participating communities and firms

Source: Ref. 72

Many factors determine the costs and benefits of energy recovery systems. Table 35 lists a number of considerations. The list is by no means exhaustive but does include some of the more important factors to be weighed on an economic evaluation.

4.5.2 Processing Costs

Energy recovery system processing costs include capital investment and operating and maintenance (O&M) costs. Specific system costs are a function of factors such as conversion technology selected, plant size, local construction and labor rates, and financing method.

Capital investment costs required for construction of large-scale energy recovery plants* are shown in Table 36. These estimates are not applicable to installation systems but do reveal approximate initial investment requirements for various technologies. Estimates are variable due to diversity of data sources used, differences in sites and technical characteristics of each plant, and uncertainties such as plant preconstruction estimates. Military energy recovery systems can be expected to be affected by these variations.

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* Process capacity of 1000 TPD of MSW.

Table 35. Factors That Influence the Costs and Benefits of Military Wastes-to-Energy Systems

Waste Stream Characteristics	Quantity and type Composition Variation factors: seasonal, daily, operations, etc. Nature of source separation and material recovery programs Nature of installation operational activities
Geographic Factors	Installation and regional population (DOD and civilian) Regional weather and climate Transportation network Subsurface geology and terrain Local construction and labor costs
Political Factors	DOD management Installation management Regional government strength
Technological Factors	Technology employed Technology performance Plant size Type of energy derived Backup or redundancy equipment required to process waste and satisfy installation energy demand
Revenue and Credit Characteristics	Prices or credit obtainable for system products Availability of installation energy market Current disposal and management costs Local landfill prices
Financial Factors	Ownership mode (DOD, regional, or private contract) Financing method

Table 36. Capital Investment Costs of Energy Recovery Technologies (literature estimates and averages for 1000-TPD plants)

Technology	Reference	Year	Total capital investment[a] (million dollars)		
			Original year $	1979 $	Average in 1979 $
Waterwall incineration to steam	94	1975	$30.8	$39.3	$37.2
	95	1975	32	40.8	
	96	1975	23	29.4	
	76	1976	32	38.2	
	97	1977	36	39.1	
Refuse-derived fuel with materials recovery	95	1975	13.2	16.9	16.7
	94	1975	10.4	13.3	
	96	1975	9	11.5	
	94	1976	14	16.7	
	98[b]	1976	10.4	12.4	
	97	1977	27	29.3	
Refined refuse-derived fuel with materials recovery (ECOFUEL-II)	94	1975	17.7	22.6	29.6
	95	1975	28.2	36.5	
Wet process refuse-derived fuel with materials recovery	94	1975	13.5	17.2	17.2
Gas pyrolysis					
• Purox	95	1975	20.8	26.6	38.3
	94	1975	22.9	29.2	
	96	1975	31	39.6	
	76	1976	37	44.1	
	97	1977	48	52.1	
• Torrax	94	1975	16.5	21.1	37.3
	76	1976	37	44.1	
	97	1977	43	46.7	
Modular incineration with heat recovery[c]	97	1977	21.4	23.3	25.8
	99	1978	27.8	28.3	

[a] Literature estimates inflated to 1979 dollars using Engineering News Record Construction Cost Index.
[b] *Cost for 750 TPD reported in Ref. 98 adjusted to 1000 TPD using scale factor in Ref. 96.*
[c] Costs for modular incinerators reported as five times the cost of a 200-TPD facility.

For small-scale modular incineration units, EPA estimated that the capital cost of refuse processed daily (with heat recovery) would be about $15,000/ton (based on 1977 dollars) (Ref. 64).* The relationship was nearly linear up to a 200-TPD capacity for capital cost per ton and incinerator capacity. Hence, a 12-TPD industrial system would cost $220,000 to $300,000 (1977 dollars)**, while a 100-TPD municipal system would cost about $1,500,000 (1977 dollars).***

Operating costs include labor, maintenance, supplies, insurance, utilities, depreciation, and other overhead. Table 37 describes estimated O&M costs for various technologies. These estimates are only rough approximations.

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* $16,350 per ton, based on 1979 dollars.

** $239,800 to $327,000, based on 1979 dollars.

*** $1,635,000, based on 1979 dollars.

Table 37. Operating Costs of Waste-to-Energy Recovery Technologies (literature estimates and averages for 1000-TPD plants)

			Operating cost[a] ($/ton)		
Technology	Reference	Year	Original year $	1979 $	Average in 1979 $
Waterwall incineration to steam	94	1975	$11.13	$13.36	
	97	1977	8.00	8.63	$11.00
Refuse-derived fuel with materials recovery	94	1975	6.36	7.63	
	97	1977	9.33	10.07	8.90
Refined refuse-derived fuel with materials recovery (ECOFUEL-II)	94	1975	8.69	10.43	10.40
Wet process refuse-derived fuel with materials recovery	94	1975	12.11	14.53	14.50
Gas pyrolysis					
• Purox	94	1975	11.92	14.30	
	99	1977	18.00	19.42	16.90
• Torrax	94	1975	10.91	13.09	
	97	1977	15.00	16.19	14.60
Modular incineration with heat recovery	97	1977	9.91-10.14[b]	10.69-10.94	
	95	1978	9.57[c]	9.57	10.40

[a] Literature estimates inflated to 1979 dollars using implicit price deflater. Averages rounded to nearest 10 cents.
[b] 200-TPD plant.
[c] 220-TPD plant.

Source: Ref. 81

EPA (Ref. 64) reported that on the basis of test data, the optimum annual operating cost of a 100-TPD municipal modular incinerator with heat recovery would be about $370,000 (1978 dollars). Accounting for optimum steam revenues and tipping fees of $305,000, the net annual operating cost of a facility would be $65,000 or $2.72/ton of refuse processed. For a 12-TPD industrial facility, O&M estimates (1978 dollars) were optimum annual operating cost of $117,944, disposal savings credit of $82,620, and energy savings of $139,594. This results in a net savings of $104,270 or $28.96/ton of refuse processed. EPA noted that the facility finances were highly influenced by the refuse processing rate, operating time, and steam sales price (Ref. 64).

4.5.3 Energy Revenues From Various Technology Options

Two sources of revenue from resource recovery systems are recovered energy and materials revenue and savings from reduced landfilling and other disposal costs. The prices obtained for energy and materials are quite speculative depending on the marketability of various products. The choice of energy products should not be solely governed by the cost of production. For example, although it costs more to produce steam energy from waste than from RDF, steam can usually be sold at a higher price and has more applicability to a military installation heating system.

Because energy conversion facilities can typically reduce the solid waste steam up to 80 to 90 percent, equivalent reductions in landfill disposal costs can be anticipated. As current landfill or other disposal methods cost an average of \$2 to \$10/ton, landfill costs may be reduced by \$0.50 to \$9/collected ton if resource recovery is used (Ref. 72).

Potential resource recovery revenues have been estimated for large-scale operations and are shown in Table 38. High transportation costs could reduce these revenues. The minimum tipping fee estimates are equal to the net cost for disposal after credits are taken for energy and material recovery. The tipping fee can be used as a direct comparison with landfill costs; it is the price a resource recovery facility must charge to accept the waste.

A compilation of tipping fees for current plants by the National Center for Resource Recovery shows a range of \$5.60 to \$16.00/ton (Ref. 98). The systems examined in Table 38 were either near or below this range.

Table 38. Estimated Revenues and Minimum Tipping Fees for Various Resource Recovery Technologies
(1000-TPD plants in 1979 - all rounded to nearest whole dollar)

Technology	Total processing cost (\$/ton)	Energy revenues (\$/ton)	Ferrous revenues (\$/ton)	Minimum tipping fee[a] (\$/ton)
Waterwall incineration to steam	\$26	\$9-17	-	\$ 9-17
Refuse-derived fuel with materials recovery	15	5-9	1-3	4-10
Refined refuse-derived fuel with materials recovery (ECOFUEL-II)	22	9[b]	1-3	10-12
Wet process refuse-derived fuel with materials recovery	21	5-9	1-3	9-16
Gas pyrolysis				
• Purox	32	11	1-3	18-20
• Torrax	29	9-17	-	12-21
Modular incineration with heat recovery	21	9-17	-	3-12

[a] Total costs minus revenues.
[b] Assumed equal to highest RDF price.

4.5.4 Economic Design Factors for Waste-to-Energy Facilities

The design of a waste-to-energy facility from an economic standpoint requires an analysis and balancing of a number of factors, such as economies of scale in waste processing and conversion;* transportation costs; revenue

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* Economies of scale of plants can result from several combinations of scale effects and economies of input substitution as the rate of output is increased with all input. The scale effects include gains from specialization of labor and capital equipment, substitution of capital for labor, gains from vertical integration of processing activities, and gains from order-size economies.

Diseconomies of plant size may result from increasing waste transportation costs and distribution of recovered energy costs (Ref. 98).

and credits from recovered products; credits for reduced landfill requirements; and other more intangible factors, such as facility siting considerations, construction delays, system shakedown, and environmental impact mitigation.

DOD service branches have developed several economic analysis methods for energy recovery systems (Ref. 54, 94, and 100). A cost effective system design is one that will handle an installation's (or region's) wastes at the lowest net cost per ton.* Candidate waste management alternatives can also be compared and evaluated in terms of least investment alternative, conventional fuel displacement savings, savings to investment ratios, payback period, and overall magnitude of required investment (Ref. 100).

The optimum waste management alternative selected should be chosen by economic judgment incorporating the above factors. Indeed, an energy recovery option with currently unattractive economic aspects may still be recommended for reasons that include the indirect and often intangible costs and benefits (i.e., environmental, political, legal, and anticipated mission changes). These intangible benefits from energy-from-waste systems can also be valued in future terms, such as resources conservation and reduction of ultimate disposal requirements.

4.5.5 Military Energy From Solid Wastes: The Question of Using Installation Versus Regional Wastes

The question of using wastes generated on a military facility or from the surrounding region is a site-specific one and cannot be answered here. This issue of scale, however, is by no means limited to only military installations. It is applicable to large numbers of small towns (less than 50,000 population), smaller factories, office buildings, and institutions.

The current resource recovery plants are based on the assumption that large operations promise significant economies of scale in processing waste. The debate over optimum size for plants has raised the issue over the role economies of scale. In 1976, the MITRE Corporation determined that economies of scale persists for plants up to 10,000-TPD capacity (Ref. 95). Further, MITRE found that optimum-sized plants were in the neighborhood of 4000 to 10,000 TPD.

Black, and Veatch, and Franklin Associates, in 1978, determined that economies of scale were no longer evident at the 1000- to 1500-TPD capacity range for all technologies, with the possible exception of Purox (pyrolysis) (Ref. 97). In addition, they noted that 200-TPD modular incinerator in Kansas City and 1000-TPD waterwall incinerators had the lowest net costs and were roughly equal in economic performance.

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* Net cost = (processing and transportation costs) - (product revenues or credits)

Interest in small-scale systems has increased. This is due partly to the concepts of "decentralized," "appropriate," or "soft" technology applications and also to the realization of the many technological, financial, and institutional barriers encountered by the large-scale systems (Refs. 96 and 97).

The waste energy customers for a 1000-TPD facility are typically electric utilities, large factories, or other large complexes with sufficient demand to consume all the energy output. However, these potential customers have become less enthusiastic in using waste-derived energy. For example, an electric powerplant use of solid waste as a fuel would represent only a small fraction of the total fuel needs to produce an output of 1000 MW_e. The potential technological, financial, regulatory, and other barriers encountered in using solid waste may not be worth the effort for only 3 percent of a powerplant's fuel needs.*

The energy output of a 1000-TPD energy recovery plant may also be too large for potential customers using steam or hot water. Space heating and cooling energy demands of office buildings are roughly 850 Btu/feet^2/day (Ref. 97). A 1000-TPD plant could, therefore, service up to 5 million feet^2**, which is a very large building complex, such as the Pentagon (6.55 million feet^2 of space) (Ref. 72).

Two alternatives emerge to approach these problems. One option is for a large, centrally located facility to serve a number of surrounding customers. The other approach would build a number of small energy recovery plants that produce steam or hot water. Military installations have the potential to utilize both approaches depending on specific siting factors.

Table 39 reviews the characteristics of using large- and small-scale energy recovery plants.

An Office of Technology Assessment study further described the importance of two characteristics regarding small and large energy recovery plants. It stated (Ref. 72)

> The consequences of system failure are potentially more serious with one large plant than with several small plants. This fact creates the need in large plants to build in costly storage space, backup landfill, or equipment redundancy. To illustrate, consider two alternative ways of providing for resource recovery in a given city: one 1,000-tpd facility without storage or landfill, or five dispersed 200-tpd plants. If the waste that goes to any one of the 200-tpd plants could be temporarily redistributed

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* Assumes 9 billion Btu/day from wastes (570,000 people) and an electrical generation efficiency of one-third, or 37 MW_e from solid waste.

** Assumes production of 4 million Btu of steam or hot water energy per ton of MSW.

Table 39. Characteristics of Small- and Large-Scale Energy Recovery Plants*

	Advantages	Disadvantages
Large Plants	• Potential achievement of significant economies of scale • Can include both materials and energy recovery	• High cost • Difficulty in identifying suitable energy customer • Problems of regionalization: logistics, politics, etc. • Vulnerability to mechanical failure, strikes, sabotage, etc. • Potential higher transportation costs • Inflexibility of future utilization due to long-term debt obligations
Small Plants	• Can add units later for future expansion • Greater compatability with large number of smaller waste producers and customers • System reliability inherent in operating several dispersed units • Avoid regionalization problems • Reduced siting problems by locating on energy consumer property • Produced in relatively large numbers in a factory technology according to standard plans and installed relatively quickly with greater use of local skills	• Potentially higher costs per unit of water processed • Need to control a large numer of relatively small air pollution sources • Requirements of solid waste incinerators for auxiliary oil or gas fuel • Materials recovery may be uneconomical since shredding and classifying would be expensive at small scale (may be able to use small scale materials recovery and cogeneration; however, no testing is done)

*Size - distinction is arbitary: small scale ≅ 25 to 500 TPD capacity
large scale > 1000 TPD capacity

Source: Adapted from Ref. 72

to the others in the event of failure in any one plant, then the system of five plants possesses a kind of built-in redundancy. It can be shown with reliability theory that the reliability (probability of successful operation) of a single 1,000-tpd plant would have to be 0.9997 to equal the reliability of the five plant system if the reliability of the individual 200-tpd plants were only 0.80.

Factory production of a larger number of smaller incinerators may also have implications for incremental technological innovation and for system performance standards, both of which relate to aspects of potential Federal involvement. With several producers of small systems competing for sales to numerous municipalities and other buyers, market forces might stimulate technological improvements with minimal Federal involvement. In the case of construction of a smaller number of large, custom-designed systems, however, which take a relatively long time to plan and construct, market forces may not be adequate to induce technological innovation, and there may thus be greater pressure for Federal assistance. But the presence of a large number of competing systems may tend to complicate the technology/vendor selection process for local officials. Under these conditions, Federal technical assistance to local governments might be as important as if larger systems were involved.

These characteristics are especially important for energy recovery because it is still an emerging technology and requires actual demonstration and evaluation for widespread use.

5.0 IDENTIFICATION AND DESCRIPTION OF POTENTIAL ENERGY RECOVERY FROM BIOMASS FEEDSTOCK SYSTEMS

This analysis was conducted to provide a preliminary evaluation of biomass energy production and impacts that may be applicable to military installations. Biomass, as used in this study, refers to materials derived either directly or indirectly as the result of plant cultivation. Urban and industrial wastes are considered biomass because a large portion of these wastes are organic and the "indirect" result of plant growth.

Biomass sources can be divided into two major categories: energy crops and wastes and residues. Energy crops include both terrestrial and aquatic vegetation expressly cultivated and managed for the purpose of biomass energy production. Terrestrial resources are agricultural crops, such as corn, sugar beets, and grains, and silvicultural resources of several tree species. Aquaculture uses kelp and other plant species. Energy-rich organic wastes and residue are from forestry, agricultural, municipal, and industrial activities.

The scope of this section will focus on silvicultural resources and forestry wastes as the sources with the nearest term potential for significant contribution to energy production. Forestry has unique characteristics suitable for biomass production at military installations: (1) energy harvest per acre can be many times that for annual agricultural crops, (2) wood is a dense storable form of biomass fuel, (3) trees grow productively for many years and provide live storage from year to year without loss of yield, (4) nutrient losses in forestry are relatively small, and (5) wood fuel burns relatively cleanly (Ref. 99).

The evaluation will examine the overall potential of utilizing silvicultural resources, assessing the potential for military installations to use biomass energy, and analyzing the barriers of developing biomass as an energy resource for DOD.

5.1 Energy Potential From Forest Resources

Literature shows that estimates of potential silvicultural resources and residue available for biomass energy are highly variable. Approximately 500 million acres were considered commercial forest land by the U.S. Forest Service in 1974* (Ref. 101). Tables 40 and 41 show a regional and ownership breakdown of commercial forest land. The energy value of stemwood growth equals approximately 11 MBtu/acre-year or a total of 5.6 quads/year. The upper energy range limit is in excess of 9 quads/year if the total tree (leaves, roots, and branches) is included. A practical limit is about 6.8 quads/year (13.5 MBtu/acre-year) (Ref. 99).

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* Production of stemwood in excess of 20 cubic feet per acre per year.

Table 40. Commercial Forest Land Statistics for 1974 by Region (Data for the tree include trunk only to the point of major branching or to a minimum bark diameter of 4 inches)

Area	Production				
	Total			Per acre	
	Cubic feet	Btu*	Softwood (%)	Cubic Feet	Btu*
		a. Stemwood Inventory			
Northeast	174.4×10^9	57.6×10^{15}	25	980	323×10^6
Southeast	184.5×10^9	55.4×10^{15}	49	959	287×10^6
West	355.6×10^9	99.4×10^{15}	93	2770	777×10^6
Total	714.5×10^9	212.4×10^{15}	67	1430	430×10^6
		b. Annual Growth			
Northeast	5.5×10^9	1.8×10^{15}	25	31.1	10.3×10^6
Southeast	8.6×10^9	2.6×10^{15}	63	44.6	13.4×10^6
West	4.4×10^9	1.2×10^{15}	88	34.2	9.6×10^6
Total	18.6×10^9	5.6×10^{15}	57	37.1	11.1×10^6

*Hardwood basis, 800 Btu/lb at 44 pounds per cubic foot; values typical for dry oak, hickory, and maple. Softwood basis, 8400 Btu/lb at 32 pounds per cubic foot; values typical for dry fir and pine.

Source: *Refs. 99 and 101*

Table 41. Commercial Forest Land Acreage and Ownership for 1974, in 10^6 Acres, by Region

Area	Acreage	Land Ownership				
		Federal	State and Local	Industry	Farm	Private
Northeast	177.9	12.3	19.6	17.6	51.0	77.4
Southeast	192.5	14.3	3.0	35.3	65.1	74.8
West	129.3	80.6	6.4	14.4	15.0	12.8
Total	499.7	107.1	29.0	67.3	131.1	165.1

Source: Ref. 101

The National Research Council estimates that forest yields could be doubled with improved management (Ref. 102). In addition, forest yield can be stored for many years. The average inventory on forest land is about 715 MBtu/acre and represents about 20 times the annual cropland yield (Ref. 99). The forest inventory represents more than 38 years of tree growth on the average, and an energy inventory (about 212 quads) that is about three times our annual usage of energy in all forms (Ref. 99). Approximately, 160 million acres of forest land acreage are needed to supply the 1978 DOD energy equivalent demand of 305 million BOE*. This represents about 30 percent of the 1974 commercial forest land acreage.

Silviculture for the purpose of producing biomass for fuel has been intensely studied. Rapidly growing trees planted in close proximity and harvested in short rotation as spindly trees can be expected to yield more biomass than does conventional long rotation forestry (Ref. 103). However, private investment in silvicultural biomass farming will depend on how biomass fuel economics compare to competitive uses of wood (fiber and pulp industries).

Research by the MITRE Corporation, with the Georgia-Pacific Corporation, has made the most detailed investigation of silvicultural energy plantations (Refs. 103, 105, 106, and 107). The study considered short-rotation management, land availability, conversion processes, site-specific cost analyses, and evaluation of forest and mill residues. An analysis of 10 representative or potential biomass farm sites exhibited these features: (1) 6-year rotation periods; (2) closely spaced plantings (4 feet by 4 feet); (3) dependence on coppice regeneration**; and (4) intensive crop management, including site preparation, fertilization, pest control, and irrigation where needed. Plantation production of 250,000 dry tons/year would require about 20,000 to 50,000 acres depending on tree species, culitivation method, land conditions, and other factors. Productivity of 5 to 13 dry tons/acre-year could be expected to rise to 10 to 22 dry tons/acre-year through improved management and selection of high-yielding species.

Besides the opportunities for energy production from both existing and new forest production, there is also the use of forest residues. Forestry residues that can be used as biomass energy are principally "slash" -- cuttings left behind after conventional logging -- and stump/root systems. Total logging residues in the United States approach 200 million tons/year divided about 40/60 between aboveground residues and stump/root systems (Ref. 108). The availability of these residues varies depending on forest type, topography, soil strength, erosion potential, and other factors.

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* Assumes 11 x 10^6 Btu/acre and 5.8 x 10^6 Btu/barrel oil.

** Coppicing involves conventional harvesting of a tree, with subsequent sprouting of stem growth from the stump. This facilitates rapid regrowth, because new root systems are not required. Only certain hardwood species are able to regenerate in this manner.

Collection and use of these residues will be dependent on development of harvesting equipment, some of which has already been developed by companies such as Morbark Industries (Ref. 108). Chipping machines located on logging sites may enhance the collection of residues. Lumber mills and pulp/paper mills are also sources of large amounts of wood residues; approximately half of the timber processed into lumber and plywood is wasted in the form of bark, sawdust, and trim at the wood mill site. Bark is unusable for pulp production, although it is often burned as a source of steam for the process.

Table 42 compares forest logging residues with other biomass residues in terms of weight and energy content. Agricultural and urban solid wastes contain more energy overall than logging residues. However, the estimates show that energy density per acre of forest residues is higher and that wood itself is a much denser form of fuel (for example, 1 cubic foot of wood contains as much energy as 5 to 10 cubic feet of baled, field residues) (Ref. 99). Dead, rough, and rotten trees (not included in Table 42) average about 9 percent of the forest inventory (Ref. 101).

Table 42. Major Sources of Potentially Usable Biomass Residues

Item	Weight (10^6 dry tons)	Energy*	
		Total (Q)	Per acre (MBtu)
	Collected		
Urban and municipal solid wastes**	160	2.1	
Large poultry and hog operations and cattle feedlots	26	0.3	
Large canneries, mills, slaughter houses, and dairies	23	0.3	
Wood manufacturing	15 to 27	0.4	
Total	~230	~3	
	Uncollected		
Cereal straw	161	2.1	22
Cornstalk	142	1.8	28
Logging residues	50 to 75	1.1	130**

* Residues evaluated at 13 MBtu/dry ton except for wood residues at 17 MBtu/dry ton.

**Estimated by assuming that the large branches, stump, and unmerchantable bole are collected and that the total average aboveground residue is 9.1 dry ton/acre.

Source: Ref. 99

5.2 DOD Considerations in Using Biomass Energy

The insignificant demand for biomass fuel is primarily due to the inability of present military and civilian establishments to use such fuels directly. While there have been some applications, for example, in the sugar, paper, and wood biomass industries, the reliance on natural gas and petroleum fuels has been emphasized. In this context, biomass resources are often considered as indirect sources of gas and oil, rather than direct energy markets (for example, combustion for heat).

It is not the purpose of this chapter to review alternative processses for converting biomass feedstocks to usable energy resources. A review of applicable conversion technologies has been underway by the Army aimed at producing combustion-based biomass-derived fuel and synthetic natural gas (SNG) and liquid fuels (Refs. 110 and 111). Near-term (to 1985) application for Army use is being considered for the production of steam and/or hot water for heating and/or cooling. As with the case for solid waste conversion systems, small-scale systems may be efficient and economical to operate. However, only site-specific evaluation will determine the extent of application.

An analysis of several Army installations was instituted to determine such potential (Ref. 112). The study investigated the potential of using biomass feedstocks at or near bases for application in direct-fired steam generators, hot water heaters, space heaters, and cooking. Some of the conclusions are summarized below (Ref. 112):

- Energy Plantations* are feasible for meeting the fuel needs for fixed facilities in at least 15 large Army bases in the eastern and central time zones;
- The cost of solid fuel produced in Energy Plantations will be about $1/million Btu, and the cost of SNG will be between about $3.10 and $4.20/thousand standard cubic feet (scf), although there is some uncertainty associated with these cost figures, particularly the technology for producing SNG from plant material;
- Plant species that are most suitable for "Btu Bushes" at the Army bases have been identified;
- Immediate steps to study the remaining open questions and to commence Energy Plantation system design should be taken; and
- By implementing the program, several significant benefits can accrue:
    - Natural gas shortages and possible unavailability will not affect continued operations at the Army bases,

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* Refers to methods for producing fuels by collecting and storing radiation in plants grown purposely for their fuel value on a large scale.

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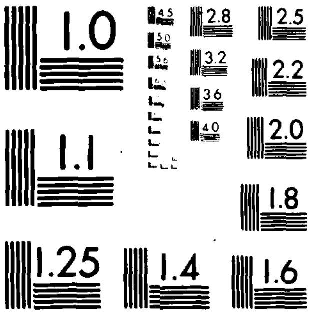

MICROCOPY RESOLUTION TEST CHART

- U.S. Army technological leadership in adaptation to future energy-tight conditions will be clear, and
- Essential military training and readiness will not be totally dependent on fossil-fuel supplies and in competition with civilian needs.

Table 43 lists the Army installations surveyed in the study. The analysis selected and evaluated large bases or training centers in which each

Table 43. Technical Suitability of Selected Large Army Installations for Energy Plantations

INSTALLATION	SUITABLE	PROBABLY UNSUITABLE AND REASON THEREFOR
Fort Polk, Louisianna	X	
Fort Hood, Texas	X	
Fort Stewart, Georgia	X	
Fort Benning, Georgia	X	
Fort Gordon, Georgia	X	
Fort Jackson, South Carolina	X	
Fort Bliss, Texas		Low Precipitation
Fort McClellan, Alabama	X	
Fort Bragg, North Carolina	X	
Fort Sill, Oklahoma	X	
Fort Huachuca, Arizona		Low Precipitation
Fort Campbell, Kentucky	X	
Fort Knox, Kentucky	X	
Fort Leonard Wood, Missouri	X	
Fort Dix, New Jersey		Densely Populated Area
Fort Riley, Kansas	X	
Fort Lewis, Washington	X	
Fort Carson, Colorado		Low Precipitation
Camp Drum, New York	X	
Fort Greely, Alaska		Climate
Fort Richardson, Alaska		Climate
Fort Wainwright, Alaska		Climate

Source: Ref. 112

facility had at least a 50-square-mile area (about 32,000 acres) and an annual fuel consumption (for stationary operations) of approximately 200 billion Btu/year (200 million SCF or 33,000 BOE) (Ref. 112). Fuel end-use requirements of several characteristics were examined, such as fuels consumption pattern, seasonal fuels demand, and types and fuel-firing capacity of directly fired stationary equipment. These factors affect the fuel(s) to be produced from the biomass resources and the design of the system.

