AD-A148 947 SOLID WASTE MANAGEMENT OPTIONS FOR NAVAL INSTALLATIONS ON GUAM(U) NAVAL CIVIL ENGINEERING LAB PORT HUENEME CA R M ROBERTS OCT 84 NCEL-TN-1711 1/1

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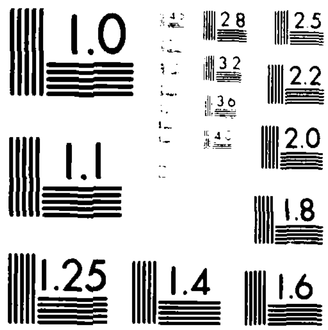

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AD-A148 947

TECHNICAL NOTE

TN NO: N-1711

TITLE: SOLID WASTE MANAGEMENT OPTIONS FOR NAVAL INSTALLATIONS ON GUAM

AUTHOR: R. M. Roberts

DATE: October 1984

SPONSOR: Chief of Naval Material

PROGRAM NO: Z0371-01-421A/B

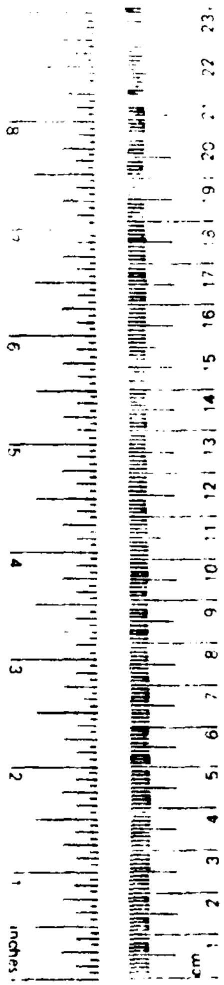
NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

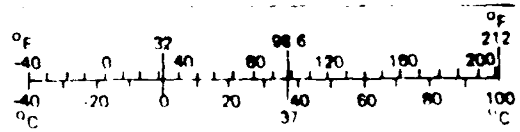
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: TN-1711	2. GOVT ACCESSION NO.: DN987113	3. RECIPIENT'S CATALOG NUMBER: AD-A148 947
4. TITLE (and Subtitle): SOLID WASTE MANAGEMENT OPTIONS FOR NAVAL INSTALLATIONS ON GUAM		5. TYPE OF REPORT & PERIOD COVERED: Final; Jun 1983 – Feb 1984
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): R. M. Roberts		8. CONTRACT OR GRANT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS: NAVAL CIVIL ENGINEERING LABORATORY, Port Hueneme, California 93043		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 64701N; ZO371-01-421A/B
11. CONTROLLING OFFICE NAME AND ADDRESS: Chief of Naval Material, Washington, DC 20360		12. REPORT DATE: October 1984
		13. NUMBER OF PAGES: 33
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS (of this report): Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Guam, solid waste management, resource recovery, waste to energy, heat recovery incinerator

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Navy's solid waste (SW) management operations and energy production/distribution systems on the island of Guam were inspected and evaluated. Air Force and Civil (GovGuam) operations were also brought into the study in the interest of exploring possible integrated concepts. It was found that SW procedures practiced by the PWC Guam conform well with NAVFAC instructions and EPA guidelines. Opportunities for resource

continued

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20. Continued

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Benefit cost analyses of alternative disposal approaches were performed. The concept of burning all of the Navy's SW to steam-drive the Naval station's air conditioning plant emerged as a possibility. Another cost beneficial approach, but one involving the other jurisdictions, would be to erect a turbo-electric (2.5-MW) facility that would fire all of the SW generated on Guam. The mass-fired plant would be owned by GovGuam and preferably operated by a full-service contractor. Since both the GovGuam and Air Force landfills have very limited additional usage and acceptable new sites are quite limited, the concept would solve the serious SW disposal problems now faced by both of those entities.

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Naval Civil Engineering Laboratory
SOLID WASTE MANAGEMENT OPTIONS FOR NAVAL INSTALLATIONS ON GUAM (Final), by R. M. Roberts
TN-1711 33 pp illus October 1984 Unclassified

1. Solid waste management 2. Resource recovery I. Z0371-01-421A/B

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CONTENTS

INTRODUCTION

The present study was performed at the request of the Commanding Officer, Public Works Center (PWC) Guam through the Naval Facilities Engineering Command (NAVFAC). The tasking letter was submitted by Pacific Naval Facilities Engineering Command (PACNAVFACENGCOM ltr 04D:sem, Ser 2372 of 18 Mar 1982). The objective of the effort was to examine the feasibility of utilizing more cost effective waste disposal techniques, particularly of converting the solid waste generated by the Navy (and possibly by the Air Force and civilian population) into a usable form of energy. The study was supported by the Naval Civil Engineering Laboratory's (NCEL) Facilities Engineering Support Office (FESO) program and NAVFAC's sponsored Solid Waste/Energy project. The scope of the effort required:

1. Determining the state of the near- and long-term solid waste management and energy policies and operating practices of PWC Guam.

2. Making a similar assessment of the parallel situations existing within the Air Force (Andersen AFB) and civic government of Guam.

3. Proposing strategies for enhancing the Navy's and the overall island establishment's position relative to the immediate and future solid waste challenge.

The task was initiated with a field trip by Don E. Brunner of NCEL, who met with all of the concerned parties and inspected all of the principal ongoing solid waste operations on the island as well as many of the energy production facilities. Data appropriate to the study were collected as was previously generated documentation pertinent to the analysis.

BACKGROUND

Guam is the largest and southernmost island in the Mariana archipelago. It is approximately 30 miles in length with a width varying from 12 miles to 4 miles at the narrowest point. Excluding the coral reef formations which surround it, the 212 square miles of Guam are comprised of two geological formations. The central and northern portions of the island are elevated limestone structures interspersed with volcanic mounts. The northern cliffs, ranging from 300 to 600 feet in elevation, drop sharply to the sea. The southern features are predominantly volcanic with a mountain ridge dividing the inland valleys and coastline. The highest point on the island is Mount Lamlam, with an elevation of 1,334 feet. The limestone plateau of northern Guam is hydrologically porous, thus serving as a source of ground water that supplies a major portion of Guam's drinking water.