Natural gas and liquid petroleum were the predominant conventional fuels burned at the major installations in 1974. Coal was not used in large quanities. Table 44 provides an indication of fuel type distribution for five installations located at different geographic localities.

Table 44. Fuels Consumption by Fuel Type as a Function of Location

Installation and Location	Estimated Normal Degree - Days/Year	Fuel Consumption - Billion Btu				Distribution of Fuel Consumption Percent of Total Consumption		
		Total	Gas	Oil	Coal	Gas	Oil	Coal
Fort Hood, Texas	2000	1700	1698	1	--	99+	1	--
Fort Benning, Georgia	2400	2073	1893	179	--	91	9	--
Fort Bragg, North Carolina	3100	3013	2032	957	25	67	32	1
Fort Knox, Kentucky	4600	2950	2482	390	79	84	13	3
Fort Lewis, Washington	5500	2494	124	2370	--	5	95	--

Source: Ref. 113

Biomass energy systems can produce a variety of end-products for military and civilian consumption. Table 45 lists these products as well as the biomass resources and conversion processes. Consideration of these possibilities for military installations in unurbanized areas have been analyzed. Factors for evaluation include (1) yield of final fuel form (per unit weight) of plant material harvested, (2) thermal efficiency of conversion process, (3) storage capability of final fuel, and (4) availability of backup fuels that could be stubstituted for the biomass-derived fuel.

Szego (Ref. 112) concluded that either a solid fuel or synthetic natural gas from biomass (through anaerobic fermentation) were the final fuel types worthy of application of Army training centers. Table 46 summarizes the fuel type and characteristics and applications.

In addition, Szego found that small heaters (less than 750,000 Btu/hour capacity) consumed the bulk of the fuels in fixed installations (Ref. 112). Tables, 47 and 48 display the fuel consumption class and capacity of Army installation firing equipment for FY 1971. The installations are arranged in the order of increasing normally expected heating degree-days* per annum.

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* A form of degree-day used as an indication of fuel consumption; in U.S. usage, one heating degree-day is given for each degree that the daily mean temperature departs below the base of 65°F (19°C).

Table 45. Activity Options for Biomass Utilization Systems

Residue Type	Conversion Process	Consumer Class
Collected Wastes	Physical Processing	Energy Applications
Municipal Solid Wastes		Boiler Fuel
Municipal Sewage	Biological Conversion	Portable Liquid Fuel
Large Feedlot Manures	Biogasification	Pipeline Gas
Food Processing Wastes	Ethanol Fermentation	
Wood Products Wastes	Other Fermentations*	Materials Applications
		Chemical Feedstocks
Dispersed Residues	Thermochemical Conversion	Lumber Products
Dispersed Manures	Pyrolysis	Pulp Products
Agricultural Residues	Gasification	Other Fibers
Logging Residues	Hydrogenation	
		Agricultural Products
New Biomass Production	Chemical Synthesis**	Food
Conventional Forestry	Methanol Synthesis	Feed
Agricultural Biomass	Synthetic Gasoline	Fertilizer
Silvicultural Biomass	Methane Synthesis	
Mericultural Biomass		
Wastewater Farms	Ecosystem Services***	

* Biomass feedstocks can be converted (with low yields) into higher alcohols and other organic compounds that may have value as specialty chemicals.

** Used only for converting synthesis gas (a mixture of CO and H_2 that can be derived from biomass either by gasification followed by water-gas shift conversion, or biogasification followed by reforming) into a portable liquid or gaseous fuel.

*** Ecosystem services, including recreation and the many ecosystem functions that support life, are provided in the absence of or beside man's exploitation of ecosystems for the production of biomass.

Source: Ref. 109

The information for the Army installations surveyed indicates that for FY 1971 (Ref. 112):

- Small heaters used very large fractions of the fuels consumed in fixed facilities at all Army installations other than the three in Alaska and were, in fact, the largest single class of consumers in 15 of the 19 installations located in the 48 contiguous states;

- Intermediate heaters in most instances (18 out of the 19 installations in the lower 48 states) accounted for 20 percent or less of the total fuels consumed in fixed facilities, the sum of the fuels consumed in small and intermediate heaters accounting for more than 50 percent (and frequently very much more) in 18 of the 19 installations in the lower 48 states;

- In 7 instances, high-pressure boilers were the largest single class of consumers, although only 4 of these instances were among the 19 installations in the lower 48 states; and except for the Alaskan

Table 46. Summary of Final-Fuel-Form Considerations

Final Fuel Form	Conversion Process	Heating Value - Percent of Heating Value of Air-Dry Plant Matter*	Relative Plantation Area Required	Major Disadvantages S=Serious T=Tolerable	Candidate for Troop Training Centers
Solid	None	100	1.0	Needs partial drying-(T) and airborne particulates control-(T)	Yes
Fuel Gas	Pyrolysis--directly heated	less than 100	more than 1.0	Heating value (150 to 300 Btu per SCF**)-(S), No backup fuel-(S), Storage problem-(S)	No
Fuel Gas	Pyrolysis--indirectly heated, high temperature (over 1400^{o}F)	less than 100	more than 1.0	Heating value (400 to 600 Btu per SCF)-(S), No backup fuel-(S), Storage problem-(S)	No
Fuel Oil	Pyrolysis--indirectly heated, intermediate temperature (~900^{o} to ~1000^{o}F)	50 to 60	1.1 to 1.6	Required heating before firing-(S), Possible poor shelf life-(T)	No
Synthetic Natural Gas	Anaerobic Digestion	65 to 85 (woody raw material); 60 to 70 (grassy raw material)	1.2 to 1.5 (woody raw material); 1.1 to 1.3 (grassy raw material)	Storage problem-(T)	Yes
Synthetic Natural Gas	Spano Technology	less than for direct anaerobic digestion	Larger than for direct anaerobic digestion	Probably lower CH_4 yield and higher costs than for direct anaerobic digestion(S)	No
Ethyl Alcohol	Spano Technology	40 to 45	2 to 2.7	Low alcohol yield from plant matter-(S)	No

* Entries in this column are the heating value of the indicated fuel as a percentage of the heating value of the air-dry plant matter directly used for producing the indicated fuel -- the entries do not take account of the fuel required to provide the mechanical energy and heat required to operate the conversion process.

** SCF = standard cubic foot, at 60^{o} Fahrenheit and one atmosphere

Source: Ref. 112

Table 47. Consumption of Energy From Fuels in Fiscal Year 1971 at Selected Army Installations by Class and Capacity of Directly Fired Equipment

Installation	Estimated Normal Degree-Days Per Year	Total Fuels Consumption Billion Btu	Percent of Total Fuels Consumption			
			High-Pressure Boilers[1]	Large Heaters[2]	Intermediate Heaters[3]	Small Heaters[4]
Fork Polk, Louisianna	1900	1578	8	<1	<1	91
Fort Hood, Texas	2000	1623	7	8	8	76
Fort Stewart, Georgia	2000	623	35	3	18	44
Fort Benning, Georgia	2400	2387	41	1	2	56
Fort Gordon, Georgia	2500	1524	49	-	9	42
Fort Jackson, South Carolina	2600	1387	49	1	4	46
Fort Bliss, Texas	2700	1589	8	11	10	71
Fort McClellan, Alabama	2900	518	34	4	11	51
Fort Bragg, North Carolina	3100	2772	42	<1	13	44
Fort Sill, Oklahoma	3100	1602	11	13	20	56
Fort Huachuca, Arizona	3700	493	29	11	8	52
Fort Campbell, Kentucky	3800	1580	46	1	1	52
Fort Knox, Kentucky	4600	3073	20	4	18	58
Fort Leonard Wood, Missouri	4800	2165	26	1	10	63
Fort Dix, New Jersey	5000	2382	50	7	7	36
Fort Riley, Kansas	5100	1993	13	11	11	65
Fort Lewis, Washington	5500	2327	45	2	12	41
Fort Carson, Colorado	6500	1851	22	2	14	62
Camp Drum, New York	7400	314	6	19	29	46
Fort Greely, Alaska	9000	212	80	4	4	12
Fort Richardson, Alaska	9000	1714	88	5	2	6
Fort Wainwright, Alaska	9000	2124	95	3	1	2

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[1] High-Pressure Boilers: Firing rate of 3.5 MBtu/hour and steam generation of ≥135 psia, located in boiler plants

[2] Large Heaters: Firing rate of ≥3.5 MBtu/hour and used for producing hot water at lower temperatures and pressures than high-pressure boilers

[3] Intermediate Heaters: Firing rate between 75 and 3.5 MBtu/hour and used for water heating, pressure steam, and space heating

[4] Small Heaters: Firing rate <750,000 Btu/hour and used for space or water heating

Source: Refs. 114 and 115

Table 48. Numbers and Firing Capacity of Direct-Fired Equipment At a Representative List of Troop Training Centers

Installation	Total Direct-Fired Units	Number of High-Pressure Boilers	Numbers of Heaters by Firing Capacity Million Btu per Hour		
			>3.5	3.5-0.75	<0.75
Fort Bragg, North Carolina	6213	9	13	99	6092
Fort Campbell, Kentucky	2776	31	2	88	2655
Fort Knox, Kentucky	1503	22	34	145	1302
Fort Leonard Wood, Missouri	1545	6	9	56	1474
Fort Riley, Kansas	1055	4	65	346	640
Fort Carson, Colorado	2538	4	39	82	2413

Source: Ref. 113

installations, fuel use in high-pressure boilers was not greater than half the total fuel used in any of the 19 installations in the contiguous states; and

- Large heaters consumed only a relatively small fraction of the total fuel consumed at any of the installatons -- in fact, less than 9 percent in 19 of the 22 installations shown in the table.

An analysis of more recent periods may reveal a tendency to fire more coal in light of the President's national energy strategy to reduce dependence on foreign oil and thereby limit vulnerability to supply disruptions (Refs. 41, 116, and 117).

5.2.1 Application of Biomass Energy Systems: Analysis of Army Installations

Fort Leonard Wood (Jefferson City, Missouri) and Fort Benning (Columbus, Georgia) were analyzed for potential application of either a solid or gaseous fuel biomass system (Ref. 112). Table 49 summarizes the requirements and associated costs (1974 dollars). General characteristics and conclusions have been drawn from the evaluation for military installations generally.

Solid Fuel Biomass Systems -- Capital, operating costs, and land requirement comparisons of solid fuel central heating systems with or without condensate return distribution suggests that the system with condensate return would be the one of choice. Although the overall capital costs of the two systems are about the same, the estimated annual operating cost of a system with condensate reuse appears to be about 10 percent less than a system in which condensate is not recycled (Ref. 112). The cause of this difference is mainly due to the larger amount of plant material required for firing if no condensate is reused.

Table 49. Summary Comparison of Two Energy Plantation Systems (Costs are in December 1974 dollars)

	FORT BENNING		FORT LEONARD WOOD	
	Central Heating System Solid Fuel Fired	SNG System	Central Heating System Solid Fuel Fired	SNG System
Area of base - acres	182,000	182,000	106,000	106,000
Plantation area - acres	25,000	32,000	22,000	29,000
Plant material - dry tons per year	220,000	280,000	180,000	240,000
Manpower requirements:				
Plantation - full-time	95	147	79	127
Plantation - 6 months/year	34	43	28	37
Central heating or SNG system - full time	98	108	88	93
Manpower totals:				
full-time	193	255	167	220
6 months/year	34	43	28	37
Capital Costs:*				
Establishing and equipping plantation - $	6×10^6	8×10^6	5×10^6	8×10^6
Central heating facility - $	43×10^6		35×10^6	
SNG production plant - $		31×10^6		25×10^6
Total System Capital Cost - $	49×10^6	39×10^6	40×10^6	33×10^6
Annual Costs:*				
Central heating system - $	7.4×10^6		6.3×10^6	
SNG production system - $		10.6×10^6		8.0×10^6
Capital Costs:**				
Establishing and equipping plantation - $	6×10^6	7×10^6	5×10^6	6×10^6
Central heating facility - $	43×10^6		35×10^6	
SNG production plant - $		22×10^6		17×10^6
Total System Capital Cost - $	49×10^6	29×10^6	40×10^6	23×10^6
Annual Costs:**				
Central heating system - $	7.4×10^6		6.3×10^6	
SNG production System - $		8.8×10^6		6.5×10^6
Unit costs of fuel value:				
Plant material as solid fuel - $/10^6 Btu	1.08	0.97	1.09	2.01
SNG production system* - $/10^6 Btu		4.20		3.70
SNG production system** - $/10^6 Btu		3.50		3.10

*Capital and annual costs for SNG production plants based on state-of-the-art from the literature. Annual costs include the cost of replacing worn-out equipment.

**Capital and annual costs for SNG production plants based on anticipated improvements in performance. Under these circumstances, the plantation areas required will be reduced to about 27,000 and 24,000 acres for Fort Benning and Fort Leonard Wood, respectively.

Cost comparisons between biomass-derived solid fuel and conventional oil or gas fuels are more difficult. The cost of the biomass system includes not only the fuel producion and delivery costs but also burning, steam distribution, and system maintenance costs. It can be reasonably concluded, however, that as petroleum and natural gas fuel increase in price, the cost of operating a solid fuel biomass system would likely remain steady, or possibly decline, especially as technology and methods improve.

SNG Biomass Systems -- Capital and operating cost estimates are less precise than for solid fuel biomass sytems because of the absense of process design data for SNG systems. However, based on state-of-the-art information, an SNG biomass system may have an estimated operating cost of about $4/thousand scf (1 million Btu) of SNG produced (Ref. 112). This figure is about one-third higher than the estimated cost of operating central heating systems with solid biomass fuel. Although this appears to favor solid biomass fuel, actual costs are dependent on the actual performance of SNG production facilities. Therefore, more precise design data are necessary to compare and evaluate SNG biomass systems.

Anaerobic digestion of woody plant species was suggested as the method of methane production (Ref. 112). The process involves the digesting or conversion of plant material (composed mostly of cellulose and other polysaccharides) to a mixture of methane and carbon dioxide and biological cell matter. Other plant materials, lignin and ash, are inert under anaerobic digestion conditions.

Research on the anaerobic digestion of woody plant material is still in the bench/laboratory or pilot stage of development. Areas of investigation pertinent to military applications include digestion characteristics of woody plant material, pretreatment requirements prior to digestion, preferred species of plant material, optimum digestion parameters, methane purification, methane gas storage, energy balance of production, and economic analysis of SNG produced.

5.3 Barriers of Developing Biomass Resources for DOD

Although the range of end uses for energy from biomass is quite broad, the number and magnitude of the barriers to biomass use are no less significant. Several end uses were described as having potential application in military facilities. Yet, in all candor, it is extremely difficult to predict the mix of energy products that will be made from biomass in a future economy that has a significant degree of dependence on biomass energy. Biomass-derived energy products must, in the final analysis, compete with all other available energy sources in various fuel markets.

Biomass as a source of energy has been touted as having several significant benefits: biomass is renewable; biofuels use will not contribute to increasing levels of carbon-dioxide in the atmosphere; biomass is typically low in sulfur content; biomass resources are available in every region; and biofuels are essentially identical to conventional fuels, thus requiring minimal consumer adjustment in use. However, despite these encouraging characteristics, several issues and barriers are apparent in the greater use of biomass resources in both military and civilian sectors.

A detailed elucidation of barriers and sub-issues is beyond the scope of this chapter. What will be examined are the major concerns presently affecting biomass energy development, with particular reference to military installation application. The concern categories are site evaluation data requirements, environmental assessment, and energy considerations.

5.3.1 Site Evaluation Data Requirements

Major data requirement elements necessary to evaluate the feasibility of using biofuels on Army installations are shown in Table 50. Characterization of a facility's present energy consumption pattern and system are generally available with current data. A detailed description of an installation's energy systems is also available from evaluations performed for refuse-derived energy systems.

Information on the production, conversion, and use of biomass resources are, however, very limited. Estimates are available for nonspecific silvicultural farms (Ref. 103), but the data are not sufficient for making specific recommendations for specific sites. For example, tree species selection information are not adequate to determine whether a particular specie would be appropriate to harvest at a specific site.

Precise data necessary for the selection and design of biomass conversion systems are in the form of laboratory or modelling results or not available. Using such estimates and other operating parameter values can subject the design of a biomass energy system to varying degrees of error. With respect to an SNG production system, for example, there is a great need to develop process design data pertaining to (1) the methane yield per pound of plant material digested; and (2) the relationships between energy used for grinding biomass prior to its anaerobic digestion, the fraction of biomass rendered soluble in water, the rate of biological digestion of the ground biomass, and the pumpability of ground biomass slurries in water.

5.3.2 Environmental Assessment

Biomass energy systems may cause environmental impacts in several different categories of biomass energy development. This section discusses issues of potentially major impact from a quantitative and qualitative perspective. Impact areas include biomass production impacts and biomass conversion to energy impacts.

Areas of concern in the production of biomass are shown on Table 51. Environmental impacts of silviculture and forestry residues are treated as an entity. The magnitude environmental impact will, of course, depend on the physical condition of the forested area, method and intensity of silviculture, and the extent of slash collected. The literature indicates a paucity of quantitative data on the inventory and estimation of environmental impacts of silviculture and residue recovery for energy recovery.

Table 50. Limitations Imposed by Available Data

Data Element	Sufficiency of the Data	Effect of Deficiencies in the Data
Fuels Consumption at Army Bases:		
Total Annual Consumption	Adequate	No serious deficiencies
Consumption by fuel type	Generally adequate	Lack of data on LPG use makes estimation of cost of additional SNG distribution network impossible
Seasonality in consumption	Inadequate	Requires estimation methodology development
Directly Fired Equipment at Army Bases	Adequate	No deficiencies
Deciduous-Species-Plant-Matter Growth Rates:		
Comparative data between species at a site	Very limited	Specific species selection for a given site often impossible.
Comparative yields for a species	Few data available	Uncertainty in effect of soil type, climate, and insolation rate on plant-matter yield from species but not serious for general estimates of effects
Harvestable yield/acre-year from stands at known age and planting density:		
o First harvests from stands	Several excellent data sets available	Data are adequate for defining relationships in general terms for planning purposes
o Second and subsequent harvests	A few excellent data sets available	Data are adequate for defining general relationships for planning purposes
Fraction of plants surviving to harvest	Adequate	Generalized relationships believed reliable for planning purposes have been formulated
Effect of cultivation	Adequate	No deficiencies
Effect of fertilization	Mixed, but adequate	Emphasis is on maintaining site fertility, not fertilizing specific plantings--data are adequate
Entire body of data viewed as a whole	Fairly adequate	Estimates of harvestable yields at specific sites believed reliable to within about ±10 percent, but yields for specific species probably are not quite as reliable
Warm-Season Grass Plant-Matter Growth Rates	Data are reasonably adequate	No serious problems; in any event, only a few localities are suitable for warm-season grasses
Plantation Operation Cost Data	Unit data (equipment costs and capacities) are good	Estimated plantation capital costs and plant-matter production costs are sufficiently reliable for purposes of the work
SNG Production Process	Essentially no precise design data are available, "reasonable" estimates have been used, capital and opeating cost factors are fairly reliable	Methane yield stimates probably on low side; hence, SNG costs and process plant capital cost probably about 15 and 25 percent high, respectively--other operating parameter estimates are less critical
Solid Fuel Systems for Forts Benning and Leonard Wood	Process engineering and capital and operating costs for central heating plants and distribution systems are good engineering approximations	Cost estimates do not include costs for alterations within buildings and fuels storage or seasonal harvesting--hence total costs for entire systems will be higher than estimates

Source: Ref. 112

Table 51. Environmental Concerns Associated With Biomass Production From Forest Residues and Silviculture

Impact Area	Concern
Land Use	• Increased land acreage devoted to biomass energy production • Increased land area needed for yard storage and drying facilities
Physical/Chemical Environment	• Biomass removal from forest land may upset the natural balance of terrestrial, aquatic, and atmospheric components • Residue collection may lead to imbalance in steady-state nutrient and organic matter cycles of a mature ecosystem • Harvesting and short practice rotation practices could induce secondary changes including (1) water holding capacity, evaporation, transpiration, and runoff; (2) soil loss; (3) nutrient release rates; (4) depth of aeration; and (5) reflectivity and heat flux • Water quality parameter increases: detached soil particles, organic materials, and associated chemical species to nearby water bodies • Removal of part of organic forest floor may decrease average infiltration rate and increase sheet and rill erosion • Deforestation may cause loss of elements (N, P, K, Al, Ca, Fe, Cl, Si, Na)
Ecological Impacts	• Vegetation removal from forest floor may affect most of the trophic levels associatd with decomposers • Higher suspended solids concentrations (reduced light penetration) may decrease primary productivity or shift to more shade tolerant acquatic species • Increased BOD and sediment loads may cause stress on fish and benthic communities • Increased nitrate levels are of concern for downstream water users • Use of fertilizers, pesticides, and other chemicals may leach into adjacent aquifers

Source: Ref. 111

The degree of ecosystem disturbance due to harvesting, removing, and storage of forest materials depends on many regional, site, and engineering parameters. Hence, terrestrial, aquatic, atmospheric, and biological components interract and respond depending on the degree of harvesting/recovery activity (Ref. 119).

Currently available erosion control technology and sound engineering design can mitigate many of the potentially adverse impacts. Some of these measures include stand selection and harvest techniques to minimize soil disturbance, development of and adherence to specified control guidelines, and establishment of buffer zones around environmentally or aesthetically sensitive areas. Silviculture can also be tried on marginal lands. For example, marginal strip-mined land can be used to restore some degree of productivity and thus may yield net positive impacts.

Concerns emanating from the energy conversion in the form of process heat, power production, or SNG are presented in Table 52. Because many

Table 52. Environmental Concerns Associated With Biomass Conversion to Fuel/Energy

Impact Area	Concern
Direct Conversion	● Air emissions of concern: CO, hydrocarbon particulates, polycyclic organic matter ● Potential high BOD and COD in wastewater, for example, from incomplete combustion of wood fiber ● Solid residues may produce highly mineralized leachates ● Handling, size reduction, and classification activities create dusts, noise, and odors ● Small amounts of toxic organic substances may cause public health impacts, for example phenols from wood lignin
Anaerobic Digestion	● Potential production of vile-smelling volatile acids (butyric and propionic) due to poisoning of bacteria by metals or acid ● Potential BOD and suspended solids problems if not controlled ● Heavy metal build-up if sewage sludge is used

Source: Ref. 111

of the systems have not progressed beyond the bench or pilot plant phase, factors of concern are necessarily extrapolations of available information.

Along with the production of fuel from the conversion of biomass resources, there are also byproducts or wastes produced in the form of nutrients and organic matter. Thermal conversion of biomass, either by direct combustion or thermochemical conversion, will incorporate all of the organic matter into the fuel itself or into inorganic forms, such as CO_2 and char, and will not be directly available for incoporation into soil. Some of the nutrients contained in the ash, however, may be used as fertilizer. Other nutrients are lost as airborne emissions (especially nitrogen) or wastewater contaminants.

Table 53 contrasts the combustion of various biomass fuels, including wood with coal. Oxides of sulfur are of particular concern for coal combustion. Inhalable, fine particulates are of concern for woodburning.

Table 53. Particulate and Gaseous Emission Factors for Direct Combustion of Biomass Fuels Compared With Coal Combustion

Source	Kg/10^6 Btu				
Parameter	MSW[a]	MSW +Coal[b]	Wood Residue[c]	Bagasse[d]	Coal[e]
Particulates	0.04-0.8	>0.04	0.6	1.1	0.04
SO_x	0.1	0.4	0.06	0	0.5
NO_x	0.2	0.3	0.4	0.1	0.3
CO	0.04	0.04	1.2	0.1	.04
HC	-	-	1.4	0.1	.02

[a] Refs. 120 and 121. 10 Kg particulates/ton refuse; 6000 Btu/lb heating value; second value refers to untreated refuse and first value is 95 percent collection efficiency

[b] 11,100 Btu/lb at 12 percent refuse content (wt/wt basis)

[c] Ref. 121. Assumes 6000 Btu/lb heating value

[d] Ref. 121. Assumes 4600 Btu/lb heating value

[e] Ref. 121. Assumes bituminous coal, stoker feed, 3 percent sulfur content, 15 percent ash, and 12,000 Btu/lb heating value

Biological conversion processing, in contrast, preserves most of the nutrients and some of the organic matter in forms that are suitable for beneficial uses. High protein distiller's dried grains (for example, ethanol fermentation of corn) and digester sludge (from biogasification) contain most of the feedstock nutrients in an organic matrix that is composed of anaerobic organisms and undigested feedstock materials. Both of these byproducts can be used as animal feeds, and it is commonly suggested that such use is necessary to allow economic feasibility of biomass bioconversion processing (Refs. 122, 123, and 124). Digester sludge is also suitable for use as a soil conditioner/fertilizer/irrigant (Refs. 125 and 126). Indeed, the same anaerobic bacteria that are exploited in biogasification are present in soil, and play a crucial role (along with aerobic organisms) in humus-building processes and in nutrient recycling. The spreading of digester sludge produced by biogasification of crop residues would supplant the need for increased use of agricultural fertilizers caused by residue removal* and would perform essentially the same soil and water retention functions that the residues provide when left in place (Ref. 109). Thus, a scheme combining crop-residue collection (or other biomass producion activities) with biogasification and return of digester sludge to the field will have significantly lower ecosystem impacts than alternative schemes.

5.3.3 Energy Requirements

The pervasive question concerning biomass energy development persists, "Will biomass production yield positive net energy? Will it provide more energy than it consumes?" The net energy balance of biomass production is defined to be positive if the nonrenewable energy input requirement of producing biomass energy is less than the renewable energy produced from biomass.

The answer to this question is highly dependent on defining and considering a number of difficulties encountered. Table 54 identifies these consideration factors in energy analysis. Energy balance for specific projects is impossible until the actual details of biomass production and use are more clearly established.