The Guam Environmental Protection Agency (GEPA) has designated almost all of this northern portion of the island as "conservation," "resource," and "recharge" zones. By law, waste disposal in these regions would either not be permitted or leachate control requirements would, if enforced, discourage the siting of landfills there.

Southern Guam is primarily a surface water province that GEPA has demarcated into "conservation" and "general use" areas. Landfills should properly be sited in the latter type areas, although only about one-sixth of the island is so zoned.

Guam's mean annual temperature is 81°F, ranging from the low 70s to the middle 80s. The coolest and least humid months, marked by prevailing westerly tradewinds, are December through February. Annual rainfall totals 80 to 110 inches. There are two seasons: the dry season, running from December through June; and the rainy season, running through the balance of the year. Although Guam experiences droughts from time to time, it is generally regarded as having an adequate water supply. This could change if Guam's role as a military base were expanded.

Guam is an unincorporated territory of the U.S., having the right of civilian rule since the Organic Act of Guam was passed in 1950. The native population of about 82,000 people reside in small, mostly coastal villages. Agana, the capital, is the only large town. The overall population density (civilian and military) on Guam is less than 600 people per square mile.

The U.S. Navy is the major business on Guam and, together with the Air Force, owns about one-quarter of the island. The Navy operates within 10 different commands that are scattered throughout the island. Most of these installations operate their own barracks, messes, energy plants, housing, exchanges, etc. The Public Works Center (PWC) located at Apra Harbor is responsible for collecting solid wastes from all the Naval facilities on Guam, including housing. The material is properly buried in a Navy-operated sanitary landfill located on the southeast portion of the U.S. Naval Station near Agat Bay.

The Navy landfill is located at a site within what has been designated as a "recharge" zone by the GEPA. Based on GEPA's regulations, any leachate from a landfill would have to be treated for discharge into the subterranean recharge (limestone) structures. Although the landfill is exempt from this requirement, corings have been taken that show no evidence of landfill leachate intrusion into the underlying drainage strata.

Approximately 1,600 tons of waste are received each month, mostly Monday through Friday. The waste is relatively free of industrial material, is probably high in calorific value, and contains little glass. This waste is produced within a community of some 20,000 military and their dependents. Landfill life expectancy is about 15 years based on the current filling rate.

Andersen AFB produces about 600 tons of solid waste per month that is disposed of at its landfill which is located in a hydrologically sensitive area. The waste characteristics resemble those of the Navy's wastes. Because of suspected contamination of ground water, the GEPA has requested the Air Force to monitor the site for leachate. The tests that have been conducted show no evidence of groundwater contamination. The facility is expected to fill in about 3 years.

The Department of Public Works (DPW) of the Government of Guam (GovGuam) is responsible for all the solid waste generated by the civilian segment of the population. Residential (excluding military housing) wastes are collected free of charge by DPW trucks. Most of the commercial wastes are collected for a fee by the Commercial Sanitation Company. Commercial/residential/municipal wastes in 1978 were estimated to be approximately 1,600 tons per month (tpm). This does not include a significant amount of waste that is illegally dumped, typically by roadsides. Current estimates of the waste rate based on demographic and economic factors point to about 1,800 tpm, a modest increase of about 2.3% per year.

Disposal of these civilian wastes is done at the Ordot landfill, which is located about 5 miles east of Agana in the center of the island. The zoning for the area is for "general use." The Ordot landfill is expected to fill up within a few years, unless above-grade disposal over the filled cells is practiced. This could extend the life expectancy to almost 7 years. Solid waste disposal at Ordot is not being handled in a manner conforming with good sanitary landfill practices. Disease vectors are not being properly controlled, and the design of the landfill is such that runoff contamination of the nearby Pago River could be occurring during rainy periods.

Resource recovery on the island of Guam is limited. This is largely due to the absence of or lack of incentives in the market place for such commodities. Automobile tires from Navy vehicles are a notable exception in this situation. Most good casings are sent to the Philippines, where they are recapped and returned to Guam. At Ordot landfill considerable scrap iron has been segregated but cannot be moved because of unattractive economics. At the same landfill, scavengers collect aluminum cans from the waste. Boxboard is being flattened and bailed at some of the military installations, but the bales are sent to landfills for lack of buyers. Waste oils and paints are separated at some Naval facilities and recycled by the Guam Oil Company at its refinery. At the Navy landfill, a hard-fill section is operated in which predominantly wood wastes are dumped. Anyone wishing to may, at designated times, work this material for salvage. As a result, about 80% of these wood wastes are utilized; the balance is burned semiannually.

Electrical power on Guam is largely supplied by the Guam Power Authority (GPA), an agency of the civil government. GPA is a partner in the Island-Wide Power System with PWC Guam under a Power Pool Agreement. The basic Island-Wide Power System is a Navy-owned system built to support the military mission on Guam. GPA has attached several power plants, transmission lines, and substations to the Navy system and operates them jointly with the Navy. The Navy generators are however, in minimum use except when GPA outages occur.

A few studies of the overall solid waste management situation on Guam have been conducted. The earliest was completed in 1976 by Naval Facilities Engineering Command, Pacific Division (PACDIVNAVFACENGCOM) (Ref 1). Dames and Moore (Ref 2) performed a similar study for GEPA in 1978.

The Navy study found that (1) the military solid waste program was being satisfactorily conducted, (2) no serious long-term problems were obvious, and (3) if improvements were to be realized, these might be found through the application of innovative technology. PWC Guam subsequently conducted an engineering investigation that recommended (Ref 3) resource recovery would be best achieved through the heat recovery incineration of solid wastes now being landfilled.

The Dames and Moore (D&M) study focused on the GovGuam solid waste management operations. Its conclusions were that (1) both collection and disposal procedures were inadequate and poorly managed, (2) upgrading of such practices through proper training was sorely needed, (3) the Ordot landfill would soon be filled and only one smaller fallback site could be identified, and (4) consideration of waste-to-heat systems was the logical corollary to the unfortunate situation. Based on NCEL's recent visit to Guam, it would appear that the D&M recommendations, all of which were well based, had some impact on improving the Ordot operations, although opportunities for further improvement were still very much in evidence.

The Department of Energy (DOE) in its Territorial Energy Assessment program retained Barrett and Harris Corp. to characterize solid waste as energy resources on selected U.S. Pacific islands. This work principally involved Guam and American Samoa. Waste mass flows processed by GovGuam were estimated but not actually measured over several months. Rough compositional estimates with calorific value calculations were also performed during the same study interval. The results are to be published in 1984. The DOE has no foreseeable plans to carry this work beyond the inventory stage.

International Energy Enterprises, Inc. (IEEI) has an agreement with the Guam Economic Development Authority to develop strategies for handling the solid wastes managed by the territorial government. IEEI has recommended that an all-island system be considered, preferably a mass-fired turbo-electric plant. They are, however, considering a wide range of other concepts. IEEI is prepared to furnish a full service approach to any scheme that may be recommended and approved. Financing is the major question. However, GovGuam is not actively pursuing any future developments in this field. Additionally, the overall financial condition of GovGuam makes it unlikely that any alternate energy source will be developed in the foreseeable future.

AVAILABLE OPTIONS FOR LONG-TERM SOLID WASTE MANAGEMENT ON GUAM

Waste disposal on Guam is a situation of contrasts. The Naval establishment, even with the Air Force as an added responsibility, is receptive to determining the feasibility of applying waste-to-energy technology. The Government of Guam is, on the other hand, frustrated in pursuing such technology due to financial constraints.

The civil administration on Guam is critically dependent on the military for its development. This dependence is emphasized by the fact that the Territory of Guam has had a poor performance record in servicing general obligation bonds and thus, is financially disadvantaged in confronting capital-intensive requirements.

The GovGuam Ordot landfill is nearly full, and the fallback site at Fadian Point (Ref 3) would fill in about 4 years. Clearly then, the civil government must explore alternative disposal techniques. This, of course, is already the line of planning followed by the Navy, which is not under the stress GovGuam is currently experiencing. It would seem logical, therefore, that the Navy consider the pursuit of its own (and Air Force) interests so as to include the welfare of the entire island. That is, any conceptual design and cost analysis of resource recovery systems envisioned by PWC should be evaluated both as all-island as well as Navy facility undertakings.

An advantage intrinsic to an all-island approach to any resource recovery scheme is the inherent scale up. This should not only reduce unit waste disposal costs but promote expansion capability should the Navy's mission on the island be significantly increased.

In the following discussions, the various options available to the Navy, Air Force, and GovGuam, acting independently or together, are considered. The options do, of course, take into account the operating conditions unique to the parties disposing of their wastes, together with the financial and mission constraints that exist.

OPTIONS FOR THE NAVAL SOLID WASTE MANAGERS, PUBLIC WORKS CENTER, GUAM

Maintainance of Status Quo

PWC Guam provides collection and disposal services for all Naval commands, the Coast Guard Depot, Naval housing, U.S. and allied Naval vessels, and assorted other facilities, such as the Army Reserve, the Guam observatory, and the Agana and Orote power plants. A small fleet of nine trucks, ranging in capacity from 25 to 40 yd^3, makes the collections. In each housing area, garbage is collected twice weekly and refuse once a month. The collection frequency at other facilities ranges from 1 to 7 days a week. The assigned collection rate (Ref 4) is from \$23.71 to \$25/ton based on an assumed trash density of 140 lb/yd^3. This can be compared with a typical Los Angeles area collection cost of \$33/ton (Ref 5).

Disposal is accomplished at the sanitary landfill located near the intersection of Shoreline Drive and Exchange Road, close to Agat Bay. Conventional landfill practices are observed. Cells 30 feet in width and of about the same depth are built up by running the refuse trucks over the top of the previous cell and dumping the refuse down the working face. The waste is compacted by bulldozers and covered nightly with stock piled excavation dirt. The surface is graded to 1% grade and compacted.

When the present site is filled to grade, and assuming that an above-grade layer of cells will be constructed, the landfill should have a life expectancy of at least 15 more years if the present disposal rate is maintained.

The PWC predetermined (Ref 4) disposal cost is \$0.60/yd^3, which is \$8.57/ton, assuming a refuse density of 140 lb/yd^3. This tipping cost may be considered high when compared to the costs for the Los Angeles area (\$3.75/ton at the Puente Hills landfill (Ref 5)). East coast CONUS costs, in contrast, are considerably higher, exceeding \$20/ton in many metropolitan areas.

Operations and Maintenance (O&M) costs at the Navy landfill can be expected to increase somewhat when operations with the cells above grade are instituted. Longer in-haul of fill material and somewhat greater working of the machines can be expected to increase tipping costs an estimated 10%. Neglecting inflationary effects, disposal costs may increase to about $0.66/yd^3 or $9.43/ton based on a refuse density of 140 lb/yd^3.

In general, the Navy's present waste management program is quite satisfactory. Operationally speaking, it conforms well with guidelines of the U.S. EPA. Costs are in line with those experienced by metropolitan operations on CONUS. The long-term outlook is good, provided no drastic expansion in Guam's Naval role occurs. Resource recovery opportunities, particularly waste-fuel-derived energy, are available that would reduce costs more effectively than such practices already in place or previously tried. On the whole, however, continuing with the present waste management program constitutes an entirely acceptable option.

Solid Waste Densification and Burial

In the preceding discussion, the possibility of an expanded role for Guam in West Pacific operations was raised. In such an event, increased waste generation rates would result in an earlier closure of the Navy's landfill and the need to develop fallback facilities. Because of the limited number of potential sites, a solution to reducing the filling rate of available landfill volume is to densify the refuse mechanically prior to disposal. This is done by shredding the solid waste, compacting, and (optionally) baling it.