Several investigators have estimated energy output to input ratios for major biomass resources: corn, 2.5 (Ref. 127) to 3.3 (Ref. 128); wheat, 5.4 (Ref. 128); alfalfa, 16.0 (Ref. 129); and forest logging, 37.0 (Ref. 130). Harvest residues are not reflected in this data. If residues are included, the output to input ratios for whole-plant harvest would increase to 5.2 for corn and 13.0 for wheat (Ref. 99). Figure 14 shows the inverse proportionality between the energy output to input ratio and the yield.

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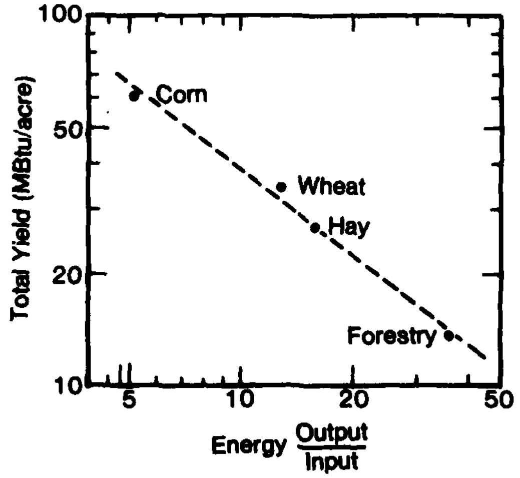
* The nutrients in sludge are retained more efficiently in soil than inorganic fertilizers, so less nutrients need be applied in this form than if inorganic fertilzers are used. In addition, the rate of nutrient leaching from sludge is much lower than from inorganic fertilizers, so this problem is reduced as well.

Table 54. Considerations in Performing Biomass Energy Analysis

Problem	Examples for Biomass Energy
Specification of system boundary	Should agricultural energy be included as an energy input? What are other nonrenewable or primary energy inputs?
Comparison of different energy types	Should energy balance be calculated for total nonrenewable energy or for only one type, particularly oil or natural gas used by installations?
Consideration of end use	What will be the final energy form produced?
Consideration of joint product	Will energy credits be included for use of conversion biomass residues? Will energy penalties be included for energy consumed for items such as soil depletion control, transportation costs, or energy costs associated with manufacture of system hardware?



Source: Ref. 99

Figure 14. Inverse Proportionality of Major Biomass Crop Yields and the Ratio of Energy Output to Input (Does not include solar energy input)

Biomass from forest land and cropland requires very high quality energy sources, such as gasoline, commercial fertilizer, and electricity. Biomass fuel is usually not fully dried or bulky and has a lower heat content per pound compared to fossil fuels. Therefore, energy input to biomass production should be valued approximately 50 percent higher than the biomass energy produced, unless biomass can be directly substituted for oil or gas on a Btu-for-Btu basis (Ref. 99).

Burwell (Ref. 99) has estimated the net biomass energy production for the United States that attempts to account for the energy to produce and collect it. Table 55 shows this potential for 1974. Major differences between gross energy yield and net energy yield are attributed to (1) high energy input required for corn production, (2) certain forest residues judged to be relatively uncollectable, and (3) rangeland production collected inefficiently in terms of its use for energy.

Table 55. Potential Collectable Net Yield From U.S. Biomass Operations Under Present Management Practices (1974)

Biomass Activity	Gross Energy Yield (Quads)	Collectible Net Energy Yield[1] (Quads)
Agriculture		
Corn	3.9 (1.9)[2]	3.0 (1.8)
Grains	3.2 (2.1)	2.9 (2.0)
Green Crops	2.2	2.1
Oil Seeds	1.2 (0.4)	1.1 (0.4)
Fruits and Vegetables	0.2	0.2
Other[3]	0.7	0.6
Silviculture	9.3 (3.7)[4]	6.6 (1.2)[5]
Pasture and Rangeland	7.0	.07
Total	27.7 (8.1)	17.2 (5.4)

[1] Energy input valued at 1.5 times biomass energy value
[2] Residual values given in parentheses
[3] Taken as 10 percent of the total for all agriculture excluding corn, in order to account for minor crop acreages
[4] All residues
[5] Excludes tree leaves, small branches, and roots; includes stump, unmerchantable bole, and large branches

Source: Ref. 99

5.4 Outlook for Application of Biomass Energy

Because biomass to energy conversion technology is in an early stage of development, it is uncertain what contribution biomass energy will provide to DOD fixed installation energy demand. However, in developing technology, emphasis should be placed on meshing biomass sources with localized facility needs. The biomass production and conversion considerations presented here provide an initial analytical evaluation that might be used in making required judgments and developing a basis for assessing biomass energy as a part of the DOD energy system.

Forestry resources provide the suitable characteristics that are required for biomass energy production. Specific forest sources when ranked from nearest to longest term entry to military installation application are forestry residues, resources from better management forestry, and intensive tree farming. In particular, military installations located in the eastern and central regions are potential candidates for biomass energy application. Such facilities provide an excellent opportunity to ensure that process technology, energy requirement management, environmental protection, and economic viability develop simultaneously.

6.0 IDENTIFICATION AND DESCRIPTION OF POTENTIAL ENERGY RECOVERY FROM HAZARDOUS WASTE FEEDSTOCK ANALYSIS

6.1 Identification of Military Hazardous Wastes

This section examines hazardous waste generated at military installations from the standpoint of using such wastes for energy. Hence, the entire problem of hazardous waste handling, transportation, and disposal will not be addressed. What is provided will be the potential energy output of selected hazardous waste and the problems that may be encountered.

A hazardous waste is defined for purposes of this study as a nonreusable material that must be treated or disposed of in a specially designed facility that meets the regulatory requirements of the Resource Conservation and Recovery Act (RCRA) of 1976 (P.L. 94-580). It might be noted that sludges generated from waste treatment facilities may also be classified as hazardous waste. Nuclear wastes are defined and controlled under separate regulations and are not covered in this analysis.

Data for total DOD hazardous waste types and quantities were not available. Instead, the Navy's inventory survey of its hazardous waste stream will be presented. From a regional perspective, the military hazardous waste stream of Hawaii will be described.

6.1.1 Navy Waste Data

Total 1978 U.S. Navy hazardous waste generation was estimated by the Navy Environmental Support Office (Ref. 131). The data cover all Continental U.S. facilities, as well as Hawaii and other Pacific Basin islands. The common hazardous wastes are as follows (Ref. 131):

- Naval shipyards* -- acids, asbestos, caustics, mercury wastes, metal wastes, paint wastes, plating wastes, sandblasting wastes (organotin), ship wastes, solvents (e.g., degreasers), and strippers;
- Naval air rework facilities** -- acids, beryllium wastes, caustics, metal wastes, paint wastes, plating wastes, solvents (e.g., degreasers), and strippers;
- Fuel depots -- oily wastes, tank bottoms, and waste fuels;
- Naval weapons stations -- ordnance wastes; and

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* These wastes may also be found at some Naval Stations.

** These wastes may also be found at some Naval Air Stations.

- All activities -- battery acids, boiler blowdown wastes, chemical cleaners, cooling tower bleedoff, corrosion inhibitors, disaster preparedness wastes (i.e., DS-2, DANC, STB, ethylene oxide), firefighting agents, hydraulic fluids, paint wastes, PCBs, pesticide wastes, photographic lab wastes, oily wastes, and miscellaneous chemicals (e.g., laboratory wastes).

Operations/processes and related hazardous wastes are as follows (Ref. *131*):

- Metal plating -- acids, pickling liquor, caustics, spent cyanide solutions, chromium wastes, and other metal wastes;
- Degreasing -- solvents (e.g., trichloroethylene, trichloroethane);
- Painting -- paint strippers, paint thinners, paint wastes (slops), and waste epoxy (resin);
- Machine shops -- cutting oils and toxic metals;
- Miscellaneous ship repair wastes -- ripout wastes (asbestos), sandblasting wasts (organotin), and welding wastes (acetylene sludge);
- Miscellaneous aircraft repair wastes -- brake relining wastes (beryllium wastes), metal stress and defect analysis wastes (fluorescent dye), and welding wastes (acetylene sludge);
- Fuel storage and supply -- waste (or slop) oil, bunker oil, fuel waste, tank bottom sediment, and tank cleaning sludges;
- Transportation -- waste oils, hydraulic fluids, battery acids, asbestos (brake linings), ethylene glycol (coolants), paint wastes, and solvents;
- Pest control shop -- unrinsed pesticide containers and waste pesticides;
- Boilers -- blowdown wastes (e.g., hydrazine, morphaline), feedwater chemicals, and feedwater testing wastes (e.g., mercuric nitrate in submarines);
- Cooling towers -- bleedoff wastes and feedwater chemicals;
- Battery shop -- battery acids, alkaline battery fluid, and heavy metals;
- Disaster preparedness -- bleach (STB), decontaminating gases (ethylene oxide), and decontaminating liquids (DS-2, DANC);

- Print shop, ADP center -- printing ink and data processing fluid; and

- Other operations/processes -- ordnance wastes (e.g., TNT, RDX, picric acid, otto fuel), photographic wastes, transformer fluids (PCBs), Industrial Waste Treatment Plant sludge, laboratory wastes, firefighting agents (e.g., AFFF), chemical toilet waste, and chemical cleaners.

These lists could be useful later in categorizing or estimating data for similar types of Air Force and Army activities.

Navy facilities were partitioned by geographic considerations into arbitrary divisions called "complexes." In states where few facilities exist, all were grouped under the state name. In other states, a single city such as Orlando, Florida, or San Diego, California, is identified as a complex because of the high density of Navy facilities. The resulting summary of waste generation by Navy complex and by type of hazardous waste is given in Table 56. Supporting details with the number and types of facilities for each complex are contained in Appendix D.

It is estimated that Navy ship and shore activities in the United States generate 19 million gallons of liquid hazardous waste and 35 million pounds of solid hazardous waste annually. Based on the reported categories and quantities of waste, a preliminary estimate has been prepared to define the total potentially recoverable energy in U.S. Navy waste. Two types of energy recovery methods appear feasible in the near-term: incineration for combustible wastes and pyrolysis for explosives. Four waste categories were defined to form the basis for total energy recovery from incineration:

- Solvents

- Strippers and thinners

- Oil sludge

- Hydraulic fluids

Some qualification is necessary. For example, the composition of the hydraulic fluids is not known. Most modern, synthetic hydraulic fluids contain flame suppressants for safety and other reasons, and they, therefore, may not be combustible at reasonable dilutions with fuel oil or solvent wastes. In such a case, they could be recovered by re-refining and still result in both net economic and energy savings. For purposes of incineration, it is assumed that the hydraulic oils are of a mineral oil base. Also, the high flash point oils are presently being incinerated by the Navy in Hawaii. Energy recovery or savings from such existing practices is not separately identified in this preliminary analysis because insufficient details are available. Another, not so obvious, assumption is implicit in the use of the higher heating value (HHV) rather than the lower heating value. The

Table 56. Annual Complex Totals

Complex	Waste Types and Quantities																					
	Solvents (KGal)	Paint Sludge (KGal)	Strippers & Thinners (KGal)	Oil Sludge (Tons)	Hydraulic Fluids (KGal)	Indus Trtmt Sludge (Tons)	Acids (KGal)	Caustics (KGal)	Plating Wastes (KGal)	Ordnance Wastes (Tons)	Mercury (Tons)	Pesticides (KGal)	PCBs (KGal)	Corrosion Inhibitors (KGal)	Decontam. Materials (Tons)	Sandblast Grit (Tons)	Batteries (Tons)	Firefighting Agents (KGal)	Misc Liquids (KGal)	Misc Solids (Tons)	Complex Totals KGal	Complex Totals Tons
Newport, Rhode Island	61.2	118.8	23.5	10.0	39.7	28.0	17.8	21.0	77.5	2.0	0.2	6.9	1.0	7.3	9.5	---	---	1.0	67.6	34.3	443.3	84.0
Maine	64.2	97.5	15.9	---	17.1	14.0	4.5	21.8	69.0	1.0	---	1.4	1.0	2.3	1.5	---	---	1.0	61.2	21.4	356.9	37.9
New Hampshire	13.2	98.0	31.2	100.0	13.8	25.0	40.7	2.3	41.4	---	2.1	5.3	2.6	17.5	4.8	88.0	1.3	1.7	52.2	21.5	319.9	242.7
New London, Connecticut	57.1	82.0	11.9	50.0	63.7	14.3	11.8	17.4	84.9	---	17.8	2.9	2.8	12.6	3.5	44.0	5.5	1.4	65.5	20.6	414.0	155.7
New York City	706.7	281.2	28.1	---	31.6	14.3	18.1	41.9	131.3	---	2.0	7.2	3.4	14.2	11.0	172.0	1.2	7.2	119.7	44.3	1389.4	244.6
Philadelphia, Pennsylvania	64.8	166.9	52.0	150.0	63.5	49.3	52.1	17.5	68.9	---	0.7	8.8	3.2	31.3	34.0	678.0	1.6	2.3	160.0	48.9	691.3	962.5
Washington, D.C.	43.3	62.3	20.1	10.0	54.1	5.2	8.7	16.5	27.0	860.0	1.0	6.0	3.5	14.6	18.5	40.0	---	2.0	112.9	58.4	371.0	933.1
Norfolk, Virginia	156.7	304.8	87.7	450.0	250.7	41.6	239.0	29.9	174.4	35.0	23.3	13.8	12.9	88.1	32.8	2390.0	29.8	48.2	489.3	71.8	1891.5	3374.3
North Carolina	207.6	172.5	44.5	160.0	52.3	15.6	6.1	23.4	60.0	---	0.5	3.0	4.5	22.8	7.6	40.0	---	2.0	118.6	30.3	717.3	253.9
Charleston, South Carolina	48.7	136.2	45.2	350.0	136.2	25.0	53.0	10.9	78.9	108.0	13.6	15.0	8.0	43.2	23.4	1860.0	14.2	13.6	240.4	48.7	830.3	2442.9
Pensacola, Florida	232.3	195.2	50.3	350.0	48.0	50.0	10.2	48.8	15.6	---	0.6	5.0	1.2	21.4	6.5	40.0	0.6	5.1	144.3	28.6	777.4	476.3
Jacksonville, Florida	136.9	200.9	52.1	300.0	103.6	40.0	64.2	27.4	89.1	---	4.0	5.0	5.5	76.4	19.5	44.0	9.1	17.7	240.4	40.8	1019.2	466.4
Key West, Florida	17.8	23.3	7.2	10.0	16.8	---	1.4	5.3	9.0	---	0.1	4.8	2.0	3.4	4.0	---	---	3.0	33.5	7.8	127.8	21.9
Orlando, Florida	0.8	---	0.4	---	6.5	---	0.4	0.4	---	---	---	0.9	0.2	2.6	0.5	---	---	4.5	4.5	6.0	21.2	6.6
Georgia	4.0	4.5	1.6	1.0	6.5	10.0	0.4	1.2	1.8	---	---	3.8	2.0	1.9	6.5	---	---	3.0	7.6	1.2	38.5	19.7
Mississippi	9.5	11.3	3.9	50.0	12.3	19.6	1.1	2.7	6.0	---	1.0	4.8	2.5	2.8	8.5	44.0	0.3	1.6	18.0	3.0	76.5	126.4
New Orleans, Louisianna	4.8	6.3	1.9	100.0	6.4	---	2.4	1.4	7.7	---	0.1	0.6	0.6	3.6	3.0	22.0	0.3	1.3	11.9	2.0	179.3	127.4
Chicago, Illinois	15.7	16.9	6.6	10.0	33.0	---	2.2	5.2	6.8	---	---	5.2	1.5	10.5	5.5	---	---	4.0	33.4	5.4	141.0	20.9
Texas	137.0	206.3	36.3	50.0	30.8	58.6	9.8	46.5	142.5	75.0	0.1	1.0	0.5	5.2	2.5	20.0	---	4.0	138.1	52.6	766.0	363.8
Tennessee	63.2	97.5	15.9	50.0	16.8	59.0	6.3	22.0	69.0	---	0.1	1.0	0.5	2.2	2.5	---	---	1.0	61.9	27.3	367.3	136.9
Seattle, Washington	36.0	124.9	39.2	110.0	64.7	3.9	54.2	8.3	59.2	---	3.3	7.3	11.0	31.6	36.5	198.0	2.6	11.9	110.6	32.6	566.5	386.9
San Diego, California	441.0	204.2	57.4	400.0	268.2	50.0	236.9	28.1	148.6	---	11.7	17.2	14.0	250.4	117.5	396.0	33.6	50.2	514.8	69.7	2231.0	1073.5
San Francisco, California	246.7	294.9	82.8	200.0	117.7	24.9	98.3	29.6	127.2	35.0	5.6	17.3	8.3	89.1	32.0	638.0	9.0	16.6	273.7	56.7	1400.9	1008.2
Los Angeles/Long Beach, California	36.0	129.4	41.5	150.0	43.5	25.0	69.9	9.5	56.0	---	1.1	8.7	11.5	46.0	16.5	2394.0	4.3	5.0	143.1	40.6	700.1	2631.5
Ventura, California	18.7	22.7	7.3	100.0	21.7	10.4	5.7	5.6	10.2	---	1.1	5.0	2.2	8.6	27.5	44.0	0.6	1.6	41.5	8.5	190.5	286.7
California (Miscellaneous)	31.7	102.5	38.6	150.0	38.9	505.3	355.7	35.7	16.5	20.0	1.1	5.4	3.0	128.5	31.6	20.0	---	1.0	92.9	92.3	1136.5	820.2
Hawaii	85.2	170.5	52.5	300.0	256.1	25.0	102.4	16.0	65.0	18.0	12.0	25.3	36.1	90.9	140.5	98.0	11.9	14.0	204.3	40.0	1137.3	664.4
Alaska	1.5	2.3	0.5	100.0	9.0	---	0.8	0.8	---	---	0.1	4.3	1.0	3.2	2.6	---	---	1.0	5.7	2.0	30.1	108.6
Puerto Rico	1.8	2.9	0.9	100.0	13.8	---	0.9	0.9	---	---	---	8.8	3.5	14.5	5.5	---	---	2.0	7.1	1.4	57.1	106.9
Guam	17.5	62.5	20.2	250.0	33.0	---	23.1	4.9	25.9	---	0.8	9.5	6.1	14.6	9.0	40.0	0.3	3.3	54.7	20.0	275.5	320.1
GRAND TOTAL																					16602.3	17946.1

Source: Ref. 132

relative difference in estimated energy recovery is approximately 5 percent and derives from the recovery of the heat of vaporization of the water formed during combustion of waste fluid (fuel). Additional capital equipment would be required to realize that energy recovery. Higher heating values were used because they are more commonly available and they represent an upper boundary for potential energy recovery when the best available technology is employed. Results of the Navy-wide analysis are presented in Table 57. It appears that if all potentially suitable liquid wastes are incinerated, approximately 1.2×10^{12} Btu could be recovered annually. This is equivalent to 206,000 barrels of crude oil annually.

Studies (Refs. 133 and 134) indicate that energy is recoverable from excess explosives by pyrolysis. Although the studies were conducted in the context of U.S. Army ammunition plant waste disposal, the results may be applicable servicewide. Currently, Army ammunition plants dispose of large quantities of neat explosives and chemical- and explosive-contaminated waste by either open-air burning or incineration. These disposal techniques presently do not take advantage of the potential fuel value (7000 Btu/pound) of these wastes.

Table 57. Annual Potential Energy Recoverable From Selected U.S. Navy Hazardous Wastes[1]

Waste Category	HHV[2] k Btu/gal	Total Quantity k gal	Recoverable Energy 10^9 Btu/year
Solvents	65 - 100	2940.6	191 - 294
Strippers and thinners	130 - 140	876.2	114 - 123
Oil sludge	150 - 160	4061.0	609 - 650
Hydraulic fluids	140 - 145	1879.0	263 - 272
	k Btu/lb	k lb	
Explosives[3] (ordnance)	4.2 - 5.2	2308.0	10 - 12
TOTAL			1187 - 1351

[1] Incineration employed for liquids, pyrolysis for explosives

[2] k = 1000, HHV = higher heating value

[3] 60 to 70 percent recovered in char and oil, 16 to 22 percent in gas not credited. See text. Assumed energy content 7000 Btu/lb

(Ref. 133)

A laboratory study (Ref. 133) was conducted to investigate the feasibility of using a pyrolysis process to convert explosive-contaminated waste into a usable, storable fuel. In that study, samples of mixed waste material, and mixed waste material contaminated with levels of 1/2 percent, 1 percent, and 2 percent TNT, were pyrolyzed at 650°C. The results showed that 60 to 74 percent of the energy content of the input feed, on a dry basis, can be recovered in the char and oil that are storable and transportable. In addition, the data show the energy content of the generated gases to be in the range of 16 to 22 percent of the energy content of the input feed on a dry basis. The gases would have to be used onsite. During the course of the experiments, there was no evidence of any explosion hazard with the contaminated wastes. Moreover, the data did not indicate that there would be any significant environmental impact from the pyrolysis of TNT-contaminated waste.

A study (Ref. 134) was conducted to determine the feasibility of adapting pyrolysis technology to energy recovery from these solid wastes. Eight Army ammunition plants were surveyed to identify the types and amount of solid waste generated, and candidate systems were evaluated to determine their suitability of this application. Safety considerations indicated that propellants, explosives, and pyrotechnics (PEP) and PEP-contaminated waste, with proper precautions, could be handled safely by pyrolysis processes, but that further work is needed to determine applicable size reduction techniques.

The potentially recoverable energy in U.S. Navy waste ordnance was also estimated for this study. Results, which are shown in Table 57, indicate approximately 10 to 12 billion Btu or 1900 barrels of oil equivalent might be recovered annually. As mentioned above, the energy derives from both a char/oil residue and from evolved gases. Because the gases may not be usable onsite (the residue is transportable), they were, arbitrarily, excluded from the recoverable energy estimate, thereby reducing the potential by 16 to 22 percent.

6.1.2 Hawaii Region DOD Waste Data

The types and sources of hazardous waste at DOD military installations vary widely depending on the type of installation and its mission. Although no comprehensive tabulation of DOD-wide military waste is currently available, some useful inferences can be made based on selective studies (Refs. 132, 135, and 136). The following is a listing of the types of expected hazardous military waste for Hawaii for the year 1975 (Ref. 135):

- Agricultural -- spent pesticide containers, spent pesticide solutions, suspended and unusable, and pesticides;
- Governmental -- digested sewage treatment sludge, expired and unusable medicines, miscellaneous chemical wastes, pathological/infectious wastes, petroleum wastes, spent pesticide and chlorine, containers, suspended and unusable pesticides, and used solvents;

- Industrial/Commercial -- acids, alkalies, contaminated soil and sand, dye/ink wastes, expired and unusable medicines, inorganic wastes, pathological/infectious wastes, petroleum wastes, sludges, spent pesticide containers, spent photo chemicals, suspended and unusable pesticides, and used solvents; and

- Military - acids, alkalies, contaminted soil and sand, chromium wastes, dye/ink wastes, explosives, inorganic wastes, pathological/infectious wastes, petroleum wastes, sludges, spent pesticide and chlorine, containers, spent photo chemicals, strong oxidizers and reducers, suspended and unusable pesticides, and used solvents.

Hazardous military wastes that have been identified as unmanageable locally in the Hawaiian Islands are as follows:

- Suspended or unusable pesticides;

- Solvents -- trichloroethylene and tetrachloroethylene;

- Strong oxidizing agents -- ammonium perchlorate and calcium hypochlorite;

- Inorganic compounds -- ammonium bifluoride, sodium sulfide, sodium metasilicate, sodium bisulfate, mercuric nitrate, and hydrazine;

- Organic compounds -- phenol, formaldehyde, and diethanolamine;

- Electro-Clean compound;

- Sand blasting abrasives containing heavy metal compounds; and

- Fluid containing polychlorobiphenyls.

Torpedo fuel contaminated wastes were recently deleted from this list because of the successful installation of a new incinerator. Some of the other wastes can be rendered safe by specific treatment/process but facilities are not locally available nor are they feasible to construct at this time. A special incinerator is planned to dispose of small arms ammuniton that is presently being stored. Facilities for the proper disposal of wastes, such as mercury and organotin, can be provided, but are costly, require skilled personnel, and are considered infeasible under current circumstances. Storage or shipment to other suitable locations therefore appears to be the only viable solution for these wastes at the present time.

The Hawaiian installations embody special circumstances, such as restricted (island) geography, somewhat specialized military units, limited land vehicle use, and (relatively) few Army installation types, but the data as a whole are expected to be reasonably representative of the range of hazardous waste types generated by individual services on a DOD-wide basis during 1975. Examination shows that expected hazardous military waste, except for explosives, is quite similar to that for governmental and industrial/commercial sources. Table 58 is a tabulation, by service, of reported hazardous waste generation in Hawaii in 1975 (Ref. 135). The quantity of waste must be considered atypical (DOD-wide) for reasons stated earlier, but the types of waste and methods of disposal are pertinent.

Although the energy content of the wastes can be estimated independent of the waste disposal method, it is of interest to examine the hazardous waste practices in the Hawaiian sample. The findings pertaining to each military service are discussed below.

Navy -- The largest volume of wastes is generated by Navy operations. Petroleum products account for the largest single category of these wastes (over 6,400,000 gallons annually). Reclamation/recycling of petroleum wastes represents an economic asset from a resource standpoint and the large volume warrants recycling. The success of maximum recycling depends on proper segregation. Currently, the Navy oil reclamation facility processes only high-flash (greater than or equal to 140°F flash point) oily wastes. The low-flash oily wastes are disposed of by a private contractor using high temperature incineration.

The discharge of solvents into storm drains was a reported practice at certain Naval installations. A substantial volume of solvent wastes was also reported to be disposed of on land surface as a means of dust control. Disposal instructions require the incineration of solvents either by Public Works Center, Pearl Harbor, or private contract services. Infectious medical wastes (pathological wastes) are disposed of exclusively in landfills. This method of disposal is acceptable provided the wastes are first subjected to sterilization, incineration, or are rendered safe prior to landfill. The direct burial of such wastes without sterilization constitutes a violation of the State Public Health Standards. A large proportion of oxidizers and reducers and miscellaneous wastes is reportedly (Ref. 135) disposed of in a manner that is in direct conflict with regulations. These categories of wastes require case-by-case study of the industrial constituents and their associated modes of disposal. These categories of wastes must be further analyzed for energy recovery potential.