This process would about double the life expectancy of the landfill, although disposal costs would be significantly increased. If resource recovery is practical (markets are available for scrap iron), the increase in cost could be reduced somewhat. This approach, incidentally, was also suggested for GovGuam's consideration (Ref 2).

The principle of operation includes shredding the refuse at a facility located near the landfill or transfer stations. The composition of Navy solid wastes at Guam makes it well suited to such treatment. It is high in paper, boxboard, and cardboard; contains little glass; and is relatively low in bulky discards typical of industrial wastes. Shredder energy and maintenance demand should be on the low side.

Output of the shredder can be landfilled directly, as was done at Madison, Wis. A small amount of fill cover can be applied or, as at Madison, the cell can be left uncovered. Compaction then becomes more of a cell-shaping process. The experience at Madison was that vermin and scavengers were not attracted to uncovered, shredded refuse. An alternative is to bale the shredded refuse. The formed output can then be stacked and buried or stored above grade without cover.

The shredding station would be enclosed and consist of a tipping floor, a recessed belt conveyor that would be charged by a frontend loader, a lift conveyor, the shredder, a discharge conveyor, and a high-volume transfer trailer. If a baler is used, it would be substituted for the receiving trailer. Made-up bales would be loaded onto and out-hauled by a vehicle similar to a hay truck.

Shredding is typically done in hammermills, although interest has recently focused on shear shredders. In comparison to the hammermill of the same throughput, the shear shredder draws considerably less power, is much quieter, emits less dust, is less likely to detonate explosives, and experiences much less metal wear. The drawback is that the output of the shear shredder is coarser, which may or may not have significance to the present application.

Studies have been conducted by Waste Energy Technology, Inc., under the sponsorship of the City of Charleston, S.C., to determine the comparative utilization by vermin of the shredded waste output of the two types of machines. NCEL has carried the studies further using the same equipment and contractor in order to determine the comparative product size consist and the maintainability of the shear shredder and hammermill. Since that evaluation is still in progress, the hammermill configuration has been utilized in the present analysis.

Based on a single-shift, 5-day/wk operation, a 10-tph horizontal hammermill is indicated. Given its excellent reliability and an appropriate spare parts inventory, a backup mill should not be required. A 200-hp hammermill (e.g., Williams Model 340) would be suitable.

Total expected costs (including engineering and contingency but not rolling stock) of a shredder plant would be about $425,000, of which about $200,000 is equipment cost. Baling equipment would add about $120,000 to plant capital costs. The impact on disposal costs (without baling) would add about $5.75/ton, excluding any recycle revenues. This is based on the estimates contained in Reference 2, which were updated using current Guam labor, power, and other rates contained in Reference 3. The assumptions are that the shredding plant would operate 8 hr/day, 5 days/wk, with a crew of three. It is assumed that with the reduced truck traffic and refuse volume at the landfill, one worker could be transferred to the shredding station without cost impact to the process.

If a baler were added to the plant, additional operators would not be required. Refuse disposal costs would increase by an estimated $1.67/ton for baling alone, or $7.42/ton for shredding and baling, excluding collection. This is based on the assumed production of 50-ft^3 bales using 5-gage ties, changing out the air-cooled hydraulic oil every 2 years, and an average power draw of 65% on a 125-hp driver. Cost savings would be available if the hauling distance between the plant and landfill were minimized.

Waste-to-Energy-Process Using a Heat Recovery Incinerator (HRI)

Refuse volume reduction by densification, while offering distinct advantages in land saving, vector control, and resource recovery opportunity, cannot decrease disposal costs. At proper scale, an economically superior volume reduction technique is to ash refuse while converting the energy released into a usable asset. Waste-to-energy systems are already prevalent throughout the world and enjoy increasing popularity. The key factor is the existence of a market for the product output, either steam or electricity.

Guam uses both, firing imported oil to furnish these utilities. The steam usage for the five larger users (all Naval activities) is shown in Table 1 (Ref 6) together with the solid waste energy equivalent.

It is assumed that the refuse-derived fuel (RDF) produced from the solid waste has an average calorific value of 4,500 Btu/lb and is fired at a thermal efficiency of 60%. It is clear from these data that the steam demand is considerably lower than the energy available from solid waste. The 28.6-tpd energy equivalent is less than 55% of what can be produced.

Alternative Energy Schemes

Another possible way of utilizing the energy available from solid waste might be to generate steam for a desalination plant to produce potable water for the island. While this is not considered a major requirement for Guam at this time, it could develop as such with an expansion of mission. HRI steam could be used as feed for multi-effect evaporators or a similar process. This option should be addressed with some sort of feasibility study.

Mining the landfill to extract its combustible gas can be considered, but only as a long-term project. At present, the Navy structure is immature and too small to work. On filling, however, and assuming an above-grade lift is installed, there should be about 3 x 10^6 yd^3 of biomass cells. The gas output of this process would probably drive a 4- to 5-MW gas turbine/generator set that could be coupled later, if desired, to a steam turbine driven by a cogenerative waste heat boiler. The principal question that would have to be addressed would be the quality of the extracted gas. Because of the probable shallowness of the finished Navy landfill (probably averaging less than 19 feet), considerable air intrusion into the fuel gas would have to be expected. Gas turbine design today, however, is such that quite lean gas (down to 200 Btu/ft^3) can be fired in some models. To ensure a gas flow of 250 Btu/ft^3, the pressure drop in the system would have to be minimized. This would be accomplished by installing about twice the number of wells (and headers) than are used in deeper landfills. Gas extraction at a rate of about 6,000 ft^3/min could then be expected for an extended period of time. Experience on the mainland has indicated that the gas extraction rate would probably not significantly deteriorate before 10 years of continuous service.

In today's dollars, a turn-key plant, including switchgear, would cost about $5.5 million. Because of the high reliability and low maintenance demand characteristics of gas turbines, O&M costs would probably only range between $50,000 and $65,000 per year. This is based on an O&M cost factor of 1.5¢/kW-hr used by the Los Angeles County Sanitation Districts for its landfill/gas-turbine operations.

The PWC Guam Proposal

PWC Guam (Ref 3) explored the feasibility of supplying steam to the galleys at the Naval Station and Naval Medical Center. They proposed the use of a two-stage refuse-derived fuel (RDF) incinerator (pyrolysis followed by combustion of the generated gases). The scheme would involve processing 80% of the Navy solid wastes going to landfill and firing all the RDF produced. The study, however, neglected to perform a process heat balance. This would have revealed that far more steam would be produced than the galleys or the entire facilities of the two commands could use.

The PWC proposal involves the installation of a plant near each user point, each operating two 50-bhp boilers (6.7 MBtu/hr total, four boilers). Each boiler would consume 1,000 lb/hr of RDF, or 8 tons/16 hr service day. Processing would consist of presorting to remove 24% noncombustibles, the balance being shredded and baled. Thus, the waste input to fire four boilers would be 42 tpd per 7-day week, or 80% of the 74 tpd collected in a 5-day collection week, based on an assumed full boiler availability. PWC expected a boiler availability of 92%.

Assuming an RDF fuel value of 5,400 Btu/lb (the average calorific value from Reference 7, which was considered a reasonable comparison, if possibly on the low side), an input of 15.1 MBtu/hr is calculated for the two plants. At a thermal efficiency of 60%, steam output from the two plants would be 9.2 MBtu/hr. This is equivalent to about 70 bhp, which is 40% higher than the nameplate rating specified in the Reference 3 proposal. The hourly average comsumption rate of steam by the entire Naval Station and Naval Medical Center is only 3.7 MBtu (Table 1). In the next section, a similar approach is suggested wherein a closer energy match would result.

<u>Other Steam Uses</u>

The steam usage at the galleys probably does represent a significant, large fraction of the steam consumed by the two commands. Furthermore, the flow rate should increase markedly during premeal periods such that demand could approach output. It is not practical, however, to try to match a higher rated generator to a small load whose peak only occasionally meets capacity.

Energy-wise, the Guam Naval activity has small steam usage but a very high air conditioning demand relative to other Naval activities. At Guam, the air conditioning demand is being fulfilled by electricity. Thus, an alternative approach could be to erect a small HRI facility to produce hot water for the Naval Station barracks and galley steam as well as to provide steam to run steam turbine drivers for a vapor compression air conditioner or heat to an absorption unit.

The air conditioning plant at the Naval Station consists of a 600-ton Carrier and a 285-ton Chrysler unit. The former is reported to be entirely capable of handling the load. Both units are of the hermetic type such that a retrofit coupling with an external driver is not practical. Carrier, in fact, recommended that even attempting to replace the hermetic-type chiller with an open-drive unit would not be wise since the latter would have to be specially engineered to drive the balance of the system. Such a one-of-a-kind unit would then constitute a special maintenance challenge. Installation of a complete new plant was therefore considered. Because of the large temperature drops often required in cooling Guam Naval buildings, it was decided to defer consideration of absorption-process air conditioning.

A 600-hp (3,600-rpm) steam turbine would be coupled to the compressor. Assuming steam conditions of 400 psia/550°F (10-in. HgA-outlet), 12,000 lb/hr of steam would be required at maximum. This would require an energy output of 14.8 MBtu/hr or a waste firing rate of 2.7 tph, assuming 60% thermal efficiency and a fuel calorific value of 4,500 Btu/lb (unprocessed). This is about 0.5 tph in excess of what is available based on all the solid waste collected by the PWC.

The average power draw is not accurately known. Ammeters are only available for the Chrysler air conditioning system, which is not capable by itself of conditioning the entire service volume. The Carrier can, however, condition the air in the entire service volume in the hottest weather. Thus, average demand is probably between 400 and 500 tons. This would imply a waste-fuel firing rate of between 1.8 and 2.3 tph, which is close to the actual Naval facility waste fuel availability (2.2 tph).

A steam and air conditioning plant conversion based on two HRIs each capable of handling 50% of the maximum load would cost out today at about the levels shown in Table 2. These costs are based on budget estimates furnished by companies manufacturing package waste-fired steam generators, freight costs out of Chicago (worst case), and standard engineering estimates for island erection and O&M.

A benefit/cost analysis was then performed based on NAVFAC P-442 procedures using the NCEL-developed cost model (Ref 8) for HRI systems. The costing parameters and values assigned are given in Table 3. The results of the analysis are presented in Table 4. The benefits available are: (1) the volume reduction of all of the refuse generated by the Naval establishment, (2) fulfillment of the energy demand of the Naval Station air conditioning system and part of the water heating requirements, (3) extension of the landfill life expectancy to almost 100 years, and (4) an annual reduction of over 24,000 bbl oil import.

Such systems are, however, capital intensive, require a rather long payback period and offer a rather modest savings-to-investment ratio. The parameters are fairly sensitive to increases in capital costs, the savings-to-earning ratio dropping by 40% with a 15% increase in capital costs and the payback period increasing to greater than the economic life of the plan (25 years). Decreases in capital costs, on the other hand, produce changes in these two parameters that are about directly proportional to a 15% decrease in capital costs.

RESOURCE RECYCLE OPPORTUNITIES

Various attempts have been made in the past to recover valuable fractions from the wastes generated at Navy and Air Force installations on Guam. Apparently, the only surviving form of this is the segregations of metal shop scrap and isolated storage of wood wastes at the Navy landfill. Scavengers are allowed access to these wastes periodically, resulting in a removal of about 80% of the material. The residues are then burned every 6 months.

Because of the large quantity of aluminum cans observed in the waste stream, it is strongly recommended that the Naval Station encourage an aluminum can recovery system for the various activities on Guam. There are a number of civilian salvors on Guam that will buy this product for about $0.20/lb. Since there is a baler available at the exchange, collections could be made market-ready without difficulty. It has been suggested that an employee organization or some other service organization, such as the Boy Scouts, be allowed to recover these cans from the waste stream. The aluminum content of municipal solid waste is estimated at about 1% (Ref 9), which is probably low with respect to Navy waste observed on Guam by NCEL. If that amount (1%) were recovered from Navy wastes containing probably 2% aluminum, the annual revenues would be $76,800.