Army -- The reported disposal modes for petroleum products and explosives are generally in accordance with accepted practice (Refs. 134 and 135). However, some small quantities are reported to have been discharged into storm and sanitary sewers. These wastes could be redirected to the Navy-operated industrial plant for proper disposal. The dependency on sanitary sewers for the disposal of strong oxidizers and reducers, disinfectants, photographic solutions, and miscellaneous wastes requires careful evaluation. Many of the sub-categories of waste within this group are well assimilated by treatment processes. A portion of the solvent wastes is disposed of onground. Solvents are a waste with potential energy recovery value (ranging from about 65 to 100 K Btu/gal) (Ref. 138).

Table 58. Summary of Military Hazardous Waste Generation -- Hawaii, 1957

	Annual Quantity (liters/gallons)							
	Navy		Army		Air Force		Marine Corps	
	Metric	English	Metric	English	Metric	English	Metric	English
Acids and Caustics								
• Sanitary Sewer	41,000	10,800	8,400	2,200	1,940	510	910	240
• Storm Drain	56,200	14,800	70[a]	160[a]	11[a]	25[a]	38	10
• Shipped to Navy Industrial Waste Treatment Plant	316,200 6[a]	83,200 13[a]	38	10	1,900	500		
• Ground Surface or Pit	14,100	3,600	4,450	170			1,410	370
• Other							910	240
Alkalies								
• Shipped to Navy Industrial Waste Treatment Plant	126,200 5[a]	33,200 10[a]						
• Storm Drain	85,100 5[a]	22,400 10[a]	18[a]	40[a]				
• Sanitary Sewer	16,300	4,300	610	160	38 11[a]	10 25[a]		
• Evaporation	190	50	150 5[a]	40 10[a]	460	120		
• Storage					650	170		
Biological/Pathological[b]								
• Landfill	5,300 Items				6,000 Items			
Chromium Wastes								
• Shipped to Navy Industrial Waste Treatment Plant	6,800	1,800	11[a]	25[a]				
• Storm Drain	230	60						
• Sanitary Sewer	80	20						
• Landfill	11	3						
Detergents								
• Ground					1,140	300		
• Sanitary Sewer	20,100 4,360[a]	5,300 9,600[a]	760 36,400[a]	200 80,100[a]	73,000 3,910[a]	19,200 8,600[a]	19,800 2,730[a]	5,200 6,000[a]
• Storm Drain	50,200 1,640[a]	13,200 3,600[a]	190	50			26,200 1,640[a]	6,900 3,600[a]
• Shipped to Navy Industrial Waste Treatment Plant	28,100	7,400						
Disinfectants								
• Sanitary Sewer	250 5[a]	65 10[a]	1,070 1,320[c]	280 2,900[c]	1,980 23[a]	520 50[a]		
• Evaporation	130	35						
• Shipped to Suitable Place	110	30			1,900	500		
• Storm Drain	38	10						
Explosives								
• Shipped to Army Makua Valley Demolition Site	150 Items		130,900[a]	288,000[a]				
Fertilizers								
• All consumed	All		All		All		All	
Infectious Medical Wastes[d]								
• Landfill	14,000 Items		100 Items		92,000 Items		100,300 Items 500[a]	1,100[a]
• Incinerator	500 Items		76,600 Items 91[a]	200[a]				
Inorganic Materials								
• Consumed or Returned to Manufacturer			9[a]	20[a]	140[a]	300[a]		
• Shipped to Navy Industrial Waste Treatment Plant	14[a]	30[a]						
• Landfill	110[a]	250[a]						
Miscellaneous								
• Storm Drain	23,200 11[a]	6,100 250[a]					6,194,000 1,360[a]	1,630,000[e] 3,000[a]
• Ground	12,500 1,140[a]	3,300 2,500[a]	45[a]	100[a]			1,100[a]	2,400[a]
• Landfill	55[a] 600 Items	120[a]						
• Shipped to Suitable Place	122,000	32,000	610	160				
• Awaiting Disposal	10,600 1,140[a]	2,800 2,500[a]						
• Sanitary Sewer			3,800 3,400[a]	1,000 7,500[a]			12,500	3,300

[a] Quantities shown in kilograms/pounds.

[b] Bacteria cultures, carcasses, and tissues.

[c] Chlorine bleach; quantities in kilograms/pounds.

[d] *Dressings and needles.*

[e] Steam plant blowdown, pool filter backwash, and engine test cell.

Table 58. Summary of Military Hazardous Waste Generation -- Hawaii, 1957 (Continued)

	Annual Quantity (liters/gallons)							
	Navy		Army		Air Force		Marine Corps	
	Metric	English	Metric	English	Metric	English	Metric	English
Pesticides/Herbicides								
• All Consumed or Stored	All		All		All		All	
Petroleum Products								
• Shipped to Navy Oil Reclamation Center or Energy Recovery System	23,900,000 110[a]	6,282,000 240[a]	285,800	75,200	97,700	25,700	13,700	3,600
• Ground	89,700 23[a]	23,600 50[a]	1,750 70[a]	460 150[a]	1,710	450	49,400	13,000
• Landfill	1,900	500						
• Sanitary Sewer	38	10						
• Storm Drain	38	10			1,140	300		
Photographic/Printing Solutions								
• Sanitary Sewer	56,200	14,800	32,700	8,600	411,200	108,200	3,200	800
• Silver Recovery Effluent	25,100	6,600			182,400	48,000		
• Shipped to Suitable Place	14,400	3,800						
• Ground	8	2						
• Cesspool	1,500	400						
Sludges								
• Landfill	1,520 5[a]	400 10[a]	1,900	500				
• Solvents	56,200	14,800	4,900	1,300	2,550	670	54,000	14,200
• Shipped to Energy Recovery Systems	30,000	7,900	33,300	19,300	113,600	29,900		
• Storm Drain	28,100	7,441	3,800	100				
• Sanitary Drain	300	80	460	120	760	204		
Spent Pesticide and Chemical Containers								
• Incineration	40 Items							
• Landfill		600 Items		248 Items				
Strong Oxidizers and Reducers								
• Sanitary Sewer			1,270[a]	2,800[a]	150	40		
• Storm Drain	1,140 3,100[c]	300 6,800[c]						
• Landfill	65 Items							
• Shipped to Navy Industrial Waste Treatment Plant	5[a]	10[a]						

[a] Quantities shown in kilograms/pounds.

[b] Bacteria cultures, carcasses, and tissues.

[c] Chlorine bleach; quantities in kilograms/pounds.

[d] Dressings and needles.

[e] Steam plant blowdown, pool filter backwash, and engine test cell.

Source: Ref. 137

Air Force -- Photographic and infectious medical wastes make up the largest volume of wastes generated by the Air Force in the State of Hawaii. An in-house study was conducted by the 15th Air Base Wing Environmental Health Service to ascertain the appropriate disposal methods for photographic chemicals. Based on methods recommended by both industry and Air Force guidance, photographic chemicals require pretreatment before discharge into sanitary sewer systems. The prescribed pretreatment methods consist of (1) recovery of silver from fixer solution and (2) adequate dilution of the remaining photographic chemicals. The Air Force has undertaken enforcement of the above recommendation in all of its photographic processing facilities. The recovery of silver represents both material recycling and energy savings.

The Air Force relies exclusively on landfill as a final means of diposal of infectious medical wastes. Sterilization procedures are applied to infectious medical wastes before disposal in compliance with standard medical procedures. Six thousand items of bacteriological culture wastes were reported by the Air Force as part of its biological and pathological waste category.

Disposal methods for petroleum products and solvents (potential sources of energy) were not identified but were considered environmentally acceptable (Ref. 135).

6.2 Potential Energy Recovery From DOD Hazardous Waste: Waste Oil Analysis

Waste petroleum, oil, and lubricants (POLs) are not generally considered under Section 3000 of the Resource Conservation and Recovery Act (RCRA) as hazardous wastes. However, significant POL waste from a variety of military operations merit further analysis as a potential waste stream for energy recovery.

The firing of POLs in existing gas-, oil-, and coal-fired boilers is technically feasible and is rapidly gaining operating experience (Ref. 139). It is the policy of each service branch that POLs be used wherever feasible (Refs. 139, 140, and 141). As new and stricter environmental pollution regulations make POL disposal methods, such as open burning, landfilling, or dust control, more difficult to apply, using such wastes as a supplementary auxiliary fuel in heat-recovery incinerators is becoming a more viable option.

6.2.1 Fuel Comparisons

Various virgin and used fuels are compared in this section:

Used Oils (Ref. 142) -- Used oils are a heterogeneous group: crankcase oil, hydraulic oil, cutting oil, and others. The most readily available used oil is crankcase oil, which is also the most likely type to be used as a fuel. Properties of used crankcase oil along with No. 2 and No. 6 oils are shown in Table 59.

Table 59. Properties of Virgin Fuel Oil (No. 2 Distillate and No. 6 Residual) and Used Oil (Automotive Crankcase Drainings)

Property*	Composite Range Values		
	No. 2 Distillate	No. 6 Residual	Used Oil, Crank-case drainings
Gravity, deg API at 60°F	30.2 to 45.3	0.3 to 26.0	20.0 to 27.9
Specific Gravity	0.800 to 0.875	0.898 to 1.022	0.887 to 0.934
Density, lb/gal	6.68 to 7.30	7.5 to 8.5	7.40 to 7.78
Viscosity, SFS at 122°F	-	24 to 350	-
Viscosity, SUS at 100°F	32 to 40	-	87 to 837
Viscosity, Centistokes	1.8 to 4.1	7 to 750	17.3 to 180.6
Pour Point, °F	(-50) to 25	(-10) to 95	(-40) to (-30)
Flash Point, °F	126 to 204	150 to 270	175 to 415
Heating Value, Btu/gal	130,900 to 141,800	146,100 to (>157,700)	105,555 to 143,360
Heating Value, Btu/lb	18,145 to 19,895	17,410 to (>20,480)	13,571 to 19,300
Neutralization Number, mg KOH/gm	-	-	4.0 to 14.3
Bottom Solids and Water, vol %	0.00 - (<0.1)	0.00 to 2.00	0.1 to 22.0
Sulfur, wt %	0.02 to 0.59	0.3 to 4.0	0.21 to 0.65
Ash, wt %	0.00 to 0.005	0.00 to 0.50	0.03 to 3.78
Silicon, ppm	-	8.2 to 164.0	10 to 875
Calcium, ppm	-	0.7 to 95.0	700 to 3,000
Sodium, ppm	-	1 to 480	16 to 300
Iron, ppm	-	10.5 to 230.0	50 to 2,000
Magnesium, ppm	-	0.4 to 27.9	10 to 1,108
Lead, ppm	-	1.7 to 4.1	800 to 11,200
Vanadium, ppm	-	1 to 380	3 to 39
Copper, ppm	-	0.5	5 to 348
Barium, ppm	-	-	10 to 2,000
Chromium, ppm	-	13.7	8 to 50
Nickel, ppm	-	3 to 118	3 to 30
Aluminum, ppm	-	0.5 to 219	10 to 800
Silver, ppm	-	0.3	1
Titanium, ppm	-	5.5	5 to 30
Molybdenum, ppm	-	2.3	2 to 3
Zinc, ppm	-	-	300 to 3,000
Phosphorus, ppm	-	-	500 to 2,000
Tin, ppm	-	-	5 to 112
Beryllium, ppm	-	-	6
Manganese, ppm	-	-	5 to 10
Cadmium, ppm	-	-	4
Strontium, ppm	-	-	10 to 30
Boron, ppm	-	-	3 to 20

*ppm (as the element) = 0.0001 wt %

Source: Ref. 142

Coal (Ref. 142) -- Properties for bituminous, subbituminous, and lignite coals are presented in Table 60. As shown, coal contains considerably higher amounts of certain trace metals than residual and used oils do. The principal trace metals in coal are aluminum, beryllium, boron, calcium, iron, magnesium, manganese, molybdenum, nickel, silicon, silver, sodium, sulfur, strontium, titanium, and vanadium. Except for lead and phosphorus, substituting waste oil for a portion of the coal reduces trace metal emissions. However, the lead emissions are of considerable concern as a hazardous pollutant.

Table 60. Properties of Coal: Bituminous, Subbituminous, and Lignite

Property*	Composite Range Values		
	Bituminous	Subbituminous	Lignite
Fixed Carbon, wt %	39 to 86	38 to 40	31
Volatile Matter, wt%	14 to 40	28 to 34	28 to 59
Moisture, wt %	2.6 to 20.6	16.5 to 24.6	34.8
Heating Value, Btu/lb	9,171 to 15,800	8,300 to 11,500	6,300 to 14,300
Sulfur, wt %	0.5 to 5.0	0.4 to 2.1	0.7 to 1.1
Ash, wt %	3.0 to 18.0	3.8 to 11.2	5.0 to 12.8
Silicon, ppm	9,818 to 38,500	7,390	4,180 to 25,000
Calcium, ppm	527 to 15,009	12,300	16,100 to 21,300
Sodium, ppm	293 to 645	98	74 to 1,921
Iron, ppm	3,230 to 25,703	5,080	2,100 to 5,910
Magnesium, ppm	190 to 2,533	1,590	603 to 5,271
Lead, ppm	4.5 to 137	-	8.9 to 89
Vanadium, ppm	19 to 41	0.8 to 44	8.9 to 89
Copper, ppm	23 to 105	1.5 to 53	8.9 to 89
Barium, ppm	53 to 462	-	132 to 134
Zinc, ppm	45 to 200	<525	8.9 to 35.8
Phosphorus, ppm	20 to 40	-	50
Tin, ppm	0.4 to 550	1.5 to 7.5	-
Chromium, ppm	20 to 28	-	-
Nickel, ppm	13 to 189	-	-
Beryllium, ppm	0.1 to 31	-	-
Manganese, ppm	13 to 189	-	131
Silver, ppm	0.5 to 2.9	-	-
Strontium, ppm	95 to 935	-	-
Aluminum, ppm	5,557 to 19,448	6,935	4,691
Titanium, ppm	315 to 1,574	188	102 - 782
Boron, ppm	8.4 to 101	-	185
Molybdenum, ppm	3.2 to 28	-	-

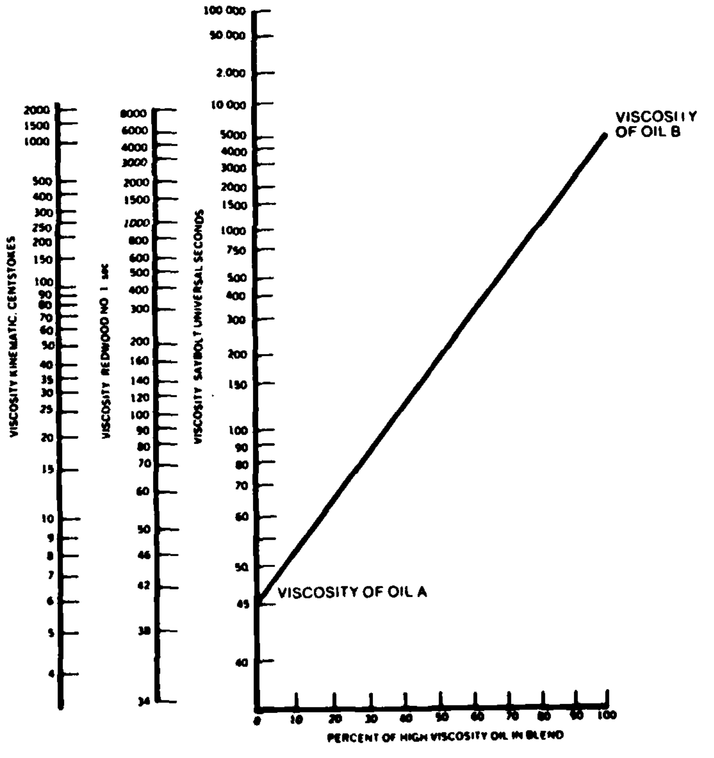
*ppm (as the element) = 0.0001 wt %

Source: Ref. 142

Many coal-burning facilities are required to use emission control devices, such as electrostatic precipitators. A properly designed and maintained precipitator is capable of an order of magnitude reduction in the emission of submicron particles. These devices should be capable of entrapping lead as well. Based on this brief review of used oil combustion with coal, it appears that this option may be the best fuel use for used oil. However, few data are available relative to the combustion of used oil with coal. A 6-day test performed by Northern States Power Company in 1973, using 6 percent of the heat input in the form of crankcase drainings, indicates that crankcase oil could be burned with no detectable increase in stack lead emissions. However, a precipitator was used in these tests (Ref. 143).

Blends of Used Oil and Fuel Oil (Ref. 142) -- Properties of blends of used oil and fuel oils vary as a function of the blend ratio. All properties except viscosity may be considered a linear function of the two constituents. Viscosity may be determined from the chart shown in Figure 15.

The heating value of the used oil and feed oil blend for either No. 2 of No. 6 fuel oil declines as the used oil fraction increases. On the average, the heat content of used oil is lower than for virgin fuel oils because of the higher water content of used oil.



Source: Ref. 144

Figure 15. Viscosity Chart for Oil Blends

6.2.2 DOD Studies

Air Force studies have indicated that many types of POL can be fired as a supplement in oil- and gas- or coal-fired boilers with minimal modification (Ref. 140). These materials include waste aviation piston-engine oil; mixtures of piston-engine oil, synthetic turbine lubricant, and hydraulic fluid; complex mixtures of piston-engine oil, synthetic turbine oil, hydraulic fluid, and Stoddard solvent; JP-4; and JP-4 contaminated with AvGas.

Wastes are produced from lubricants, fluids, and solvents when contaminants of metal, water, grit, and other petroleum products accumulate, and from the breakdown of additives and base stocks. Contaminated fuels are generated by the accumulation of water, grit, and also by bacterial growth. Regular draining and purging of aircraft and truck fuel tanks produce contaminated fuels yielding, for example, low-flash JP-4 with a mixture of petroleum-based purge oil and high-flash JP-5. Contaminated fuels are also generated when jet fuel and oils are transported through multifunctional pipelines during the transition phase (i.e., when cleaning out fuel pipeline).

No reliable data are available regarding the quantities of waste POL generated at DOD installations. A 1974 survey of 98 major Air Force installations in CONUS revealed that about 221,000 gallons/month of spent lubricants and fluids and nearly an equal quantity of contaminated fuel was being generated (Ref. 140) (Table 61). However, based on the new POLs purchased, the data appear to be low, and a more realistic quantity would be approximately 40 to 50 percent higher (Ref. 140). For example, about 4 million gallons of synthetic turbine lubricants are purchased annually. Accounting for "in use" consumption, the quantities of spent lubricants and fluids would be expected to be much higher.

Table 61. Generation of Waste POL at 98 Air Force Installations (Gallons/Month)

	Total	Range	Average
Spent lubricants and fluids	221,186	55 - 19,600	2,257
Contaminated fuels	219,354	0 - 20,000	2,238

Source: Ref. 140

Combustion with heat recovery in existing heating plant boilers may be a viable disposal option for spent lubricants, fluids, nonhalogenated solvents, and contaminated fuels. Waste POL (without water) may attain the approximate equivalent Btu content (15,000 to 18,000 Btu/lb) as distillate fuel oils. Research by Esso Research and Engineering Company and TRW Systems, Inc., investigated this method of waste POL disposal using a York Shipley dual-fired horizontal tube boiler (Ref. 140).

Various waste POL component blends were tested with varying concentrations of No. 2 fuel oil, No. 6 fuel oil, and natural gas. For steady state tests, a concentration of 5 percent by volume for lubricants, fluids, and solvents and up to 50 percent by volume for JP-4 in fuel oil was selected. It was noted that it was unlikely for a base to combust all its waste POL at such high concentrations as tested.

Emission data were developed for CO_2, O_2, NO_x, CO, HC, SO_2, Bacharach smoke No., particulates, and stack temperature. The results indicate that no significant emission increase in the tests were realized, except for NO_x concentration in the natural-gas-fired mode. Further, although tests were about 3 to 4 hours each in duration, no observable corrosive action was observed. Future testing will hopefully be at actual Air Force installations that produce significant volumes of waste POL but do not have suitable means of disposal.

An Army study determined that the best method to dispose of waste POL was combustion in a facility's boilers (Ref. 145). The Red River Army Depot produces about 135,000 gallons annually, while the depot boilers burned 1,040,247 gallons of No. 2 fuel oil in FY 1973. Laboratory analysis revealed that the waste POL was acceptable as a supplementary boiler fuel. However, further sampling and analysis was needed prior to actual implementation of a waste POL burning program.

At a Naval installation, the use of waste oil with base solid waste was analyzed (Ref. 55). Waste oil could be used either for direct ignition of the solid waste or afterburning. Subsequent evaluation determined that the waste oil should be used as an ignition fuel rather than all clean fuels.

A Coast Guard study revealed that waste lube oil could also be safely burned in fleet diesel engines, boilers, and gas turbines (Ref. 137). After proper filtering to remove particulates, insolubles, and water, burn-off mixtures of 1:100 by volume in fuel oil could be attempted without affecting diesel engine emissions, performance, or wear rates.

6.3 Military Installation Analysis

Not every military installation may generate sufficient quantities of hazardous waste to justify capital expenditures for a facility to recover the potential energy locally. For those that might be suitable, an estimate of the local savings can be made. The U.S. Navy complex in the San Diego area was selected by The Aerospace Corporation for analysis as a representative example. The particular area encompasses a wide range of both ship and shore facilities whose activities might easily be compared to a large Air Force or Army complex. Included are 2 bases (Marine and/or Navy), 3 Air

Stations, 2 hospitals, 1 Public Works Center, 1 Naval Training Center, 1 Naval Air Rework Facility, 2 Naval Supply Centers, 1 Naval Undersea Center, 1 Naval Submarine Base, 96 ships, and 15 submarines. The total hazardous waste generated is identified in Table 56.

Items of hazardous waste that might be salvaged for energy recovery are listed in Table 62. As with the analysis on a Navy-wide basis, the assumed types of energy recovery processes are incineration and pyrolysis. In the case of San Diego, however, no waste ordnance appears to be generated. Recoverable enery is estimated to be approximately 144.5 billion Btu, which corresponds to an annual savings of 24,900 barrels of oil equivalent.*

Table 62. Annual Potential Energy Recoverable at the San Diego Naval Complex From Selected Hazardous Wastes[1]

Waste Category	HHV[2] k Btu/gal	Total Quantity k gal	Recoverable Energy 10^9 Btu
Solvents	65 - 100	441.0	28.7 - 44.1
Strippers and thinners	130 - 140	57.4	7.5 - 8.0
Oil sludge	150 - 160	400.0	60.0 - 64.0
Hydraulic fluids	140 - 145	268.2	37.5 - 38.9
	k Btu/lb	k lb	
Explosives[3] (ordnance)	4.2 - 5.2	0.0	0
TOTAL			133.7 - 154.9

[1] Incineration employed for liquids, pyrolysis for explosives

[2] k = 1000, HHV = higher heating value

[3] 60 to 74 percent recovered in char and oil, 16 to 22 percent in gas not credited. See text. Assumed energy content 7000 Btu/lb.

Source: Ref. 133

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* Assumes 1 barrel oil = 5.8×10^6 Btu.

Further analysis is required to determine how and where the hazardous waste could be utilized for energy recovery. One alternative would be to use waste-derived fuels as supplementary or auxiliary fuels to the facility's heating plant system. Such future disposal methods of hazardous and solid wastes generated at the complex may be appropriate, especially if current practices for disposal would be greatly restricted.

6.4 Barriers to Energy Recovery From DOD Hazardous Waste

Improved inventory and characterization of hazardous wastes are the necessary first steps for the proper disposal and/or recovery of wastes from military installations. There are several disposal and recovery alternatives available to DOD installations, none of which are universally applicable. A highly desirable option at one installation may not be appropriate at another installation even though the two installations may have identical missions and generate the same types and volumes of hazardous waste.

A number of barriers to energy recovery from DOD hazardous waste can be identified. Most obvious is the wide variation in waste types or quantities generated at different facilities. Stricter regulation beginning in calendar year 1980 could force transportation to a central disposal facility but it is not intuitively obvious now how the various facilities will adapt to more stringent handling and disposal requirements.

Hazardous wastes contain a myriad of contaminants. For example, waste lubricating oils contain oxidation products, sediment, water, and metallic particles resulting from machinery wear. In addition, waste lubricants may contain organic and inorganic chemicals used in oil additives and metals that were present in gasoline and transferred to the crankcase during combustion (blow-by) (Ref. 146).

Other types of hazardous waste will have other characteristics that will affect the energy recovery potential and method. The use of combustible wastes and explosives for personnel training, for example, may require special rulings as to the proper and safe method of disposal. Limitations on open burning and detonation imposed by RCRA may in itself force adaption of alternative methods of handling.

Technical, economic, and environmental barriers are significant and as varied as the types of DOD hazardous wastes. The analysis considered using hazardous waste as an ignition or supplement fuel in combustion processes. Obviously, much more work must be accomplished to alleviate the technical problems, reduce environmental impacts, and produce cost effective systems.

According to the U.S. Army Armament Research and Development Command studies, there are indications that adapting a pyrolysis technology to energy recovery from explosive contaminated waste may not be an economically competitive approach (Refs. 133 and 134). Capital cost for a 50-TPD facility was estimated at $4.1 million (1979 dollars). Additional operating costs were expected to be about $623,000. On the other hand, capital costs of waste petroleum oil and lubricant firing can range between $500 and $10,000/boiler, depending on the extent of burner modification required and the cost of handling the material (Ref. 137). Savings of virgin fuel could be expected to pay back these relatively small investments in 1 to 4 years.

The combustion of hazardous waste without proper removal of toxic materials can cause adverse environmental effects. From the public health point of view, lead emissions are the most significant contaminant from waste POL combustion (Refs. 143, 146, and 147). This and other environmental impacts can be minimized by employing existing control technology to remove the contaminants prior to combustion or by the use of high efficiency air pollution control equipment to remove contaminants in the stack gas prior to entering the atmosphere. Further evaluation is required to determine the toxicity and potential hazard the combustion residue may produce. These restrictions will increase the cost of using hazardous waste as a fuel, and its economic desirability will be affected by the availability and acceptability of alternative disposal methods.

7.0 OVERALL ASSESSMENT OF ENERGY RECOVERY SYSTEMS

7.1 Site Selection Considerations

Performance information has been increasing for military scale and small community about (10 to 120 TPD) waste-to-energy conversion systems. These developments have been discussed in previous chapters. Yet although considerable experience has been gained; the assessment of the technical-economic feasibility of recovering waste energy must be made by individual installations.

No two military installations are exactly alike even though they may be the same size and have the same type of operation. Characteristics related to waste generation and energy consumption are unique to each facility. For example, geographic characteristics will greatly affect the type of waste generated and the energy production system of a facility. Installation commanders must be aware of these considerations when evaluating the larger variety and number of energy recovery technologies available or that will be available on the market.

An evaluation approach is suggested that will assist in the technology selection process of an installation (Ref. 148). Although solid waste feedstock is evaluated, the approach could be used with the biomass and hazardous waste feedstock as well. The framework established recognizes and operates within the current military construction procurement process and emphasizes participation of facility decisionmaking. In addition, the evaluation will incorporate feedstock selection on the basis of the specific situation at a site, a framework to facilitate periodic review and reevaluation during the project development to design phase, and an emphasis on quantitative hard data rather then estimates.

The approach will be described in terms of (1) establishment of a set of criteria that the technology selection procedure should adhere to, (2) major steps of approach, and (3) application of the approach.

7.1.1 Evaluation Criteria for Waste-to-Energy System Selection

Proper selection among energy recovery systems requires that site-specific criteria be established. Although the developed criteria are used to support site feasibility studies, they also have the potential to formulate and periodically revise state-of-the-art surveys. Criteria set forth should include technical feasibility and development status, economic viability, reliability and utility, environmental impacts, and waste disposal and energy production impacts.

- Technical feasibility measures of both the degree to which a design follows a prior proven act and the potential of the designed system to withstand predictable wear. Predictability of dependable performance and the chance of unforeseen outage are critical factors in determining the site-specific potential of waste-to-energy systems.

- Economic viability is linked to experience and technical reliability since both provide a basis for an accurate estimate of a system's recurring costs and length of its functional life. Initial capital costs include investment for equipment and facility, as well as implementation expenses for start-up, field alignment and shakedown, and operator training. Economic analysis must also assess the recurring costs of operating and maintaining a system.

- Reliability and utility concerns system characteristics such as practicability, conservation, and experience. Practicability is measured in terms of the system's degree of complexity, which would make its proper performance contingent on skilled personnel, the case of performing routine daily and periodic maintenance and repair, and the degree of management impact of new requirements added by the essential functions of the energy recovery system (transportation, processing, marketing, and ultimate disposal). Conservation refers to the efficiency with which a system reuses or recaptures energy, materials, and water or the extent to which a system consumes these resources suppled by external or virgin sources. Experience forms the critical basis for predicting and guaranteeing the life cycle performance of a system with reasonable accuracy. The operational history of similar equipment for energy recovery at or near the scale of application that the site requires and the number of facilities of similar design presently in operation constitute the major input to determine experience.

- Environmental impacts consider the compatibility and impact of a system on the immediate air, water, and land environment. Analysis and assessment should include effects of atmospheric emissions, water effluents, and landfill disposal of system byproducts. Further, pollution abatement measures should be determined that control fugitive system byproducts and transient failures. System compatibility also includes the degree to which a system is a nuisance or affects traffic increases, odor, aesthetics, noise, and other parameters.

- Waste disposal impacts consider the effect waste-to-energy recovery systems may have on current waste disposal practices. Energy impacts are associated with the potential net energy savings attributabe to the substitution of nonrenewable energy resources with waste-derived energy.

7.1.2 Major Steps of Approach

The basic objective of the approach is to identify applicable waste-to-energy systems and to select the technology that is superior in light of site-specific requirements and established criteria. The time of technology application should conform to the Military Construction period of 2 years.

The basic scope of the approach will be to assist in the initial problem definition, followed by an identification of functional objectives of the technical solution, and then an identification of the most applicable system technology. Following this stage, project development continues by applying established engineering and costing techniques leading to system design. Figure 16 shows the general process, the specific steps of which follow.

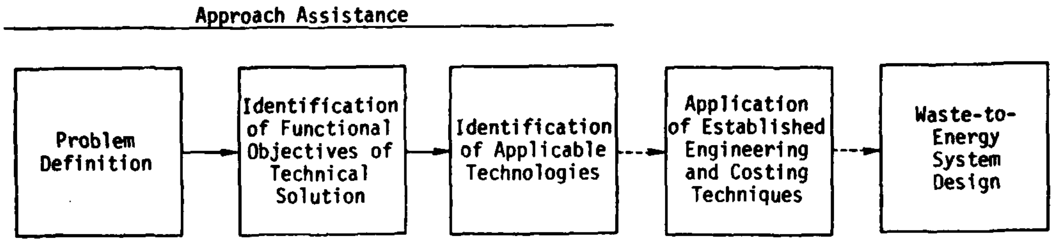


Figure 16. General Analysis Areas for Potential Waste-To-Energy Systems at Military Installations

(1) Problem Definition -- Analysts develop with consultation from the installation command both general and site-specific considerations affecting waste management operations. General factors include laws, regulations, and DOD policy directives in force or pending. Site factors include the problems associated with current disposal practices; for example, the facility may be faced with decreasing landfill capacity.

(2) Identification of Functional Objectives -- After assessing the nature and magnitude of the problem, the technical solution will address the prioritized list of objectives that have been developed.

(3) Establishment of Criteria in Alternative Technologies Selection -- General considerations include legal and political factors as well as broad technical characteristics. Specific criteria were discussed in 7.1.1 and include technical reliability, practicability, conservation, environmental impact, experience, and economics.

(4) Broad-Based Technological Options Survey -- This step constitutes the largest effort due to the necessary thorough evaluation of potential system technologies. This phase can also be used to determine the acceptability of specific systems according to established criteria.

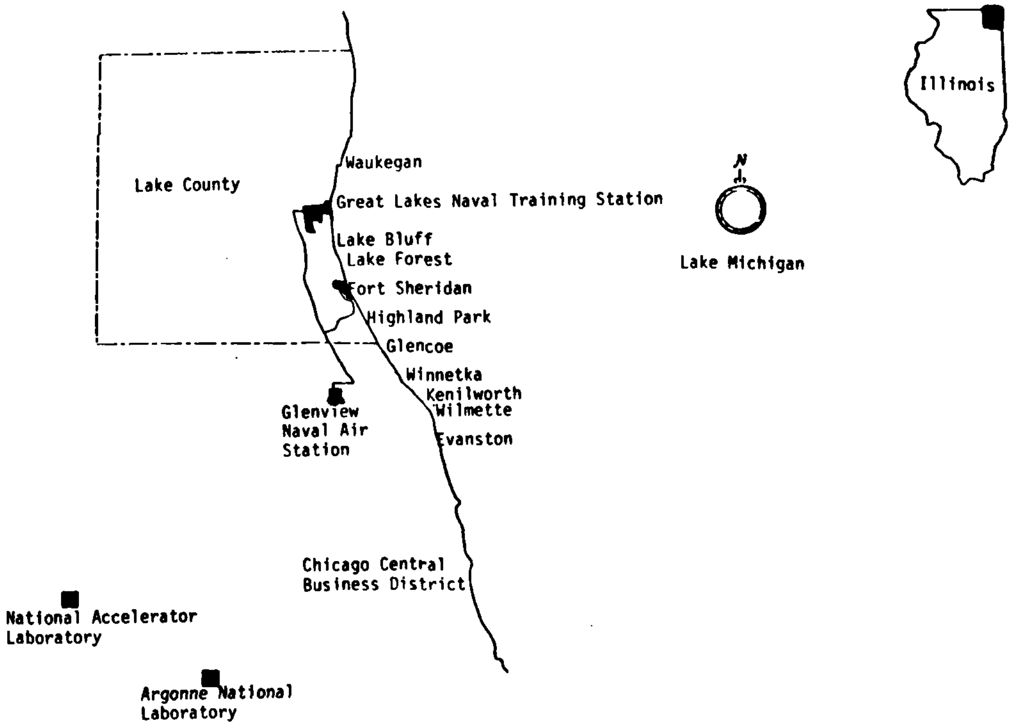
(5) Availability of System Technology -- Generally, systems that will be commercially available within the 3-1/2 years between project development and design in the military construction cycle can be considered for installation application.

(6) Selection of Candidate Technology -- Using prescribed criteria and a comparative rating system, the most applicable available technology can be suggested for more established engineering and costing techniques.

7.1.3 Application of Approach

The evaluation described in this section was performed at the Naval Training Center, Great Lakes, Illinois (the Center). The U.S. Army Construction Engineering Research Laboratory conducted the investigation under supervision of the Naval Facilities Engineering Command in 1978. Much of this section is based on the report issued (Ref. 50).

Background -- Naval Training Center, Great Lakes is located in Lake County, Illinois, on the western shore of Lake Michigan approximately 35 miles north of the Chicago central business district. The Center is within the Chicago Standard Metropolitan Statistical Area (SMSA). Adjacent residential communities are North Chicago and Lake Bluff. Other major Federal facilities located in the SMSA are the Naval Air Station (NAS) Glenview, Fort Sheridan, Argonne National Laboratory, and the National Accelerator Laboratory (Figure 17).



Source: Ref. 50

Figure 17. Naval Training Center Great Lakes and Major Nearby Federal Facilities

Solid waste generated at the Center* is disposed of in an activity-operated landfill that has an expected life of 3 years. It is probable that solid waste will be collected and hauled by a single contractor in the near future and disposed of in either a private or municipal landfill up to 40 miles west of the Center. This measure is foreseen to increase future waste disposal costs significantly. This study was initiated by the Center and the Northern Division, Naval Facilities Engineering Command, to investigate the possibility of minimizing future waste disposal costs while conserving conventional energy resources by establishing a waste-heat reclamation solid waste thermal processing facility at the Center.

The evaluation consisted of the six steps described in 7.1.2. Results of the study follow.

Problem Definition -- The first stage of the technology evaluation was to formulate a concise definition of the problem as follows:

(1) Can available technology be applied to a 20-year functional life at the Center to economically recover energy and materials from waste generated at the Center alone and at Federal facilities within the Chicago SMSA?

(2) What are the costs and benefits of using technically viable resource-recovery technologies as compared to continuing conventional waste disposal?

Technological Objectives -- The functional objectives of the solution were defined in light of the problem definition. The Center is rapidly running out of landfill space and has no alternative disposal site on its grounds. Hence any solution must result in a highly efficient waste processing system with a minimum residual disposal requirement. (This includes the disposal of bypass wastes, process rejects, ash and residue.) This highly efficient system would supply the maximum recovery of energy and materials based on long-term market or user compatibility. Because the Center will probably dispose of residue in an outside landfill, the technological solution should result in a maximum reduction of the organic content of material being transferred out of the Center for disposal. It is imperative that any technological solution be in full compliance with the laws, regulations, guidelines, and directives pertaining to military solid waste disposition and resource-recovery operations in the Chicago metorpolitan area. It was on the basis of these general criteria that the technology survey was conducted to reveal technologies that might be considered applicable at the Center.

Technology Survey -- The technology survey formed the bulk of this investigation. Table 63 displays the energy- and materials-recovery techogies evaluated. As shown in Table 63, there are five technology categories:

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* The Center's generation rate is 40 TPD. A total of 109 TPD of solid waste is generated among the major Federal facilities.

(1) production of refuse-derived fuel, (2) energy recovery incineration, (3) pyrolysis, (4) simple separation of recyclable materials, and (5) biological conversion of waste to fuel. Of these five categories, only three were considered to be of potential applicability to the Center.

Table 63. Energy/Materials Recovery Technologies Evaluated

Process	Description
RDF Production	Solid waste processed to a solid fuel for supplementary firing in existing steam generators
Energy Recovery Incineration	As-delivered or processed solid waste fired in incinerator equipped with heat-recovery/steam generating hardware
Pyrolysis	Conversion of as-delivered or processed solid wste to a low-Btu gaseous or liquid fuel for supplementary firing in existing steam generators
Materials Separation	Mechanical processing as-delivered solid waste to separate materials saleable on salvage market
Biological Conversion	Capture and use of low-Btu gas from biological degradation of solid waste (anaerobic digestion, composting, landfill gas recovery)

Source: Ref. 50

Materials separation was discarded on the grounds that it did not substantially affect the bulk reduction of the waste. In any materials separation effort, only a very small mass of the total waste stream is recyclable as raw materials. A very large residual mass remains as a disposal requirement. This was not in line with the general criteria by which the survey was conducted.

Also, biological conversion did not conform with the general criteria. Any biological conversion system (anaerobic digestion, composting, or landfill gas recovery), would require the use of a significant land area at the Center. Land area of the magnitude required for biological conversion of waste is not available at the Center; therefore, biological conversion was not considered in line with the general criteria.

Three general categories of technologies were found to be of potential applicability. RDF production involves processing solid waste as delivered into a refined refuse-derived fuel for use in the existing boilers. This was considered to conform to the general criteria in the technology survey because the central boilers at the Center will probably be coal-fired and hence are candidates to use a supplementary solid waste fuel.

The distinction between RDF and incineration was made on the basis of an economic trade-off; it may be more economical to process waste into refined fuel for use in existing boilers than it is to build a new combustion capital and not fire an extensively processed waste.

Pyrolytic processes were considered of potential applicability at the Center because pyrolysis produces a gas-phase, refuse-derived fuel that can be suspension-fired in boilers designed for fuel oil, natural gas, or coal.

Availability Survey -- Following the technology survey, an investigation was conducted into the availability of the three candidate processes revealed. The results of this part of the investigation are shown in Table 64.

Table 64. Energy-Recovery Processes Available in Near Term

RDF Production	Process solid waste to a light (shredded, air classified) fraction for suspension firing, further process (shredding, pelleting) to densified RDF for grate firing; cofire with coal; no long-term firing experience
Pyrolytic Conversion	Union Carbide process is most advanced and is beginning commercialization; other processes available only in long term
Energy Recovery Incineration	Waterwall incinerator and package controlled air systems are commercial; other processes either highly specialized industrial applications or available only in long term; improved stoking mechanisms should make waterwall more reliable

Source: Ref. 50

Insofar as RDF production is concerned, the production processes are further developed than are the utilization processes. There is no long-term firing experience with RDF, either in suspension or in grade firing. On the other hand, there is some experience with the production of RDF as a waste fuel.

Where pyrolytic conversion of a solid waste to a gaseous fuel is concerned, it was found that the Union Carbide process is the most advanced and is beginning commercialization. Other processes will be available only in the long term. Therefore, the Union Carbide pyrolysis process was considered to be a technical candidate in this investigation. The availability stage of this study also revealed two energy recovery incineration systems candidates.

The first is the field-erected waterwall incinerator system such as the Navy incinerator in Norfolk, Virginia, which has been operating for 10 years and has provided sufficient performance and operational data to allow the design of improved systems.

Next, the investigation revealed that package or modular incinerator systems are commercial. The most widely used package incinerator system is the controlled-air system. The technologies found to be available are (1) controlled-air incinerator, (2) waterwall incinerator, (3) Union Carbide (or Purox) pyrolysis system, (4) use of fluff RDF in suspension firing, and finally (5) use of pelletized or densified RDF in cofired boilers.

It is emphasized that this portion of the study was intended to reveal candidate technologies as they would be available within the military construction cycle. For example, the Purox pyrolysis system is not immediately commercial, but may be expected to be so within 2 to 4 years.

7.1.4 Selection of Technology

Technical Goals -- The final stage of the technology evaluation portion of this study was application of site-specific technical goals to determine the most applicable of available technologies. In this stage of the study, a set of site-specific criteria was drawn up that included (1) technical reliability, (2) practicability, (3) conservation, (4) environmental compatibility, (5) experience, and (6) economics. These criteria were described in 7.1.1.

The major subcategories of each of the six site-specific criteria are shown in Table 65. As shown in Table 65, a matrix was devised to give a relative score to each of the five potentially applicable technologies and to each of the subcategories. Rankings were determined so that each row sum was 13 points. A subtotal for each of the six major site-specific criteria was then determined. Under technical reliability, for example, the highest score is achieved by the waterwall incinerator: 8.5. The lowest score of 2.0 is achieved for the use of densified RDF. The remaining three technologies fall somewhere inbetween.

It is emphasized that Table 65 is not based on a rigorous quantitive determination of the factors involved, but is rather a means by which to quantify judgmental factors in order to determine the superior resource-recovery system. As experience in the energy-recovery field grows within the next 10 years, and as more hard data on resource-recovery systems are published, it will be easier to implement and improve upon the method of evaluation outlined in Table 65.

Table 65. Process Raw Scores of Alternative Waste-To-Energy Technologies

	Controlled Air Incinerator	Waterwall Incinerator	Purox Pyrolysis	Fluff RDF	Densified RDF	Row Sum
Technical Reliability						
Proven art	3.5	4.5	1.5	2.5	1.0	13
Predictable wear	3.5	4.0	2.0	2.5	1.0	13
Subtotal	7.0	8.5	3.5	5.0	2.0	
Practicability						
Complexity	4.0	3.5	3.0	1.5	1.0	13
Maintenance and repair	4.0	3.5	3.5	1.0	1.0	13
Management impact	3.5	3.0	3.5	1.5	1.5	13
Subtotal	11.5	10.0	10.0	4.0	3.5	
Conservation						
Energy	3.5	4.0	3.0	1.5	1.0	13
Material	2.0	2.0	2.0	3.5	3.5	13
Water	3.0	3.0	3.0	2.0	2.0	13
Subtotal	8.5	9.0	8.0	7.0	6.5	
Environment						
Air	2.5	3.0	3.5	2.0	2.0	13
Water	2.0	2.0	2.0	3.5	3.5	13
Land	2.0	3.0	3.5	2.5	2.0	13
Nuisance	2.0	2.0	2.5	3.5	3.0	13
Subtotal	8.5	10.0	11.5	11.5	10.5	
Experience						
Operational history	3.0	5.0	2.5	1.5	1.0	13
Number of facilities	4.0	5.0	1.5	2.0	0.5	13
Subtotal	7.0	10.0	4.0	3.5	1.5	
Economics						
First costs	4.0	3.0	3.5	1.5	1.0	13
Recurring costs	4.0	3.5	3.0	1.5	1.0	13
Subtotal	8.0	6.5	6.5	3.0	2.0	

Source: Ref. 148

The reader is cautioned to interpret the approach and results. The approach was selected only to illustrate the criteria factors necessary in technology assessment. No recommendation or approval of this method or any other analysis method is intended.

Relating Important Factors -- The next step in scoring the technologies according to site-specific criteria was to develop importance factors for each of the six major criteria. These importance factors ranged from 0 to 1 in relative order of importance with 1 being the highest. In conversation with the personnel at the Center, they felt technical reliability was of the foremost importance; it is hence given an importance factor of 1. This is determined on the basis of the specific waste disposal problem at the Center. Any system designed to process waste must operate reliably because the Center does not have a landfill backup at its immediate disposal.

Next in importance is environmental compatibility. This is considered to be nearly as important as technical reliability, particularly in light of the strong environmental regulations in the Chicago metropolitan area. Hence, environmental compatibility is given an importance factor of 0.9.

Third in degree of importance is practicability. This is given a score 0.8, ranking it behind technical reliability and environmental compatibility, but still high. A score of 0.7 is given to conservation. Experience and economics are given relatively lower scores.

Evaluation -- A weighting factor is employed in order to adjust for the subcategories of each of the six major criteria (Table 65). The weighting factor is a simple, convenient way to bring the different number of criteria subcategories into compatibility for scoring. Table 66 presents the weighted scores for the processes evaluated, which were determined by multiplying the raw process score of Table 65 by both the weighting factor and the importance factor. As is shown in Table 66 the highest score of 32.98 is achieved by the waterwall incinerator, and the lowest score, 13.84, by densified RDF. Also shown in Table 66 are the normalized scores for the candidate processes. The waterwall incinerator score is hence 1, and the controlled air incinerator score is 0.92. The lowest normalized score is 0.42 for densified RDF. This analysis shows clearly that the waterwall incinerator is the best candidate technology according to the site-specific criteria at the Center. The controlled air incinerator scored 10 percent lower, while pyrolysis was 26 percent lower, fluff RDF 40 percent lower, and densified RDF 58 percent lower.

Table 66. Process Weighted Scores* of Alternative Waste-To-Energy Technologies

Category	Weighting Factor (WF)	Importance Factor (IF)	Controlled Air Incinerator	Waterwall Incinerator	Purox Pyrolysis	Fluff RDF	Densified RDF
Technical Reliability	1.00	1.00	7.00	8.50	3.50	5.00	2.00
Practicability	0.67	0.80	6.16	5.36	5.36	2.14	1.88
Conservation	0.67	0.70	3.99	4.22	3.75	3.28	3.05
Environment	0.50	0.90	3.83	4.50	5.18	5.18	4.73
Experience	1.00	0.65	4.55	6.50	2.60	2.28	0.98
Economics	1.00	0.60	4.80	3.90	3.90	1.80	1.20
Total			30.33	32.98	24.29	19.68	13.84
Normalized Score			0.92	1.00	0.74	0.60	0.42

*Weighted Score = Raw Subtotal Score x WF x IF

Source: Ref. 148

In this stage of the evaluation, the controlled air incinerator was eliminated from further consideration because of its recent history of extensive operating problems. Heat-recovery controlled air incinerator plants are just beginning to be developed, while the waterwall incinerator at the Norfolk Naval Base in Virginia has a longer history of operation than any controlled air incinerator in existence. These types of problems can be anticipated with a waterwall incinerator, but to a substantially lesser degree.

The recommended energy-recovery system is a waterwall incinerator equipped with a double reciprocating grate stoker and a periodic selective size reduction of large combustibles. Waste generated at NAS Glenview and Fort Sheridan is consolidated at a transfer station at the latter location and delivered on a regular daily schedule to the incinerator plant located in the Foss Acres area of the Center. A capital investment of $5.3 million in FY 1982 dollars is required. The system will save 8000 tons of coal annually.

The study also indicated that the cost effectiveness of the energy-recovery system is highly sensitive to the avoided costs of future waste disposal operations. Since waste disposal operations, both at the Center and Fort Sheridan, will soon change in response to the forth-coming depletion of landfills at those locations, future waste disposal costs were indeterminable. At a unit disposal cost of approximately $20.00/ton, the regional system breaks even (savings/investment ratio = 1.0). At a cost of $32.50/ton, the savings/investment ratio is 2.0. The study recommends that future (FY 1982) waste disposal costs be established and used with data in this report to indicate the cost-effectiveness of the recommended energy-recovery system and that steps toward its implementation be taken as appropriate.

7.2 Overall Summary of Near-Term Systems and Applicability to Military Requirements

7.2.1 Availability

The availability of solid waste, biomass, and hazardous waste and the technologies to convert these resources to energy is of vital importance towards implementing waste-to-energy systems. Unfortunately, the present data base cannot adequately address the availability question for both resource and technology.

Much of the military and civil research in these areas has focused on the solid waste stream and its conversion processes. The biomass and hazardous waste streams are, however, gathering increased interest -- biomass, from the standpoint of being a synthetic fuel source, and hazardous waste, from the critical management and disposal viewpoint. All three potential resources must be further analyzed and characterized on a DOD-wide level to determine their respective availability for energy recovery.

Conversion technology is rapidly advancing, particularly in small-scale uses such as military installations. Current knowledge has been gained mainly from using solid municipal waste. Emphasis has been in the thermal conversion processes, namely direct combustion, pyrolysis, and refuse-derived fuel. The military procurement cycle for capital projects normally requires about 3½ years from initial project development to final design approval. Waste-to-energy technologies available during this period are considered applicable for the military.

7.2.2 Applicability

Thermal conversion processes are currently considered the most applicable to military facility requirements. Many industrial plants could generate a substantial portion of the process steam they need by using solid waste fuel. Industrial and other operational activities at military bases, by implementing such recovery systems, could reduce their consumption of fossil fuels as well as the quantity of various waste products generated that would otherwise be landfilled or stored.

Waste-derived fuel may also be suitable for use in existing installation boiler systems. For example, RDF has been tested for cofiring with coal in coal-fired boilers. With the renewed emphasis to shift from oil and natural gas to coal, RDF/coal cofiring offers an attractive alternative. An added benefit is that higher sulfur coal can be used because RDF has little sulfur, and the mix results in acceptable stack emissions.

8.0 POLICY ANALYSIS

8.1 Evaluation Context

The importance to national security of identifying alternative domestic sources of energy was recently summed up by the Secretary of Defense in the following statement: "The present deficiency of assured energy resources is the single surest threat . . . to our security and to that of our allies." (Ref. 149). George Marienthal, Deputy Assistant Secretary of Defense for Energy, Environment, and Safety, shared this concern. He stated: ". . . In a real sense that series of small -- but cumulatively vital -- decisions by which we in DOD and the rest of society save or squander energy will truly affect this Nation's security. . . . The Department of Defense's responsibility for national security is, thus, heavily dependent on the assured availability of energy in all forms. . . ." (Ref. 150).

As the Federal Government's largest energy consumer and waste generator, the Department of Defense and its military departments are mandated to develop effective energy management and reduce environmental impact. A variety of alternatives exist to approach either issue. Waste-to-energy systems offer the unique opportunity to rectify both issues.

The preceding description and analysis of various feedstock and technology options are directly responsive to these concerns and complements similar analytical activities presently underway within and outside of DOD. The evaluation differs from previous programs in that it considers (1) the relative merits and technological feasibility of recovery of energy and resources from a range of military waste streams on a DOD-wide perspective and (2) the implications of using the identified waste streams on DOD energy and waste management policies.

8.2 Comparison of Available Recoverable Energy With DOD Energy Requirements: A Perspective

Total energy recoverable from the national and DOD solid waste can provide about 2 percent of each of their energy demands. Energy from noncommercial forest and residue could contribute to over 10 percent of the Nation's energy supply (Table 67).

While contributions from these resources provide a small portion of the overall energy supply, the magnitude should be placed in proper perspective.

A report by the General Accounting Office called solid waste "one of the least recognized alternative sources of energy" (Ref. 151). Traditionally, waste management officials have been concerned with collection and disposal of solid waste aspects. Military service officials have been reluctant to initiate energy recovery from solid waste projects due in part to technology development problems but mainly because most installations have sufficient landfill areas (Ref. 152).

Table 67. Quantity of Recoverable Energy With Projected Military Fixed Installation Facility Energy Needs

Energy Source	Energy Recoverable Quad	Energy Recoverable Barrel of Oil Equivalent	Percent of Total
Solid Waste			
National	1.7[a]	2.9×10^8	2.2[b]
DOD	0.01[a]	1.7×10^6	1.8[c]
Biomass[d]			
National	9.1	1.6×10^9	12[b]
DOD	NA	NA	NA

Notes: [a] Table 26
[b] Assumes approximately 77.5 quads/year consumed
[c] 0.57 quads for DOD facility energy consumption (FY 1978) (Ref. 41)
[d] Non-commercial forest production and residue (Ref. 99)

Recognition of solid waste as an energy resource will introduce a variety of potential benefits and advantages of waste-to-energy conversion including the following:

- Waste is utilized as a resource and not considered a nuisance to be disposed of and forgotten;
- Energy equivalent value in nonrenewable conventional fuels is conserved, resulting in a saving of natural resources;
- Waste volume is greatly reduced, saving transportation costs and disposal space;
- Combustible solid waste produces low sulfur oxide emissions due to its low sulfur content; and
- Waste resource is a readily available, inexhaustible, and domestic source of energy.