Some boxboard is isolated from waste at some of the Navy activities. The collected material, however, is buried at the landfill, ostensibly for lack of a market.

Boxboard is a reasonably valuable waste fraction with good demand in Japan, Korea, Taiwan, and Australia. Most West-Coast-CONUS-used boxboard is shipped there; virgin factory scrap is mostly recycled in the same area or plant in which it is produced. Although a very volatile commodity, current export price is $80/ton freight on board (FOB) Los Angeles. Thus, even better prices could be gotten FOB Apra. Navy wastes on Guam are particularly rich in boxboard scrap. If an equivalent of 5% of the mass stream were expressed as recovered and baled boxboard, an annual revenue about equal to that projected for aluminum ($76,800) could be realized.

AN ALL-ISLAND INTEGRATED APPROACH TO SOLID WASTE MANAGEMENT ON GUAM

Overview

For the reasons discussed in the BACKGROUND section, an integrated waste management program for Guam that would serve the military facilities and the civilian population merits serious consideration. The island is small enough to be organized as a single solid waste district. It also produces enough waste to justify consideration of a single metropolitan-type waste processing or disposal center. By using transfer stations and large-capacity packer vehicles, the existing collection apparatus could be maintained by the organizations presently responsible (PWC, GovGuam, Air Force), who could route their collections to a centralized facility. Alternatively, the entire collection system could be turned over to GovGuam or a private firm.

The resource recovery system can include any of the concepts discussed previously. A notable difference, of course, will be that the system would be significantly scaled up, although still relatively small in terms of CONUS practice. This will permit the consideration of better proven technology while enjoying the economies of scale. Concomitantly, however, capital costs become large enough to fall beyond the reach of GovGuam. An all-island project will doubtless require outside funding support, as from a third-party financier (owner/operator).

The waste load of a combined operation is estimated as follows:

Solid Waste Source	Tons/Mo
Navy facilities	1,600
Anderson AFB	600
GovGuam	1,800
Total available Solid Waste	4,000

This represents a waste rate of 131.5 tpd for a 7-day/wk plant or 184 tpd for a 5-day/wk plant.

Alternative Systems

Centralized Solid Waste Mechanical Densification/Refuse Recovery Plant. The need to conserve landfill volume is considerably more pressing for GovGuam than it is for the Navy. With Ordot landfill offering an additional 7 years of use (assuming an additional lift is worked), densification is a logical consideration (Ref 2). As discussed in the Solid Waste Densification and Burial section earlier, solid waste could be shredded and baled for compact burial. Shredding without baling is not recommended since the greater density of the baled product would be a key factor in conserving landfill volume. Landfill volume use would be reduced about 40%, and the present nonsanitary practices observed by NCEL at Ordot would become acceptable. Little or no cover would be required, and disease vectors would be largely eliminated in building the cells with baled refuse.

A densification plant could be operated by GovGuam near the Ordot landfill or, preferably, at the location of a new site, such as Fadian Point (Ref 2). This arrangement would have little impact on the existing collection and haul operations of GovGuam. It would increase costs for the Navy and Air Force, although the incremental distances (between the military landfills and the densification plant) are not great. Another option would be to close Ordot and site the densification plant at or near the Navy landfill. If all the solid wastes of Guam were baled and emplaced in the Navy landfill, it would reduce its life expectancy from 15 to 10 years.

The cost of a densification plant capable of handling all of Guam's normal solid wastes would be just slightly less than $1 million. This is based on the assumption that the plant would process 185 tpd 5 days a week and one shift per day. If two shifts were employed, capital costs would be reduced to about $650,000.

Processing costs excluding any debt service would be slightly lower than for the Navy system proposed in the Solid Waste Densification and Burial section, or about $7.25/ton for shredding and baling, based on one-shift operation. A two-shift operation would involve much higher O&M costs, coming to almost $11/ton.

Centralized RDF Plant. Another possibility, suggested in the Dames and Moore study (Ref 2), would be to process solid wastes into refuse-derived fuel (RDF) and saleable recovered materials. Various process configurations are possible, but typically involve an initial stage of shredding or flailing followed by size sorting in a trommel or other active screening device. Oversize is sometimes subjected to secondary shredding while underflow is air-classified to reject heavy noncombustible objects. The output can be stored in live-bottom bins as input to a process, or further processed into bales (as discussed earlier) or pellets. Magnetic iron removal is usually done after the first stage of shredding. Removal of other fractions, such as glass cullet and non-ferrous scrap, is generally regarded as cost ineffective. Aluminum, boxboard, and paper are best removed at the source.

The RDF produced at such a plant could be exported or be fired in a water-wall furnace retrofitted to or coupled with an existing oil-fired turbo-electric unit. Such combined firing is commonplace in Europe, although such systems typically are integrally designed rather than retrofitted. Refuse is fired to heat boiler feedwater or generate low enthalpy steam, which is then brought to turbine conditions in a fossil-fuel-fired furnace section. The main advantage of this approach is to reduce the fireside corrosion associated with mass firing refuse alone in water-wall furnaces operating at higher steam temperatures. This problem has now been largely mitigated through the application of more corrosion-resistant materials, particularly in the superheater sections and redesign of overhang sections to reduce flame impingement.

In the present context, retrofitting any existing power plant unit on Guam is probably not feasible because of the type of design represented in that inventory. Retrofitting to produce a tandem-firing arrangement, as discussed above, would entail extensive modifications of the existing boilers, steam, feedwater, and air preheat circuitry to operate satisfactorily with a working fluid being input at much higher heat content. Although less modification would be required to achieve a cofiring configuration (both fuels burned in the same furnace), gas volumetrics limit the fractional amount of RDF that can be employed. It would probably not be cost effective to modify any oil-fired boiler to accommodate bottom and fly ash, an increased combustion air requirement, and an RDF feed mechanism and still be able to input perhaps only 50% or less of the energy from RDF. It would thus appear that the most viable role that an RDF plant could fulfill would be as an integral part of a new plant specifically designed to accept that fuel. This option is considered in the next section together with steam generating plants firing solid waste in less refined forms.