These benefits may perhaps be more evident on a regional or site-specific scale in which contributions from waste-derived energy would have a more significant impact than on a national level.

Uncertain future energy costs for conventional sources and reliance on foreign energy sources are among the motivational factors installation decisionmakers use to pursue alternative energy management practices, such as conservation, efficiency, and alternative energy sources. In addition, energy recovery system capital costs can be offset by the savings in energy costs to the base and by the savings in waste disposal costs.

8.3 Barriers and Approach Options

Several factors influence the application of any waste-to-energy conversion project. To analyze the feasibility for such systems on military installations, it is necessary to identify the barriers and appropriate management approaches in project implementation. This section will briefly outline a few of the major factors influencing implementation.

8.3.1 Risk Factors

Numerous uncertainties and risks associated with energy recovery systems will undoubtedly be of concern to participants engaged in the planning and procurement process. Since the outcome of such activities cannot be predicted exactly, there is an inherent risk in pursuing a waste-to-energy project. The greater the investment by a facility at a given level of uncertainty, the greater the risk.

To overcome the risks and uncertainties that stand in the way of implementation, DOD officials must be aware of these factors. Should energy recovery prove feasible after a thorough investigation of the waste management problems, facility commanders and others in the procurement process must decide whether an economically and politically defensible decision to proceed with energy recovery implementation can be made. The decision must be determined in light of probable risks of the following factors, which have been discussed previously:

- Technical uncertainty
- Cost uncertainty
- Energy utilization uncertainty
- Waste stream uncertainty
- Energy markets uncertainty
- Environmental uncertainty

The final decision of whether or not to go ahead with an energy recovery system project should be after a careful consideration of all risks. Table 68 summarizes key questions that need to be answered prior to a final decision.

Table 68. Areas of Uncertainty in the Procurement of Waste-To-Energy Conversion Systems

Area of Uncertainty	Concerns
Technical	• Use of often new, often insufficiently proven technology • Technology performance in terms of reliability, practicability, and yield of energy products with expected quality • Little experience overall in planning and procurement of energy recovery systems
Cost	• Cost comparisons with traditional disposal methods particularly in initial years of operation • Cost of facility and operations
Energy Utilization	• Securing commitment to utilize recovered energy products • Magnitude of potential energy savings to facility
Waste Stream	• Delivery to system in expected quantity and quality • Securing long-term commitment (~20 years) for waste utilization
Environmental	• Potential new environmental regulations concerning waste-to-energy systems • Potential identification of new environmental hazards from waste conversion • Often trading solid waste problem for air and water problems.

Everyone involved at critical energy recovery decision points should seek to reduce the overall level of risk or share the total risk. However to do both, it is advisable for facility decisionmakers to complete a thorough front-end planning effort prior to system procurement. Such planning is often a time-consuming expensive activity, but the investment will be justified in ensuring the later success of implementation efforts.

8.3.2 Information Problems

Although a number of feasibility studies and demonstration facilities have been implemented for specific military installations, considerable uncertainty remains concerning the waste conversion technology's overall technical and economic performance and fixed installation applicability. Civil efforts have previously emphasized large-scale systems, although small-scale technology is now being evaluated. Because of the newness of energy recovery technology, it is not yet an "off-the-shelf" purchase and supporting information is not widely available.

From the military installation point of view, the problems of technical and economic uncertainty are compounded by the institutional complexity and barriers in the way of planning and operating systems successfully. Accurate engineering, operating, economic, and legal information are all required. However, since installation management cannot be expected to have such expertise, past evaluations have been performed by the service branch research laboratories or by outside consultants.

Besides an inadequate information base, facility decisionmakers are often bombarded on one hand by proponents who try to oversell energy recovery technology and on the other hand by group opposition, for example by some local trash disposal companies or local residents.

There is also input by environmentalists opposing wasteful landfill practices and resistance by some citizens over the siting of landfills and recovery plants. A thorough, objective source of information would be of significant help to the base command.

8.3.3 Jurisdictional Problems

Responsibility for DOD waste collection and disposal has been at the military installation level provided either by a contracted private disposal firm or by base personnel. Landfilling (either on the installation or regionally offsite) is the predominant method of waste disposal.

Should DOD installation managers consider participation in a regional resource recovery system, there may be several jurisdictional problems to be considered: coordination among several governmental units, cost sharing arrangements, private and public roles, and waste stream ownership and control.

Effective regional resource recovery programs require cooperation and coordination among several local governmental units, as well as between different levels of governments. Typically, it is not uncommon for cities, counties, regional planning agencies, and special waste management districts to be individually involved in some aspect of operating or regulating the collection and disposal of waste. Conflicts often arise in attempting to establish a regional energy recovery system. Consequently, accomplishing resource recovery at a regional level requires time-consuming, expensive, and complex planning, coordination, and management.

Devising an equitable and effective method for sharing the costs of transportation, transfer, and processing of wastes in a centralized energy recovery system is probably one of the most difficult jurisdictional issues. An economically optimal system for a region would process all of its wastes at the lowest overall net costs. Some DOD installations may incur higher costs under such a regionally optimal system than they would under some alternative or present method of disposal. It would appear that it may be necessary for some communities whose costs are reduced by regional energy recovery to subsidize those that would otherwise face higher costs, in a case where the total region is served at the lowest cost. A region with many separate communities and governmental entities will find great difficulties in devising an acceptable cost-sharing formula. Failing to develop the lowest yet most equitable cost system or securing additional revenue or subsidy may price regional energy recovery out of the market.

In many regions, both public agencies and private firms have operating responsibilities for collecting, processing, and disposing of waste. The extent to which each has a role in managing MSW varies between communities. There may be problems in reaching accord in regions where energy recovery would be economically justified due to the different mixes of public/private activities. For example, private operators may be concerned about losing business opportunities from landfilling or incineration should a public energy recovery system be implemented.

The control of the waste stream is one of the most difficult problems to overcome in planning a regional or any energy recovery system. Quality and quantity control are two areas of utmost concern. The waste stream quality was discussed in Chapter 2 and will not be discussed here. Minimum solid waste quantities are absolutely necessary to secure project financing, ensure proper design, and obtain long-term commitments (about 20 years) for waste supply. In regions, individual long-term commitments must be received from many communities and agencies. This task is a monumental one, especially when a proposed regional energy recovery system is a voluntary one.

8.3.4 Implementation Problems

There is a group of issues that concern the implementation plan and are related to the technical and economic problems of energy recovery. Depending on the specific nature and magnitude of the energy recovery system, difficulties are often met in military construction procurement; facility siting; and environmental, health, and safety concerns.

DOD decisionmaking on military construction proposals involves a series of complex, multiyear review and evaluation processes. No single project planning and implementation process can be used to describe in sufficient detail DOD's decisionmaking processes. This is true largely because DOD's mission, and hence its organization and procedures, are so diverse.

For an energy recovery proposal initiated at a facility level, system procurement can be obtained through several options. These include installation operating and maintenance budget; military construction; and research, development, test and evaluation funds. Regardless of which source of procurement funding is selected, each proposal is subject to a number of reviews along the chain of command, including the Congress, and must adhere to DOD's Management by Objectives and multiyear (usually 5-year) defense program plan.

The military construction funds require about a 3- to 4-year process from system proposal to construction award. Figure 18 shows the Air Force process and review participants. With fiscal budgetary constaints and the situation in the general economy, installation decisionmakers may not desire to propose high capital investment projects such as energy recovery. The initial capital cost plus the long time period for review may not justify, in the eyes of a facility's management, the benefits and eventual payback of the energy recovery system

Specific plant siting is rarely accepted in total harmony by surrounding residents. The attitude of "dispose and forget but not in my neighborhood" is often thoroughly ingrained by citizens. Thus, siting facilities, such as transfer stations, processing and recovery plants, and residue disposal landfills, pose problems for energy recovery systems both for a military installation and a regional municipal system.

The characterization and status of energy recovery facilities as generators of air, water, and noise pollution; bacterial and viral disease vectors; and safety hazards to workers and the community are unclear. Small-scale operations envisioned for installation application with appropriate controls may be of small impact compared to larger municipal systems. However, no health or environmental performance standards for various types and sizes of resource recovery facilities have yet to be established.*

For example, the Occupational Safety and Health Administration requires that a healthy environment should be maintained in such facilities, but no specific levels of control are established (Ref. 153). The possibility that emissions from energy recovery and facility workplace environments may be regulated in the future is a source of uncertainty for potential investors in such systems.

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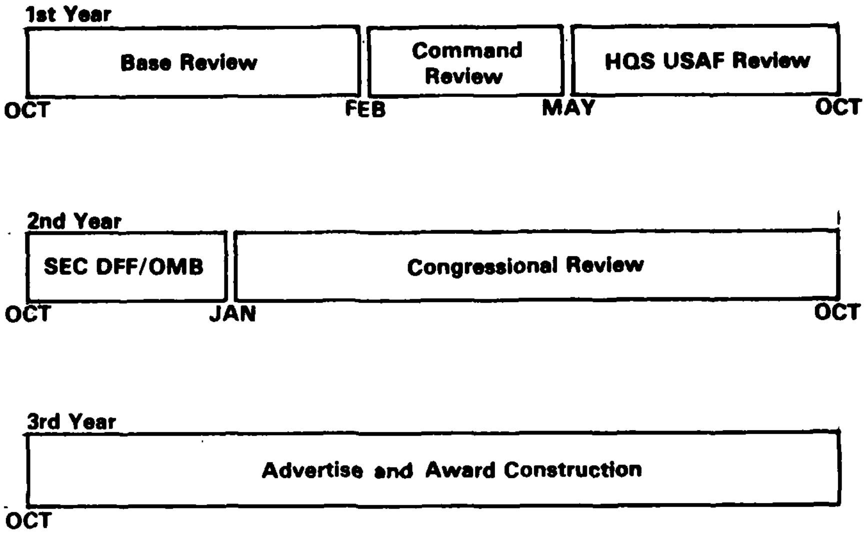
* New Source Performance Standards exist for incinerators with 50 TPD capacity.



USAF = MCP: Military Construction Program
Army = MCA: Military Construction Appropriation
Navy = MILCON: Military Construction

Figure 18. 3-Year Air Force MCP Cycle*

* The capital improvement procurement cycle is approximately the same for all services. Due to longer base level and command reviews and lag time between construction award and construction startup, the cycle usually requires 3 years or longer.

8.4 Energy Recovery Implications for DOD Waste Management

There are many identifiable as well as unforseen obstacles to energy recovery implementation that delay what is already an inherently complex implementation process. Despite these barriers, energy recovery remains a widely pursued waste disposal option, and the extensive research in the field is an indication of the abiding interest in this technology. Ongoing studies and operations will add to experience and the information base that will hopefully lead to improvement of technology applications and procurement feasibility.

The national commitment to improve environmental quality and maintain a dependable supply of energy has greatly expanded the need for effective solid waste management. Current management practices may no longer be environmentally or economically acceptable, just as past burning in open dumps is not now acceptable.

Innovative management is needed at all DOD levels of responsibility to comply with current and future requirements. Environmental and energy policies vitally apply to all waste management operations on military operations.

Among the motivation factors that influence DOD installation managers to evaluate waste-to-energy systems include the need to (1) conduct waste disposition activities in an environmentally acceptable manner (Ref. 152), (2) minimize the costs of installation waste management (Ref. 24), and (3) conserve scarce and costly fuels (Ref. 41). At present, the principal driving forces for resource recovery are rising costs and problems associated with waste disposal and the increasing constraints from environmental regulation. Energy and material shortfall are not, as yet, a primary motive, though the alleviation of shortages and the need to conserve resources will progressively assume greater significance.

9.0 CONCLUSIONS AND PROPOSED DOD POLICY INITIATIVES TO OVERCOME BARRIERS TO WASTE-TO-ENERGY UTILIZATION

9.1 Conclusions

The results and conclusions of this investigation have been described in previous chapters of this report. The purpose of this section is to summarize the principal findings, which form the basis for the policy recommendations in Section 9.2.

9.1.1 Findings

1. The (annual) quantity of military waste-to-energy recoverable is estimated as follows: solid waste (1.7 million barrels of oil equivalent) and biomass (1.6 billion barrels of oil equivalent).

   The energy derived from solid waste is an estimate based on the amount produced from DOD installations only. The value of energy derived from DOD solid waste could be worth approximately $44 to $51 million. Nationally, the energy recoverable from MSW is about 290 million BOE. The national MSW total represents about 9 percent of the 1979 energy import total, or 2 percent of the total 1979 domestic energy consumption.* Energy from DOD installation solid waste represents about 1.0 percent of the FY 1979 DOD fixed installation petroleum equivalent demand.

   Data regarding biomass energy potential were not available specifically for DOD installations. The 1.6 billion BOE of biomass represents the national total and includes forest residues, surplus growth, silviculture energy fauna, and other contributions from noncommercial timberland. This total represents about 11 percent of the 1979 domestic consumption total.

   No energy potential data are available from hazardous waste produced nationally or by DOD.

2. Energy recovery is the best environmental long-term waste disposal method presently available, but it cannot be considered a major new energy source.

   DOD officials should continue to identify alternative methods of waste disposal that will provide a long-term answer to disposal needs in a manner that is both environmentally and economically acceptable.

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* Based on 1979 energy import total of 19 quads and total domestic consumption of 78 quads (Energy Information Administration, DOE, 1980).

Energy recovery can provide such a long-term answer; however, it is only a partial solution to the major national environmental problem and can be expected to contribute to a small percentage of the total DOD energy demand.

Energy recovery options can have significant benefits over conventional landfilling operations. Although many of these benefits are not readily apparent in traditional cost accounting, they are nonetheless significant both in a present and future perspective. For example, waste energy recovery can be viewed as an intangible but valued benefit through energy conservation and saving of nonrenewable resources.

3. Data on the input waste stream need to be reliable and accurate in order to effectively manage the waste stream or to properly design energy recovery facilities.

The biomass and hazardous waste stream were especially difficult to characterize and assess. Attempts have been made to further characterize these streams as in the case for solid waste, but no overall systematic DOD data are available.

Because there are currently no comprehensive or practical procedures to develop a reliable waste inventory, design of energy recovery systems is now more an art than a science. Large-scale recovery technologies may not be readily applied to small-scale applications. Indeed, caution should be applied in comparing one installation with another because intangibles, such as mission, location, climate, and other factors, can all influence waste generation, collection, processing, and disposal practices. Without due cognizance of these and other factors, highly erroneous conclusions on energy recovery assessment and feasibility could be made.

Development of improved input characterization procedures as well as technology scaling methods are two definite areas of research need.

4. The available waste-to-energy conversion technologies are field-erected combustion systems, small-scale modular systems, and refuse-derived fuels.

All of these technologies have been applied to various municipal systems and at selected DOD installations. However, it must be stressed that appropriate application is highly dependent on the site-specific characteristics of the waste stream, conversion system, and end use.

The production of steam from waterwall incineration of solid waste is currently the only technology to be demonstrated on a full-scale commercial basis for more than 20 years (and at the Norfolk Naval Shipyard for over 10 years). Other systems, such as the modular systems, are being applied in a number of small municipalities and industrial uses. RDF firing with fossil fuels look promising but, to date, only limited testing has been done. Pyrolysis technology is still in the development and demonstration stage.

5. Reluctance to initiate energy recovery at DOD installations is due in part to technology problems, but mainly it is because most bases have had sufficient landfill areas.

This is concluded by the Government Accounting Office (Ref. 152) in its evaluation of the DOD solid waste management system. The conclusion implies that waste disposal is not perceived as a major problem area in the overall mission of the facility until the problem escalates, such as when landfill capacity is constrained or when environmental regulations prohibit current practices. DOD has taken measures to close open dumps and cease environmentally unacceptable disposal practices. However, until resource recovery systems prove more cost effective on an installation level, the landfill method will be the predominant disposal option.

6. The capital and operating costs of waste-to-energy systems to industry as a whole are not sufficiently defined.

Until more accurate data from full-scale, commercially operating conversion systems become available, accurate maintenance costs, unscheduled outages costs, boiler efficiency loss cost, environmental cleanup costs, and other expenses cannot be determined with sufficient precision required to evaluate system application. Better definition of the costs and the benefits of waste-to-energy systems could enhance investment in such plants.

7. Regional involvement by DOD agencies can lead to suitable approaches in implementing energy recovery ventures.

Energy recovery opportunities can be enhanced in areas where the waste produced can be centrally recovered with greater efficiency and at less cost. Joint planning and system implementation between local municipalities and DOD installations is one example of a feasible regional approach. Despite these advantages for a regional system, there are also institutional constraints, such as jurisdictional and implementation concerns. The regional studies conducted by DOD and other Federal agencies should give a clearer indication on the feasibility of the regional approach. Although the DOD-lead studies have been forwarded to EPA, EPA has not planned future actions to be taken.

8. Local installation decisionmakers should initiate, wherever feasible, the evaluation of energy recovery potential.

Because resource recovery is ultimately a local function, the impact of higher DOD management to directly affect change is somewhat limited. For example, technical and economic assistance may be provided to the installation management; however, project initiation and subsequent action are the responsibility of the facility command. It is very important that installation managers understand the resource recovery concept and role in both facility energy and waste management.

9.2 Proposed Policy Initiatives

As stated in Chapter 1, the objectives of this study are to analyze the characteristics of the military waste stream, identify potential energy recovery options, and assess the barriers of implementing various alternatives. The findings were summarized in Section 9.1. This section outlines some of the major policy options available to DOD to overcome the barriers to waste-to-energy utilization identified in this study, and recommends appropriate policy actions.

The policy options and recommendations presented may reflect current DOD policies. In these cases, directives will be identified and emphasized.

Three overall considerations should guide DOD actions to address problems in energy recovery:

- Resource recovery is one of a variety of alternative options to waste management, and management programs should not be designed to promote one option to the exclusion of others.
- The primary concern of waste management should remain the protection of public and occupational health and safety through cost-effective waste disposal.
- The wide differences in local installation conditions must be recognized and a wide range of local responses and planning should be provided for.

DOD policy action options are grouped into the following general categories:

- Actions to resolve technical uncertainties and problems,
- Actions to stop environmentally unacceptable disposal practices,

- Actions to resolve institutional uncertainties, and

- Actions to assist local-regional planning and implementation systems.

9.2.1 Actions To Resolve Technical Uncertainties and Problems

1. DOD should continue to support, coordinate, and direct expanded efforts to collect and evaluate the military waste streams.

   Past efforts to collect relevant information on the military waste stream are either too site specific or unreliable and not applicable on a DOD-wide basis. A management system should be developed to ensure that proper and accurate information is collected. These data will be useful in waste management activities and also in any energy recovery evaluation. Where applicable, waste information for areas surrounding DOD installations should also be assessed, especially in areas where joint civil-military efforts may produce an efficient regional resource recovery system.

2. DOD, in conjunction with other Federal agencies, could promote research demonstration and application projects of near-term but commercially unproven waste-to-energy processes to remove existing technological uncertainties.

   Examples of such processes include incineration systems (both large- and small-scale), RDF cofiring, and pyrolysis. This recommendation is based on the finding that the above technologies have not been adequately demonstrated on a large enough scale and for an operation period long enough to remove uncertainties.

   One demonstration is not sufficient to accurately assess a process feasibility. Recent examples, such as the waterwall steam-generating incinerator at the Norfolk, Virginia, Naval Station and the RDF firing at the Pentagon, will still produce questions as to the "success" of a project with regard to system application and reliability, emissions control, systems costs, etc. DOD should coordinate and work in conjunction with other Federal agencies to accelerate the knowledge base on technological and economic viability. Recent DOD-DOE joint activities in energy development are positive steps in this direction.

3. DOD could undertake an extensive test program of installing several applicable types of energy recovery systems and closely observe results from these installations.

   This option was suggested by DOD in 1977 (Ref. 152); however, no sustained program has been initiated. Documentation of both operating (thermal systems) and environmental parameters should greatly increase the relevant data necessary for design. Careful consideration should be paid to the test system applicability to other installations. Again, DOD and other Federal agencies, such as DOE or EPA, could jointly pursue test and evaluation of waste-to-energy systems.

9.2.2 Actions To Cease Environmentally Unacceptable Disposal Practices

1. DOD should take appropriate measures to close existing environmentally substandard methods of waste disposal.

Policies and actions by DOD have already been initiated toward implementing EPA's guidelines for waste disposal. These measures include DOD management by objectives and individual installation's efforts to conform with environmental requirements. Besides not being in compliance with existing environmental regulations, cheaper disposal methods (substandard dumping or landfill areas) often compete with waste-to-energy recovery projects.

2. Environmental regulatory uncertainties should be resolved regarding the promulgation of new source performance standards for waste-to-energy processes.

Uncertainties over the regulation of waste-to-energy systems can hinder the investment of such systems. The likelihood of imposing limits on particulate and trace metal emissions, for example, is of considerable concern in procuring such systems as combined firing of RDF and coal.

9.2.3 Actions To Resolve Institutional Uncertainties

1. DOD could establish a tri-service system of research, demonstration, and evaluation.

A formal working sytem should be established to coordinate efforts for development of waste management information. Past experiences have shown close working relationships among the services' research offices but little coordination at the higher management levels. The tri-service system would provide better utilization of current expertise and fiscal resources in solving common barriers in waste management. The expansion of responsibilities of the DOD Hazardous and Solid Waste Management Committee is a positive step in this direction. Local coordination is also necessary at the installation level. This coordination should involve the entire DOD command chain in providing proper directives, information, and assistance to local installations in their liaison with local civilian municipalities.

2. DOD could provide sufficient funding for advanced engineering and economic planning of a number of individual waste-to-energy projects.

   This initiative is based on the assumption that more projects might be procured if DOD installations had the funds for sufficient planning to determine, on the basis of detailed economic and engineering studies, what the real costs of this projects would be in specified cases. The problems faced now include using operating costs for installations and "tight" overall budget appropriations. At the present time, it appears that even near-term waste management and energy-producing technology application programs may not be able to compete with other budget needs.

9.2.4 Actions To Assist Local-Regional Planning and Implementation Systems

1. In conjunction with EPA, DOD could develop plans to establish regional resource recovery systems wherever feasible.

   DOD agencies under 41 FR 2359 have studied 13 SMSA regions for potential regional resource recovery systems. All of these reports have been transmitted to EPA, and DOD is currently awaiting further EPA guidance. In cases of tight fiscal limitations, waste-to-energy recovery could be enhanced by permitting several municipalities and Federal agencies to join together in applying for planning funds, especially when one town or installation may not generate sufficient waste to justify a recovery system.

2. DOD could provide specific guidance to its installations on whether to pursue resource recovery.

   DOD could provide specific guidance direction to installations to determine the circumstances for which projects recovering energy from waste would be beneficial, either on a local or regional scale. Overall coordination and planning in issuing criteria and guidelines for resource recovery feasibility studies are needed.

GLOSSARY

AQUIFER -- A geological formation of porous, water-bearing material (e.g., rock, sand, etc.).

BASKET-GRATE INCINERATOR -- An agitated bed incinerator where refuse is burned in a perforated grate shaped like a truncated cone and rotated about its axis of symmetry.

BIOMASS -- Materials derived directly or indirectly as the result of plant cultivation.

BTU (BRITISH THERMAL UNIT) -- The quantity of heat required to increase the temperature of one pound of water one degree Fahrenheit.

BULKY WASTE -- Large items of solid waste such as appliances, furniture, trees, large auto parts, branches, stumps, and other oversized wastes whose large size precludes or complicates their handling by normal collection, processing, or disposal methods.

COMBUSTION -- The chemical combining of oxygen with a substance that results in the production of heat and usually light.

COLLECTION CONTRACT -- The collection of solid waste carried out in accordance with a written agreement in which the rights and duties of the contractual parties are set forth.

CONSTRUCTION AND DEMOLITION WASTE -- The waste building materials, packaging, and rubble resulting from construction, remodeling, repair, and demolition operations on pavements, residences, buildings, and other structures.

CONTROLLED-AIR INCINERATOR -- A two-chamber incinerator in which the first chamber is kept oxygen deficient and the second chamber is oxygen rich. The second chamber uses large amounts of clean fuel to complete combustion.

DOD FACILITY -- Any building, installation, structure, land, or public work owned by or leased to a DOD component. Ships at sea, aircraft in the air, or forces on maneuvers are not subject to DOD Directive 4165.60.

DEFENSE PROPERTY DISPOSAL OFFICE (DPDO) -- The DOD office having responsibility for and control over disposable property. A component of the Defense Logistics Agency.

DEMILITARIZATION -- The act of destroying the military offensive or defensive advantages inherent in certain types of equipment or material. The term includes mutilation, dumping at sea, scrapping, melting, burning, or alteration designed to prevent the further use of equipment and material for its originally intended military or lethal purpose.

ECOSYSTEM -- The interdependence of organisms and their surroundings.

EFFLUENT -- The wastewaters discharged from a designated source or facility.

EMISSIONS -- Material that is released into the air either by a discrete source (primary emission) or as the result of a photochemical reaction or chain of reactions (secondary emission). (Used as a synonym for solid waste by the military.)

ENCAPSULATED -- A method used in the disposal of hazardous substances that uses an impervious container made of plastic, glass, or other suitable material that will not be chemically degraded by the contents. This container should then be sealed within a durable container made of steel, plastic, concrete, or other suitable material of sufficient thickness and strength to resist physical damage during and subsequent to burial or storage.

ENVIRONMENT -- The conditions, circumstances, and influences surrounding and affecting the development of an organism or group of organisms.

FOOD WASTE -- Animal and vegetable waste resulting from the handling, storage, sale, preparation, cooking, and serving of foods; commonly called garbage.

GENERATION -- The act or process of producing waste.

GROUNDWATER -- Water present in the saturated zone of an aquifer.

HAMMERMILL -- A broad category of high-speed equipment that uses pivoted or fixed hammers or cutters to crush, grind, chip, or shred solid wastes.

HAZARDOUS WASTES -- Any waste or combination of wastes that poses a substantial present or potential hazard to human health or living organisms because they are nondegradable or persistent in nature, can be biologically magnified, can be lethal, or may otherwise cause or tend to cause detrimental effects.

HEAT VALUE --

HIGH -- The Btu liberated when a pound of solid waste is burned completely and the products of combustion are cooled to the initial temperature of the solid waste, as in a calorimeter.

LOW -- The high heat value minus the latent heat of vaporization of the water that is formed by burning the hydrogen in the fuel.

HEAVY METALS -- Metallic elements of higher atomic weights, including but not limited to arsenic, cadmium, copper, lead, mercury, manganese, zinc, chromium, tin, thallium, and selenium.

HIGH GRADE PAPER -- Letterhead, dry copy papers, miscellaneous business forms, stationery, typing paper, tablet sheets, and computer printout paper and cards.

INCINERATION -- The controlled process by which solid, liquid, or gaseous combustible wastes are burned and converted into gases. The residue produced contains little or no combustible material.

JUNK -- Unprocessed materials suitable for reuse or recycling.

MAGNETIC SEPARATOR -- A device that removes ferrous metals using magnets.

MODIFIED CIRCULAR REGISTER BURNER -- One of five common suspension fired burners that can be easily adapted for use in burning pulverized coal and fluff refuse-derived fuel in boilers.

MOISTURE CONTENT (SOLID WASTE) -- The weight loss (expressed in percent) when a sample of solid waste is dried to a constant weight at a temperature of 100° C to 105° C.

1. $\text{Wet} = \dfrac{100\ (\text{water content of sample})}{\text{Dry weight of sample \& water content of sample}}$

2. $\text{Dry} = \dfrac{100\ (\text{water content of sample})}{\text{Dry weight of sample}}$

OFFICE WASTES -- Solid wastes generated in the building, room, or series of rooms in which the affairs of a business, professional person, branch of government, etc., are carried on, but excluding wastes generated in cafeterias or snack bars or other food preparation and sales activities in those buildings.

OPEN DUMP -- A land site where solid waste is dumped on the surface of the soil and is not covered or buried.

PATHOGEN -- An organism capable of producing disease.

PELLETIZER -- A device that compacts refuse derived fuel into a small (pellet sized) usable form.

PERCOLATE -- To seep through a layer of porous material (layers of either earth or refuse). A liquid percolating through a layer of refuse material may become contaminated.

PERSONAL PROPERTY -- Property of any kind or any interest therein, except real property and records of the Federal Government.

PROCESS CHEMICALS -- The chemical(s) remaining after or produced by a given industrial process (e.g., chrome plating, aluminum etching).

PYROLYSIS -- The chemical decomposition of a material by heat in the absence of oxygen.

REAL PROPERTY -- Lands, buildings, structures, utilities systems, improvements, and appurtenances thereto. It includes equipment attached to and made part of buildings and structures (such as heating systems) but not movable equipment (such as plant equipment).

RECLAMATION - Restoration to a better or more useful state, such as land reclamation by sanitary landfilling, or obtaining useful materials from solid waste.

RECOVERABLE RESOURCES -- Materials that retain useful physical or chemical properties after serving a specific purpose and can, therefore, be reused or recycled for the same or other purposes.

RECOVERY -- The process of obtaining materials or energy resources from solid waste. Synonyms are extraction, reclamation, and salvage. (Energy refers to the energy available from the heat generated when solid wastes are incinerated.)

RECYCLING -- The process by which waste materials are transformed into new products in such a manner that the original products may lose their identity.

REFUSE DERIVED FUEL -- The burnable fuel that is the result of special processing of various types of solid wastes. Such processing includes a mechanical sequence of operations to improve the physical, mechanical, or combustion characteristics compared with the original unsegregated, unprocessed solid waste.

RESIDENTIAL SOLID WASTE -- The food wastes, rubbish, and trash resulting from the normal activities of households.

REUSE -- The reintroduction of a commodity into the economic stream without any change.

ROTARY-KILN INCINERATOR -- A two-chamber incincerator whose primary chamber is a refractory lined cylinder that rotates about its centerline.

RUBBISH -- A general term for solid waste, excluding food waste and ashes, taken from residences, commercial establishments, and institutions.

SALVAGE -- The utilization of waste materials.

SANITARY LANDFILLING -- An engineered method of disposing of solid waste on land in a manner that protects the environment, by spreading the waste in thin layers, compacting it to the smallest practical volume, and covering it with soil by the end of each working day.

SCRAP -- Discarded or rejected material or parts of material that result from manufacturing or fabricating operations and are suitable for reprocessing, but exclude paper, cardboard, newspaper, and all high grade paper to be source separated in accordance with EPA solid waste guidelines.

SEPARATION -- The systematic division of solid waste into designated categories.

SLUDGE -- The accumulated semi-liquid suspension of settled solids deposited from wastewaters or other fluids in tanks or basins. It does not include solids or dissolved material in domestic sewage or other significant pollutants in water resources, such as silt, dissolved materials in irrigation return flows, or other common water pollutants.

SOLID WASTE -- Garbage, refuse, sludges, and other discarded solid materials, including solid waste materials resulting from industrial, commercial, and agricultural operations, and from community activities.

SOLID WASTE MANAGEMENT -- The purposeful, systematic control of the generation, storage, collection, transport, separation, processing, recycling, recovery, and disposal of solid wastes.

SPECIALLY DESIGNATED LANDFILL -- A landfill at which complete, long-term protection is provided for the quality of surface and subsurface waters from pesticides, pesticide containers, and pesticide-related wastes deposited therein, and against hazard to public health and the environment. Such a facility complies with the Agency Guidelines for the Land Disposal of Solid Wastes as prescribed in 40 CFR Part 241.

STOKER -- A mechanical device to feed solid fuel or solid waste to a furnace.

STORAGE -- The interim containment of solid waste, in an approved manner, after generation and prior to collection for ultimate recovery or disposal.

TRANSFER STATION -- A site at which solid wastes are concentrated from transport to a processing facility or land disposal site. A transfer station may be fixed or mobile.

TROMMEL (ROTARY SCREEN) -- An inclined, meshed cylinder that rotates on its axis and screens material placed in its upper end.

USABLE PROPERTY -- Commercial and military property other than scrap and post-consumer waste.

VECTOR -- A carrier, usually an arthropod, that is capable of transmitting a pathogen from one organism to another.

WASTE -- See also BULKY WASTE, CONSTRUCTION AND DEMOLITION WASTE, HAZARDOUS WASTE, AND SOLID WASTE.

SPECIAL WASTE -- Those wastes that require extraordinary management.

WOOD PULP WASTE -- Wood or paper fiber residue resulting from a manufacturing process.

YARD WASTE -- Plant clippings, prunings, and other discarded material from yards and gardens. Also known as yard rubbish.

WASTE PROCESSING -- An operation such as shredding, compaction, composting, and incineration, in which the physical or chemical properties of wastes are changed.

WASTE SOURCES -- Agricultural, residential, commercial, or industrial activities that generate wastes.

WET CYCLONE SCRUBBER -- A device that is designed for the removal of air suspended particulates.

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APPENDIX A. LIST OF WASTE MANAGEMENT REGULATIONS, GUIDELINES, AND DIRECTIVES PERTAINING TO MILITARY OPERATIONS

The following list contains laws, regulations, and DOD directives pertaining to waste management. It is an illustration of the breadth of provisions DOD must adhere to and is not meant to be an exhaustive list. Service department policies are not listed.

Federal Laws, Regulations and Orders

1. Resource Conservation and Recovery Act of 1976 (P.L. 94-580) Supercedes the Solid Waste Disposal Act of 1965 (P.L. 89-272) and the Resource Recovery Act of 1970 (P.L. 92-512)

2. National Environmental Policy Act of 1969 (P.L. 91-190)

3. Code of Federal Regulations, Title 40, Protection of the Environment, January 1, 1972, especially Parts 240-241

4. National Materials Policy Act of 1970 (42 U.S.C. 3251)

5. Occupational Safety and Health Act of 1970 (P.L. 91-596)

6. Toxic Substances Control Act of 1976

7. Clean Air Act Amendments of 1977

8. Clean Water Act of 1972 (P.L. 92-500)

9. Safe Drinking Water Act of 1974 (P.L. 93-523)

10. Marine Protection, Research and Sanctuaries Act of 1972 (as amended by P.L. 93-254)

11. Executive Orders (various) to further clarify and strengthen the purpose and policies of environmental laws applicable to Federal agencies

12. DOD Directive 4165.60 (October 4, 1976), Solid Waste Management--Collection, Disposal, Resource Recovery, and Recycling Program

13. DOD Directive 7310.1 (July 10, 1970), Accounting and Reporting for Property Disposal and Proceeds for Sale of Disposable and Personal Property and Lumber and Timber Products

14. DOD Environmental Quality Program Policy Memorandum (DEQPPM) No. 79-4, DOD Hazardous Material Disposal Policy, December 17, 1979

15. DOD Memorandum: Oil Recycling and Reuse Policy, June 4, 1979

16. DOD Environmental Quality Program Policy Memorandum (DEQPPM) No. 80-5, DOD Hazardous Material Disposal Policy, May 13, 1980.

17. DOD Environmental Quality Program Policy Memorandum (DEQPPM) No. 80-7, DOD Hazardous and Solid Waste Management Committee, May 13, 1980.

18. Other guidelines include:

    a. Guidelines for Beverage Containers (Federal Register, September 21, 1976, Vol. 41, No. 184)

    b. Guidelines for Resource Recovery on Facilities (Federal Register, September 24, 1976, Vol. 41, No. 184)

    c. Solid Waste Management Guidelines for Source Separation (Federal Register, April 23, 1976, Vol. 41, No. 80)

    d. Guidelines for Storage and Collection of Residential, Commercial, and Institutional Solid Waste (Federal Register, February 13, 1976, Vol. 41, No. 31)

State

State governments primarily develop minimum compliance standards and comprehensive disposal plans. Typical regulatory responsibilities of state solid waste agencies include administering the state solid waste management program, providing technical and financial assistance for various regulating agencies, reviewing local solid waste management practices and plans, and acting as the official governing body for all aspects of solid waste disposition.

Local

Local regulatory agencies are concerned with enforcing legislation and protecting community health and well-being. Local agencies are not necessarily separate offices. Often, public health, air pollution control, water pollution control, and solid waste offices are combined under a department of health or department of environmental quality. Water pollution control and solid waste authorities are sometimes under the jurisdiction of the department of sanitation or department of public works. Land use planning authorities may be found under the department of city planning or the zoning board.

APPENDIX B. TECHNOLOGY DESCRIPTION OF ENERGY RECOVERY SYSTEMS AVAILABLE FOR MILITARY INSTALLATION APPLICATION

The energy recovery processes are described briefly, and the major unit processes of the technologies are identified schematically. This appendix is based on published literature and on conversations with industry, military, and government officials. In particular, information was obtained from the U.S. Army Construction Engineering Research Laboratory (Ref. 2), Office of Technology Assessment (Ref. 81), and the U.S. Environmental Protection Agency (Ref. 64).

B.1. Mass Incineration Processes

B.1.1. Waterwall Incineration

In waterwall incineration, raw municipal solid waste (MSW) is burned directly in large waterwall furnaces, generally without preprocessing the waste. The primary product is steam, which can be used directly or converted to electric power, hot water, or chilled water. Figure B-1 shows the main features of a waterwall furnace for unprocessed MSW.

Data from plants are beginning to lead to improved plant designs. Operational data from modern plants indicate that shredding of delivered waste is being recommended more often to improve furnace performance.

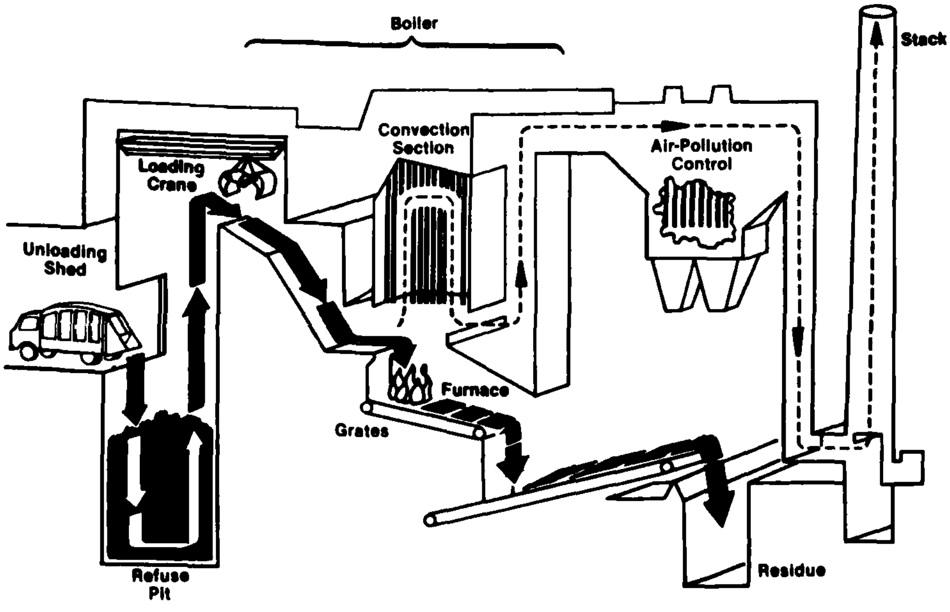


Figure B-1. Typical Waterwall Furnace for Unprocessed Solid Waste

The theoretical advantages of shredding are numerous. It loosens and reduces the waste to a smaller and more easily handled size; increases the charge's surface/volume ratio, which improves its combustion performance; ballistically rejects many bulky incombustibles that adversely affect combustor material; and by mixing, makes the charge somewhat less variable than its unprocessed feedstock. The disadvantages are plant problems in maintenance, reliability, materials handling, and safety.

A variety of relatively short-term shredder maintenance data exists, and indications are that complete overhaul must be done as much as 12 times annually, most hammers on hammermills must be replaced after 400 to 1000 tons have been processed, and hammer hardfacing or tip rewelding must be done daily (requiring about 4 hours per shredder). Cyclic maintenance requirements are not fully known. In the case of hammer replacement, worn hammers must ordinarily be disposed of, because most are made of specialized hardened steel that has no use in the current salvage market.

Reliability of shredders is very speculative. It is not unusual for unforeseeable downtime to last several weeks until special replacement parts are made, delivered, and installed and the unit is tested. Shredder explosions are not infrequent and, aside from unit outage, endanger plant personnel. Explosions may be caused by a variety of phenomena, including discarded explosive materials in the waste, presence of volatiles such as solvents and gasoline, and ignition of suspended dust by sparks generated when the hammers strike other metallic objects in the feed. Despite the well-publicized dangers of shredders, many processing plants persist in stationing personnel (such as pickers who remove adverse materials from the feed conveyor) close to the units. Some plants have installed acoustic/blast partitions around shredders, with breakaway panels in the roof to accept the forces and shrapnel liberated by the explosion.

Other hazards involving shredders are dust (including airborne bacteria and viruses) and fire. Modern plant designs include an air hood near the shredder to prevent a dangerous concentration of dust near the unit. Despite the obvious possibility of fire spreading rapidly throughout the waste processing system, many designs neglect adequate fire protection, either in the form of special construction, a quench system, or clearly marked personnel escape routes.

Although the disadvantages associated with shredding are numerous and serious, at the current state of the art, neither the disadvantages nor the advantages (in the form of improved combustor performance) can be quantified in a cost-benefit manner to provide a basis for decisionmaking.

Other problems revealed in the field erected systems that are not apparent in most large incinerator plants include sanitation and pest control. It is prudent to plan a sufficient budget for these items.

Scientific research has brought us improved firing and stocking methods, so that the double reciprocating grate is now preferred over the conventional traveling grate and other configurations. The frequent and costly grate burnout problems encountered with conventional traveling grates (necessitating bar replacement as often as once a week) will probably be greatly reduced.

When designed properly, field erected systems will function in a way far superior to modular incinerators and densified refuse-derived fuel (DRDF) at the current state of the art. This is not to say that there are no challenges. Unknown areas include slagging potential, grate fouling, corrosion, whether to shred, how to shred, how to cope with the variability of input material in design and practice, and combustion control methods. There is also a need for economic data to provide a sound base for life cycle and value analyses in assessing the feasibility of applying a similar technology elsewhere.

B.1.2 Small-Scale Modular Incineration

Small-scale modular incinerators feature heat recovery as steam or hot water and usually forego materials recovery. Most applications to date have been in hospitals, schools, other institutions, and industry whose wastes are more homogeneous than MSW. Thus, application of this technology to MSW is a relatively recent development. Modular systems include predesigned, off-the-shelf, highway-shippable components that have a procurement time usually no longer than 8 months. A modular heat recovery line would include the furnace, a package watertube boiler (with appropriate sootblowing and residue capture capability), air pollution control equipment, stack, and ash removal. The boiler may be equipped with a separate windowbox and burner so it can remain online after incinerator shutdown. Equipment is usually housed in a pre-engineered building that has sufficient floor area and clearance to accommodate a tipping floor/front-end loader waste handling operation. Of central interest are modular incinerators, which, because of size limits for transportation, rarely have rated throughput capacities greater than 1 ton per hour of civilian-type waste.

Modular incinerators are advantageous in that they are less capital intensive than their custom-designed, field-erected counterparts. Their disadvantages, however, are substantial. First, modular incinerators will not accept bulky wastes of the type often found on military installations. If an average waste load can fit easily into the trunk of a large sedan, then most modular incinerator feeders will accept the material. Even nonbulky wastes will not settle evenly in feed hoppers, and often rather drastic improvisations are required to compact the material.

Second, because modular incinerators are predesigned for municipal rather than military waste, which has a significantly higher heat release rate, they must usually be derated by up to 30 percent. Hence, the average Army installation, which generates 35 tons/day of solid waste, would require a plant processing capacity of at least 50 tons/day just to allow for derating. To process waste on a one-shift basis (6.5 hours effective burn time), this installation would require an installed hardware capacity of about

8 tons/hour. The plant would therefore require a minimum of eight units rated at 1 ton/hour operating in parallel. Since each unit must be fed every 7.5 minutes, the plant operator would have to load each incinerator feeder in less than 1 minute to sustain optimal use and total plant performance.

One approach to the derating problem has been to install a water spray either at the feeder or within the furnace itself. It is speculated that quenching the waste lowers its heat release rate, makes the mass throughput capacity of the furnace more controllable, and extends the load cycle time. However, this approach contradicts one essential objective of heat recovery incineration, which is to use heat liberated economically through combustion in a furnace to evaporate water to steam in a controlled downstream heat exchanger--not to wet down the charge and evaporate virgin water in the furnace. Higher than necessary combustion heat losses and lower than desirable system efficiency and economy are inescapable consequences of this measure.

Another frequently encountered combustion problem stems from the advice given by some manufacturers to operate modular incinerators at furnace temperatures in the neighborhood of 2200°F. Stationary bed incinerators (Figure B-2) are particularly prone to severe slagging at temperatures above 1800°F, where the viscosity of refuse ash (particularly glass, ceramics, ferro-aluminum compounds) is in the plastic range. An expected result is accelerated refractory wastage. Attendant operational problems include plugging of underfire air ports, bed channeling, and incomplete combustion. Even at lower operating temperatures, it is not unusual for some units to require manual reamout of frequently inaccessible underfire air ports several times during an operating shift.

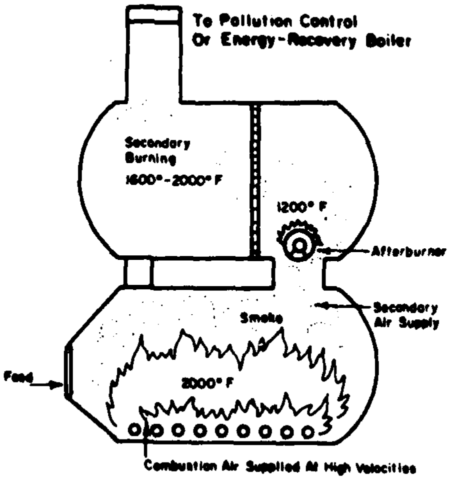


Figure B-2. Starved-Air Incinerator (first major configuration)

A third major disadvantage of modular incinerators is their questionable durability, which has spawned divergent approaches toward their use on Army installations. The first approach is to protect the combustor, either by installing redundant furnaces and alternating operation or by processing the waste (shredding, magnetic removal of ferrous metals, screening for removal of glass and other inerts) before it is fired. If the processing alternative is selected, the waste will gain a substantial value added before it enters the furnace, and the plant will require additional skilled operating personnel and control and safety systems. The second approach is to fire as-received waste (with oversized bulky incombustibles removed), perform the minimal maintenance required to keep the unit reasonably operational, and repair by replacement when the rising cost of minimal maintenance so warrants. It is not known which approach toward solving the durability dilemma is more appropriate, because operational data on these developing systems are just beginning to accumulate.

The vital parameters that permit accurate economic and value analyses of modular incinerators are not known. Routine operating and maintenance requirements, cyclic maintenance requirements, and length of economic life are currently only speculative. An often travelled path around the latter factor is to assume that a modular system will last a specified period of time, usually 20 years. This assumption has been so widely proliferated that, despite the absence of any substantiative data, it is being increasingly and dangerously considered a fact.

The controlled air incinerator is presently the most widespread of the four major modular incinerator configurations. It is a stationary bed furnace semi-continuously fed by a hydraulic ram feeder. The controlled air incinerator may have a "piggybacked" secondary chamber of equal size to the primary chamber (Figure B-2), or may consist only of a primary combustion chamber and a small afterburning volume immediately after (Figure B-3). In one modular incinerator resembling the controlled air unit, ash is discharged through refractory-lined bomb bay doors, which close to form the floor of the furnace. In the more conventional systems, ash is removed by positive displacement out the bottom of the primary chamber. Throughput ratings for municipal waste rarely exceed 1 ton/hour, meaning that the average Army installation may require up to 16 controlled air units installed in parallel, depending upon operating hours per day and the approach taken to the durability problem discussed above.

The rotary kiln is an inclined rotating furnace, which, with some modification, has had some munitions demilitarization applications. The general concepts underlying operation of the rotary kiln modular incincerator are shown in Figure B-4. Although the controlled air incinerator has a 2.5-year history in small city heat recovery operations, the rotary kiln has no such record. It is theoretically superior to the controlled air configuration in that it mechanically mixes the burning material. But, as with the controlled air unit, bulky incombustible materials jam at the ash pass and result in unit outage until manually removed. The rotary kiln furnace is about three times more costly than the controlled air configuration ($450,000 versus $150,000 procurement cost).

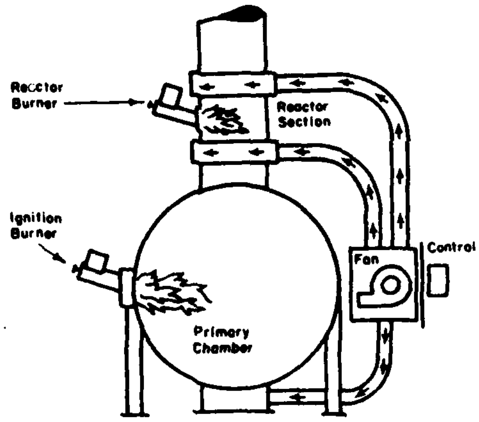
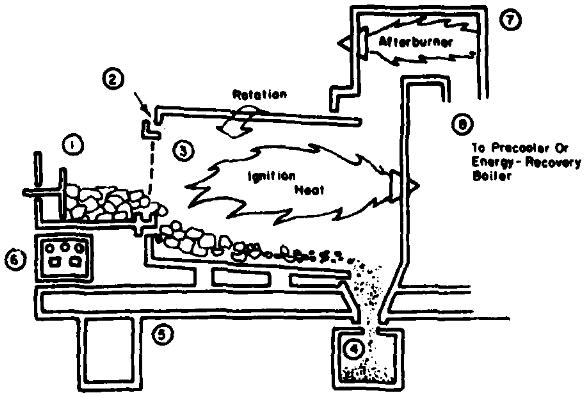


Figure B-3. Front View of Starved-Air Incinerator
(second major configuration)



1 Coarse RDF Auto-Feed (Hopper, Pneumatic Feed, Slide Gates)
2 Forced Air
3 Refractory-Lined Rotating Cylinder (Primary Chamber)
4 Ash Hopper (Incombustibles)
5 Support Frame And Piers
6 Control
7 Secondary Chamber
8 To Appurtenances

Figure B-4. Rotary-Kiln Incinerator

Two of the four basic modular furnace configurations have only recently been developed. The basket grate (Figure B-5) is a continuously fed, inclined rotating cone-shaped grate, which has yet to completely demonstrate its capabilities in energy recovery. Two operational problems of major significance are the tendency of incombustibles to collect in and reduce the effectiveness of the furnace volume and the tendency of fine combustibles to sift through the grate while still burning. The augered bed incinerator resembles the controlled air in appearance (Figure B-6); however, waste is conveyed through the furnace by a water-cooled spiral flight. The basket grate is rated at 3 tons/hour capacity, and the augered bed incinerator claims an hourly throughput capacity of 5 tons. Like the basket grate, use of the augered bed incinerator in the contiguous United States is limited to a single operating prototype, and few conclusive performance data are available.

The encouraging aspect of both the basket grate and augered bed incinerators is that they are attempts to provide greater throughput capacities in modular, low-cost packages. With a reliably operating augered bed incinerator, the average installation could process all its solid waste in one shift per day. Reduced labor requirements alone argue persuasively in favor of further developing and applying such promising technologies.

B.2 Refuse-Derived Fuel Systems

Solid refuse-derived fuel (RDF) is produced by separating MSW and mechanically removing the organic combustible fraction using wet or dry processes. The fuel product of dry processing can be fluff RDF, densified RDF, or dust or powered RDF depending on the subsequent processing used. Most RDF plants also recover one or more of the following materials; ferrous, aluminum, glass, or mixed nonferrous metals. Figure B-7 schematically portrays the main processes for producing the different RDF fuels.

The rationale for using RDF is based on economic trade-off: is it less costly to process waste into RDF for use in an existing boiler, or is it more cost-effective to install new combustion equipment to fire a less-processed waste? At present, RDF is highly developmental, and its most immediately foreseeable use is as a 10- to 12-percent supplement (by as-fired heating value) in pelletized form with coal in central boilers equipped with traveling chain grate or spreader stokers. To date, some boiler tests have been performed, and there is reason for tempered optimism. Unfortunatley, however, many experiments have not produced the quality of design-type data required to support engineering feasibility studies at other locations.

There are as many suggested ways to produce DRDF as there are individuals who have an interest in producing it. This is essentially because DRDF production is still more an art than a science. Few data are available to support rational argument for or against any particular process, but it is commonly agreed that any process will include multiple shredding stages, air classification, screening, drying, and pelleting.