Centralized Waste-to-Energy Plant. Because the steam demand on Guam is limited and dispersed, a centralized waste-to-energy plant should probably be exclusively turbo-electric. This would allow greater freedom of siting. The plant would receive refuse from the various jurisdictions, convert it to power for the Island-wide power grid, and send rejected materials and ash to an appropriate landfill. Because of the hydrological sensitivity of the area, a wet ash handling system that leaches out solubles should be employed. Then any or all of the landfills now operating on Guam could be used to receive such ash. Leaching the ash in the quench tank would, however, result in a blowdown that would require treatment. Economics favor that form of waste processing over the cost required for the safe burial of untreated ash.

Firing refuse in a waste-to-energy power unit can involve (1) mass firing (no processing of waste other than to remove oversized, noncombustible objects); (2) firing waste that has undergone single-stage, coarse shredding, usually with iron removal; or (3) "fluff" RDF firing. Although burnout is somewhat greater the more the fuel is processed, the energy imparted in achieving the refinement is considerably greater than the additional burnout that is incrementally achieved. The principal advantage of RDF over raw waste is that the former can be fired in some types of steam generators that are of conventional design, specifically spreader-stokers. Extensive preparation of the solid waste otherwise offers little benefit in terms of resource recovery since, in the Guam context, this would better be done at the source.

Mass firing, while requiring a specially designed moving grate and stoker systems, is, on the other hand, not as susceptible to "frontend" failures that occur in the processing of the refuse.

Also possible is the reduction of variously prepared solid waste in pyrolyzers wherein combustible gas, char, and, under selected conditions, liquids ("garboil") are produced. Although this technology has been under study for quite some time, at the present scale it is not considered by NCEL as being adequately proven.

A high-reliability system of simple process design is recommended for an all-island, centralized waste-to-energy plant. This is prompted by the tendency to outages already experienced at GPA that would probably increase if a complex waste-to-energy system were included in the island-wide power generation system. Processing of the refuse should be held to a minimum since a majority of process failures do occur in frontend equipment. Thus, refuse should be mass-fired or, at most, subjected to a single stage of shredding with iron removal.

Of the mass-fired systems, the Norfolk Naval Base units should be considered. These boilers (one duty, one stand by) fire an average of 140 tpd of solid waste that is considerably more industrial in nature and, thus, more difficult to stoke than the Guam solid waste. The throughput is just about what is estimated here as being produced on Guam (131.5 tpd). These units have been in service since 1968, and while used to generate dockside steam, they could also drive a steam turbine-generator set.

The failure mode, which is largely associated with the industrial nature of the fuel fired, predominantly involves jamming of the reciprocating grate. A more reliable moving grate has been identified (Josephus Martin Co.), and plans are going forward to retrofit both units, provided funds become available and the Naval Base waste fuel is not diverted to a new plant being constructed at the Norfolk Naval Shipyard.

The spreader-stoker boiler is a proven system for firing solid wastes. This device pneumatically charges refuse upwards into the fire box, the burning material falling onto an endless-belt grate. The refuse must be shredded for such firing, but a single stage of coarse (80% $\leq$ 5 inch) shredding will suffice. Although stoking is more susceptible to problems, burnout is superior to what is achieved in a mass-fired unit. Residual carbon is usually less than 2%, while ash from a well-designed mass fired unit may contain up to 5% combustible residue. The units being installed at the Norfolk Navy Shipyard are of this type, although coal will be cofired with the shredded refuse.

Another mass-fired boiler configuration that has seen service, although not as long and mostly in Japan, utilizes a feedwater-cooled, rotary-drum combustor coupled to a water-wall boiler. This is the O'connor system, which NCEL has observed in operation at a waste-to-energy plant in Galatin, Tenn. The throughput of that plant (150 tpd) is again in the same range as what would be needed at Guam if the all-island steam plant concept is pursued.

The Galatin plant represents a reasonable basis for projecting costs for Guam, although it is rated at somewhat higher operating capacity (150 tpd design; 200 tpd maximum). The 1980 costs for the Galatin installation, including all design engineering, construction contracts, and equipment (which included an Apitron Corp. electrostatic baghouse), were $9.8 million.

The two-unit plant, which operates continuously, requires a staff of 22 people. Current O&M costs tabulated by the operators have been totalling $942,000/yr, excluding any debt service. Revenues from steam sales are not relevant since the Guam plant would be turbo-electric. It is estimated that, at a 131.5-tpd throughput, a power export capability of 2.5 MW would be achieved in the Guam plant. At the probable avoidable cost of 6¢/kW-hr currently assessed on Guam for electricity, an annual revenue would be $1.3 million for power. The peak load on Guam, incidentally, exceeds 140 MW for all milit--y and civilian users.

A spreader-stoker plant (two 75-tpd units) with a duty and standby shredder in the input conveyor line (shredded product is not stored) and electrostatic precipitator would cost about $11.5 million. This is based on an extrapolation of cost for a like system of larger scale planned for the Compton Energy & Resource Recovery Facility in California. Annual O&M costs would run about $1 million.

Because of its lower capital and O&M costs, the mass-fired system was selected for benefit/cost analysis. The plant consists of two 100-tpd reciprocating grate boilers, each operating at about two-thirds of capacity. Two turbine-generator systems are used, each of which can receive steam from either or both of the boilers. A 550-ton storage pit is provided, the contents of which would be transferred to the charging chutes by an overhead bridge crane. Bottom ash would drop into a quench tank as would the flyash from downstream hoppers after being mechanically conveyed back to the quench tank for leaching. Quench tank blowdown and other process water would be processed for solids removal and neutralization before being sent to the sewer. The Air Pollution Control requirements would be fulfilled with the installation of an electrostatic precipitator. The plant structures would be prefabricated to the extent practical, although the project would be essentially site erected.

The estimated costs for the system that were used in the NCEL model are given in Table 5. The net present value (NPV) costing bases are shown in Table 6, and the model output data are shown in Table 7. Because the model is designed to handle steam plants only, the present analysis was approached on that basis. This does significantly impact results for an electrical plant. That is because the differential costs compared for the HRI and the fossil-fuel-fired equivalent system remain the same whether steam or electricity is taken as the output product.