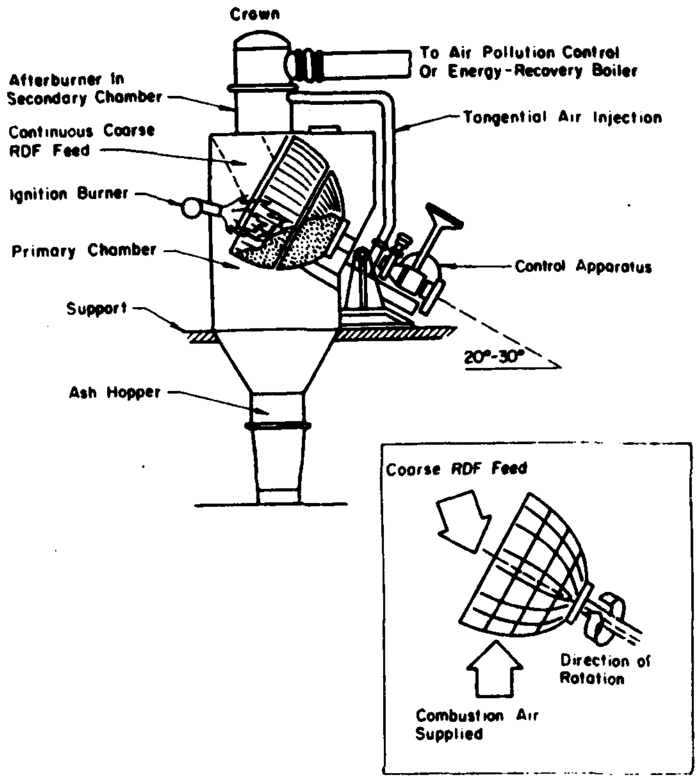


Figure B-5. Basket-Grate Incinerator

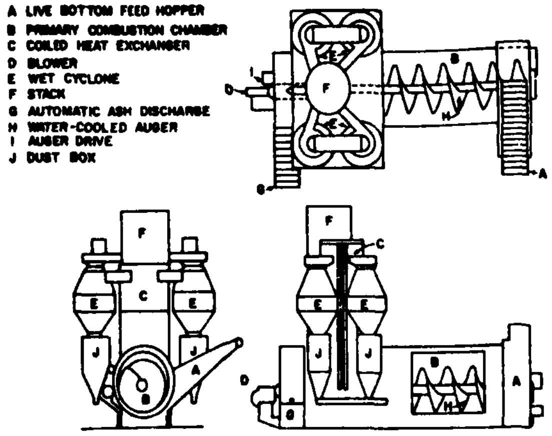


Figure B-6. Augered-Bed Incinerator

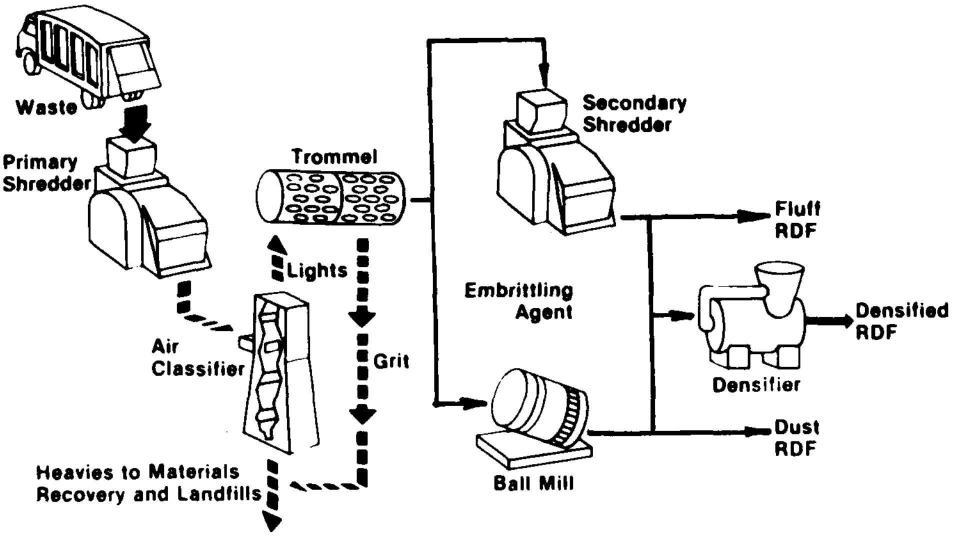


Figure B-7. This Simplified Flow Diagram Shows How the Dry Processing Approach (No Water Slurry) Can be Used to Produce Fluff, Densified, or Dust RDF

Recent work has shown that for every unit of waste put into a DRDF production line, between 0.4 and 0.5 units of DRDF will be produced. Hence, between 0.5 and 0.6 units will appear as process rejects (this includes dust, true reject waste, and some potentially recyclable materials). These materials remain a handling and disposal requirement. The average installation generating 35 tons/day of solid waste would be fortunate to realize half that mass as DRDF. And since at least half its waste stream would remain a disposal requirement, there would likely be at best only negligible reduction of its waste disposal costs.

The true economy of DRDF production is still largely speculative. It has been shown that a plant with a daily input of 100 tons can produce DRDF at a per ton input cost between $10 and $12, excluding reject handling, amortization of the $2.3 million equipment and building investment, and delivery to and handling of DRDF at the using point. But the capital use factor is well below 0.20 for a one-shift operation because of high preventive maintenance requirements and low total system reliability.

While progress is being made toward producing a DRDF that will handle like coal, there are still no convincing data to indicate that the waste fuel pellet will not structurally deteriorate when subjected to normal coal conveyor vibration, and even under moderate load in coal storage bunkers. Recent research into the mechanical properties of DRDF and DRDF/coal mixtures has indicated that most coal handling and storage systems will require redesign to reliably handle the bulk solids that they were not originally intended to accommodate. Because of its unique properties, DRDF is not prone to coal-type gravity mass flow from storage bunkers, but instead will exhibit at best funnel flow and most probably no flow at all. In the latter case, the fuel cannot be easily removed from its storage vessel by any means. Indeed, under agitation, the rate of structural deterioration of the pellet is increased, and the fibrous material becomes even more dense and immovable.

However, it should be noted that certain types of DRDF may flow from some existing coal storage bunkers. Nearly all military coal storage vessels were fabricated and installed as long as 40 years ago, when their design was based upon experience and informed engineering intuition. Only recently has a scientific approach been taken toward storage and flow of bulk solids that considers their dynamic properties in storage vessels. Thus, some existing bunkers handle their coal well, while others do not. Although some of these bunkers might also successfully handle DRDF and/or DRDF/coal mixtures, this appears to be attributable to good luck, and the available data are not the type on which contemporary engineering design is customarily based.

Similarly, little scientific research has been performed on the behavior of DRDF in a boiler. We know that DRDF has a lower calorific value and ignition temperature than nearly all coals, and usually burns with a cooler and larger flame. We also know that it has a much more rapid rate of reaction than coal. The facts argue convincingly that if the boiler is to be kept at rated capacity when firing DRDF, the furnace volume must be considerably enlarged.

It is not easy to pin down the combustion behavior of DRDF to make conclusive assessments about the feasibility of its use. Many standard testing methods successfully used for coal characterization fail when attempts are made to similarly analyze DRDF. The American Society for Testing and Materials has recognized this problem, and its Energy Subcommittee is currently developing RDF testing procedures.

Despite the fact that essentially the same kind of input characterization problems plague the use of DRDF as hinder proper incinerator design, general studies continue to assert that DRDF is easily usable in substantial numbers of Federal boilers. Such studies often take for granted that established boiler coal feeding equipment will perform adequately with DRDF. However, the types of flow problems encountered with DRDF in existing coal bunkers may be anticipated in attempts to pass the waste fuel through the conventional weigh larry in traveling grate applications or the standard mechanical feeder in spreader stoker systems.

It is generally accepted that a DRDF production line will include multiple shredding stages, air classification, screening, drying, and pelleting. Few appliances used in any currently operating system have been designed to process variable solid waste, but rather have been adapted from other industrial applications. It is currently better known what most equipment does rather than why it works on solid waste. Processing plants often contain a nearly randomly sequenced range of poorly selected, adequate, and brilliantly designed equipment, with the aggregate result of nonoptimal system reliability, controlability, and predictability. The proper performance of many systems depends upon skilled labor with qualifications both to operate advanced and adapted equipment and to innovate quick, artful changes in the process to obtain desired output. To guarantee smooth operation of such plants for an acceptable economic life is highly risky. The high degree of complexity in using DRDF is exceeded only by the magnitude of the challenge with which the problem confronts the engineer and scientist. In either case, vigorous scientific inquiry is needed and should be encouraged.

B.3 Pyrolysis Systems

Pyrolysis is destructive distillation or decomposition of organic materials in MSW at elevated temperatures in an oxygen deficient atmosphere. The product of pyrolysis is a complex mixture of combustible gases, liquids, and solid residues usable as fuels or chemical raw materials. The characteristics of the pyrolysis products depend on such variables as time in the reactor, process temperature and pressure, oxygen content of the gas in the reactor, particle size of the MSW feed, and the choices of catalysts and auxiliary fuels. Differences in these parameters distinguish the several proprietary processes that have been developed. Four proprietary systems are presently in some stage of demonstration. Two of these produce low-Btu gas: Monsanto's Landgard and the Andco Torrax processes. The Union Carbide Purox system produces medium-Btu* gas. The Occidental Research Flash Pyrolysis process produces a liquid fuel.**

In the Monsanto system, Figure B-8, MSW is shredded before it is pyrolized with a supplementary fuel in a large (20-foot diameter, 100-foot long), horizontal, refractory-lined kiln. Solid residue from the kiln is water quenched and separated into ferrous metal, glassy aggregate, and char. The char is dewatered and landfilled. In the Andco process, Figure B-9, raw MSW enters a vertical shaft furnace after large items are removed and is pyrolyzed with auxiliary fuel. As the charge descends, it is dried and converted to gases, char, and ash. The low-Btu gas produced must be burned onsite to produce steam or hot water.

The only Monsanto system in operation is currently undergoing modification to solve air pollution and other technical problems. Monsanto has withdrawn from the project. Andco has no plants in the United States. A

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* Low-Btu gas has a heating value of around 100 to 150 Btu per standard cubic foot (scf), the heating value of medium-Btu gas is 300 to 400 Btu per scf. By comparison, natural gas has a heating value of about 1000 Btu per scf.

** Liquid pyrolysis oil has a heating value of about 10,000 Btu per pound, roughly half that of No. 6 fuel oil.

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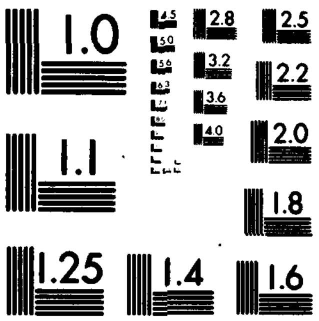

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU

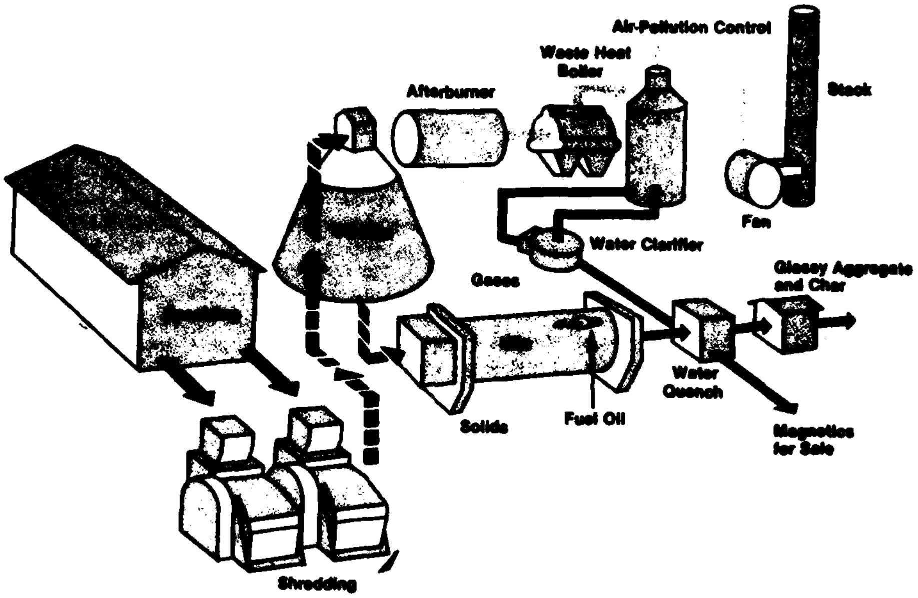

Figure B-8. The Monsanto Landgard System Produces a Low-Btu That Is Immediately Burned Onsite for the Production of Steam

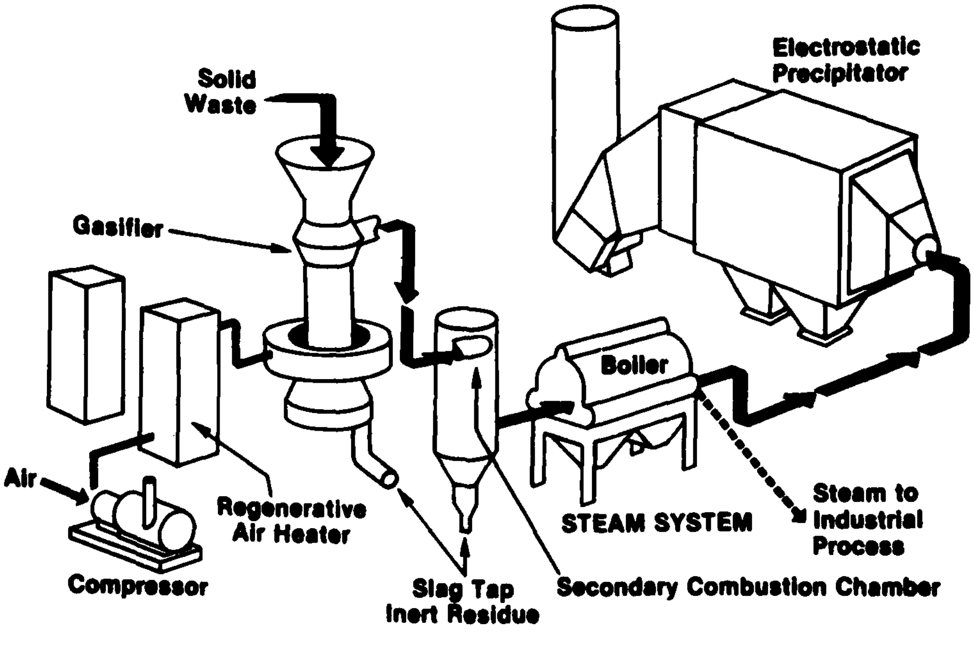

Figure B-9. Torrax Slagging Pyrolysis System

200-ton/day plant is in startup in Luxembourg, and two others are under construction in Europe.

In the Union Carbide Purox system (Figure B-10) ferrous material is magnetically separated from shredded MSW prior to feeding. Shredded refuse fed into the top of the vertical shaft furnace descends by gravity into zones of increasing temperature where drying, then pyrolysis, and finally char combustion and slagging take place. The temperature in the bottom zone, the slagging zone, is high enough to reduce the residual to a molten slag that continuously drains into a water quench to produce a hard granular aggregate material called frit. The Purox process feeds the furnace pure oxygen, rather than air as in the Monsanto and Torrax systems, and produces medium-Btu gas product. Its smaller volume and higher Btu content facilitates economic shipment over reasonably long distances.

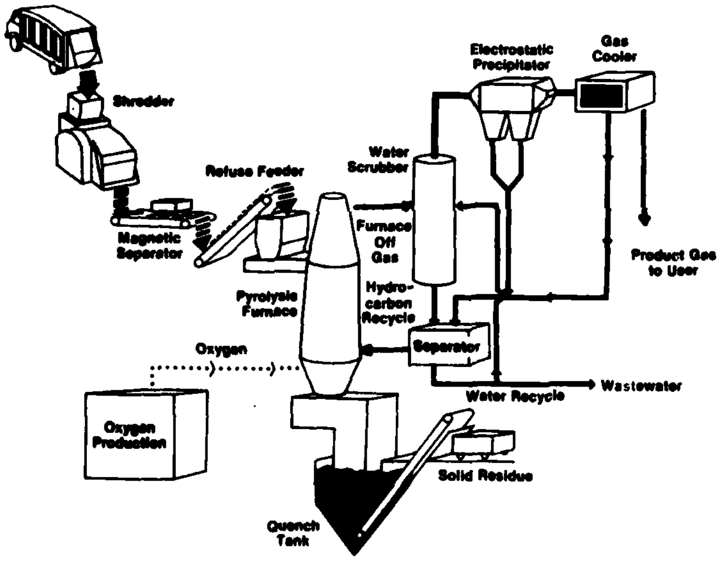

Figure B-10. Union Carbide Purox System Produces a Medium-Btu Gas for Sale to Offsite Users

In the Occidental liquid fuel pyrolysis process (Figure B-11) raw MSW is first shredded and air classified to recover ferrous metal, aluminum, and glass prior to pyrolysis. The light organic fraction is dried, shredded again in an inert gas atmosphere, and then introduced to the pyrolysis reactor. Pyrolysis in the reactor vessel produces an oil-like fluid somewhat comparable to No. 6 fuel oil that can be burned in existing oil-fired, steam-electric powerplants. A 200-ton/day demonstration plant was reported to be undergoing operational testing in early 1978. A subsequent report in May 1978 indicated that this sytem was not operating and faced major cost increases if it were to be continued.

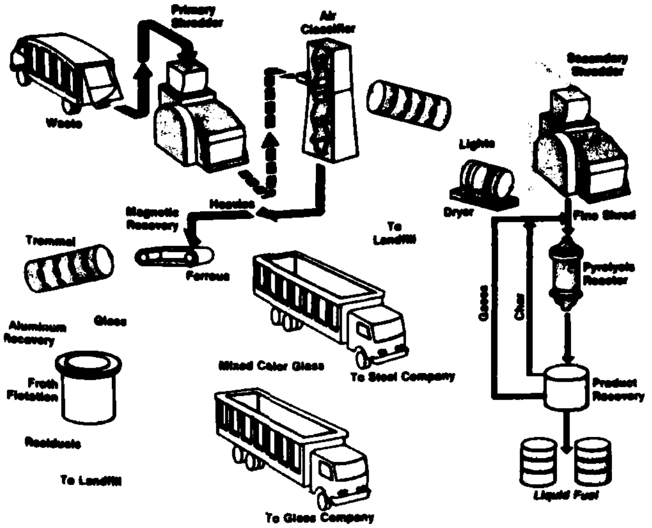

Figure B-11. Production of Liquid Fuel From Solid Waste Using the Occidental Process

APPENDIX C. DOD INSTALLATION ENERGY GOALS AND OBJECTIVES

C.1 Installation Energy Supply

Installation energy consumption accounts for about 40 percent of total energy consumption. DOD is committed to a comprehensive program structured to satisfy mission requirements while applying economic criteria, such as payback and cost/benefit analyses and identifying and selecting new technologies and energy alternatives that will make DOD more energy efficient in the installation energy area.

Goal: Achieve a reduction in the use of natural-petroleum fuel consumed in the onbase generation of utility energy from the 1975 level of consumption.

These reductions will be met according to the following timetable:

- A 30-percent reduction by FY 1985,
- 35 percent by 1990,
- 40 percent by 1995, and
- 45 percent by 2000.

This goal will be met through the use of nonpetroleum fuels, geothermal and renewable energy sources, and conservation techniques.

Goal: Obtain an increasing percentage of total energy from coal (solid coal, coal liquids, and coal gas), refuse-derived fuels and wood.

These increases in percentage of usage will be met according to the following timetable:

- 10 percent of the total facility's onbase generation of utility energy by fiscal year 1985,
- 15 percent by 1990,
- 20 percent by 1995, and
- 35 percent by 2000.

At present, only solid coal is providing a significant amount of energy in DOD.

Goal: Obtain an increasing percentage of total installation energy from geothermal and renewable energy sources using the following technology applications: geothermal heating and electric, low-head hydropower, solar heating and cooling, solar electric, biomass (municipal solid waste, refuse-derived waste fuels, and wood), wind, and ocean thermal.

These increases in percentage of usage will be met according to the following timetable:

- 1 percent of the total facility's utility energy by fiscal year 1985,
- 5 percent by 1990,
- 10 percent by 1995, and
- 20 percent by 2000.

C.2. Energy Conservation and Efficiency

Energy conservation goals for installation utility consumption focus on reducing consumption in new and existing buildings. Specific goals have been set to increase energy conservation and efficiency.

Goal: Reduce energy usage in existing buildings per gross square foot from the 1975 baseline usage.

These reductions in percentage of usage will be met according to the following timetable:

- 20-percent reduction of energy per square foot by fiscal year 1985,
- 30 percent by 1990
- 35 percent by 1995, and
- 40 percent by 2000.

Goal: Achieve a 45-percent reduction in energy usage for new buildings per gross foot from the 1975 usage.

New buildings, scheduled for completion after November 8, 1978, will be designed to achieve the 45-percent reduction.

Goal: Energy reductions for industrial or production operations, training, research and development, etc., should be expressed in terms of increased energy efficiency per unit of production or other appropriate productivity measure. Each service/agency should develop and utilize methods to measure energy efficiency improvements appropriate to the peculiarities of service/agency operations.

DOD is committed to becoming more efficient. As a part of this commitment, DOD is now in the process of establishing measures of energy efficiency. In addition, DOD will establish a timetable for meeting improvements in efficiency. Because each service/agency has operations that differ and because energy consumption, for training and research and development especially, have not been considered on an energy efficiency basis in the past, the standards developed initially may change. The standards will probably take the form of such measures as number of Btu per production manhour for aircraft overhauls or number of Btu per student trained for electronic engineering training.

Goal: Comply with the yearly retrofit requirements of the National Energy Conservation Policy Act (NECPA).

At present, the services plan most energy conservation projects by functional area (such as insulation or lighting). These projects (for example to improve the insulation of all housing on the base) are believed to save more energy per dollar invested than projects that would enhance all the energy systems in one building. Currently, however, overall energy savings cannot be attributed to any specific project, nor to individual buildings, because

- Less than 1 percent of DOD buildings are individually metered and
- It is impossible, even with individual metering, to distinguish between savings achieved through improved equipment, new materials, and modified operating procedures.

So that compliance with the National Energy Policy Conservation Act (P.L. 95-619) retrofit requirements can be determined, each military service and defense agency will retrofit existing, owed Federal buildings to make them life-cycle cost effective in accordance with the formula and methodology developed by the National Bureau of Standards. Retrofits will be planned on the basis of data derived from the preliminary energy audit, technical surveys, and other appropriate material. Potential projects will be evaluated for energy savings in comparison with estimated cost to ensure effective expenditures. It is estimated that retrofit costs will be about $5 per square foot.

Source: Department of Defense Energy Management Plan, Office of the Deputy Assistant Secretary of Defense (Energy, Environment, and Safety), July 1, 1980.

APPENDIX D. TYPES OF HAZARDOUS WASTE GENERATING FACILITIES (U.S. NAVY)

COMPLEX	MCB/ NAVSTA	NAS/ MCAS	HOSP	NWS	PWC	NTC	NARF	NSY	NCBC	NSC	NSGA	NUSC	SUB BASE	COMM STA	LABS	SHIPS	SUBS	NIROP/ NWIRP	TOTALS
Newport, Rhode Island		1	1			2			1			1						2	8
Maine		1									1			1				1	4
New Hampshire			1					1								1	3		6
New London, Connecticut												1	1			2	32	1	37
New York	1	2		1												4		3	11
Philadelphia, Pennsylvania	1	4	1					1								5			12
Washington, D.C.	1	2	1	3											6				13
Norfolk, Virginia	1	3	1	1	1		1	1		2						94	11		116
North Carolina	1	1	1				1												4
Charleston, South Carolina	2	1	2	1				1		1						34	24		66
Pensacola, Florida		4	1		1	1	1					1				2			11
Jacksonville, Florida	1	2	1				1			1						26			32
Key West, Florida	1	1	1																3
Orlando, Florida			1			1					1								3
Georgia	1	1																	2
Mississippi		1							1								2		4
New Orleans, Louisiana	1	1														1			3
Chicago, Illinois		1			1	1													3
Texas		4	1															2	7
Tennessee		1	1															1	3
Seattle, Washington	1	1	1					1		1			1			5	4		15
San Diego, California	2	3	2		1	1	1			2		1	1			96	15		125
San Francisco, California	1	2	1	1	1		1	1		1	1					24	5		39
L.A./Long Beach, California	1	2	1	1				1		2						14			22
Ventura, California		1							1						1	2			5
Misc. California	2	1		1											1			2	7
Hawaii	2	2		2	1			1		1			1	1		28	21		60
Alaska	1										1				1				3
Puerto Rico	2			1							1			1					5
Guam	1	1	1		1			1		1				1		1			8
	24	44	20	12	7	6	6	9	3	12	5	4	4	4	9	339	117	12	537

Abbreviations:

MCB - Marine Corps Base; also includes Marine Corps Logistics Support Center and Marine Corps Recruit Depot (large)

NAVSTA - Naval Station; also includes Naval Support Activity, Navy Yard

NAS - Naval Air Station; also includes Aircraft Parts Center, Air Development Center and Amphibious Base

MCAS - Marine Corps Air Station, includes Marine Corps Air Facility

HOSP - Naval Hospital and Naval Regional Medical Center; also includes National Naval Medical Cente

NWS - Naval Weapons Station; also includes Naval Ordnance Station, Naval Weapons Center, Naval Ammunition Depot, Naval Magazine and Naval Surface Weapons Center

PWC - Public Works Center

LABS - Naval Laboratory; also includes Ship Research and Development Center, Naval Research Lab, Observatory, Civil Engineering Laboratory

SUBS - Submarines

NTC - Naval Training Center; also includes Naval War Colleges, Naval Academy, Postgraduate School

NARF - Naval Air Rework Facility

NSY - Naval Shipyard and Ship Repair Facility

NCBC - Construction Battalion Center

NSC - Naval Supply Center; also includes Supply Depot, Fuel Depot and Supply Annex

NSGA - Naval Security Group Activity

NUSC - Naval Undersea Center; also includes Ocean Systems Center, Coastal Systems Laboratory

SUBASE - Naval Submarine Base; Submarine Support Facility, Naval Torpedo Station

COMMSTA - Communications Station and Radio Station

NIROP - Naval Industrial Reserve Ordnance Plant

NWIRP - Naval Weapons Industrial Reserve Plan