The NCEL modelling of the all-island refuse disposal facility shows a reasonable benefit/cost situation. The payback period of 10.7 years actually includes 4 years of lead time such that payback following plant commissioning would take place in 6.7 years. The savings-to-investment ratio, 2.81, is also reasonable, particularly when considering the benefits that such a plant would make available. These include: (1) sanitarily disposing all the solid waste (other than those produced in catastrophic situations) generated by all the jurisdictions on Guam, (2) extending the life of the only island landfill (Naval Station) with future operational potential to about 50 years, (3) reducing the demand on the Island-wide GPA power system by 2.5 MW, (4) reducing oil import by almost 58,000 bbl/yr, and (5) virtually eliminating the existing disease/vermin vectors and ground water contamination problems.

CONCLUSIONS

1. The Navy has acted on most of the recommendations contained in the 1976 NAVFAC study aimed at improving landfill procedures.

2. The same study and the Dames & Moore study (Ref 2) have had less than the intended impact on the other jurisdictions: the possibility of leaching at the Air Force landfill still exists, and the GovGuam Ordot landfill is still not fully sanitary.

3. While the Navy's Solid Waste disposal situation is relatively comfortable, the Air Force and GovGuam face serious short-term problems.

4. Attempts at resource recovery have not been successful, ostensibly because of unattractive market conditions. A search for new market pathways has not, however, been vigorously pursued.

5. Solid waste disposal facilities on Guam would be inadequate if the military role there was suddenly expanded.

6. Because of the hydrological sensitivity of much of the island, potential new landfill sites are very limited. Some form of waste volume reduction eventually needs to be practiced.

7. Inadequate information is available concerning the mass flow and composition of the various jurisdictional solid waste streams.

8. The most cost-effective means of achieving solid waste volume reduction (about 80%) is through incineration with heat recovery. Such systems, which usually operate with reserve capacity, are readily expanded.

9. Because of the poor situations that both the Air Force and GovGuam contend with, any solid waste disposal project considered by the Navy should not overlook them. An all-island centralized disposal system could well prove beneficial to all jurisdictions over the long run. The Navy is, of course, not obligated to include GovGuam in a solid waste disposal scenario because GovGuam faces a problem. There should be good incentives (i.e., reduced utility rates, elimination or reduction of tipping fees, etc.) for the Navy to include GovGuam in any solid waste disposal plan. GovGuam's past performance in managing and operating a solid waste disposal system has not been outstanding such that the Navy should be careful in participating in a joint effort. The Navy's solid waste disposal situation could become more serious rather than better by trying to assist GovGuam.

10. To avoid involving the Navy in responsibility for handling civilian wastes, any integrated solid waste management operation should properly be controlled by GovGuam. This could even include collection responsibilities. If, however, giving GovGuam control of such an integrated operation resulted in unsatisfactory system performance, withdrawal of the Navy could become necessary. Assurance that DOD activities are properly serviced would be preemptive.

11. A waste-to-energy plant serving Guam would best be of the turbo-electric type, since steam demand is considerably less than the available solid waste fuel can generate.

12. In view of the design of the boilers on Guam, attempting to retrofit any units there to accept refuse fuel appears impractical.

13. Historical experience with the reliability and effectiveness of refuse processing discourages consideration of such a plant. The refuse-fired steam generator should be mass-fired or accept feed that has undergone preparation in a processing train that is simple and rugged. A single stage of in-line shredding would be acceptable, if fuel processing is required at all.

14. The operation of a waste-to-energy plant firing all of the solid wastes collected on Guam would result in an annual reduction of almost 58,000 bbls of import oil, would realize payback in an estimated 6.7 years following commissioning, and would have a savings-to-investment ratio of 2.81.

15. In the event solid waste management is restricted to Navy-only scenarios, an opportunity for a waste-to-energy system for supplying air conditioning requirements exists. The economics are about as attractive as for the all-island HRI approach.

RECOMMENDATIONS

Improve Characterization of Waste Streams

Considerable uncertainty exists concerning mass flow and composition of the waste stream. Available resources in this stream cannot, therefore, be accurately estimated. Volumetric metering of the solid waste flow should be discontinued, and a weigh station should be installed and operated at the Naval Station landfill. Technical services should also be contracted to determine on a sound statistical basis (e.g., Ref 10) the average composition of the waste stream as a function of season and other variables. These action items should also be recommended to GovGuam and the Air Force.

Review Resource Recovery Programs for Waste Fractions

Resource recovery programs previously pursued on Guam should be reviewed for possible reimplementation. Markets and brokers for source-separated aluminum cans, boxboard, and possibly other waste stream fractions should be sought. If local dealers are not motivated to move these materials, outside brokers should be consulted.

Determine GovGuam's and Air Force's Long-Range Solid Waste Management Situations

Determine the status of planning for disposal of civilian solid wastes following closure of the Ordot landfill. Establish GovGuam's current disposition towards, and capability of, effectively managing an all-island solid waste operation. The Air Force's long-range solid waste management plans should also be better defined.

Establish Feasibility of an All-Island Waste Disposal Operation

Studies should be conducted to determine the most cost-effective means for achieving long-term solutions to Guam's solid waste management problems. Components of this overall task should include:

Centralized Resource Recovery Facility. Establish the optimum configuration for realizing an all-island solid waste disposal/resource recovery system. Priority should be given to a waste-to-energy approach, alternatives being to establish feasibility of an all-island waste disposal operation and refuse densification with or without ferrous metal recovery. Obtain budget estimates for the candidate systems.

Collection System. Based on the use of a centralized, all-island resource recovery/disposal facility, the collection operations of the three participating jurisdictions should be revised as required to achieve optimum effectiveness.

Responsibility for Solid Waste Management. Develop and analyze scenarios defining the economic benefits to the Navy of the management by GovGuam of various and all components of an integrated management apparatus for solid waste collection and disposal.

Funding Alternatives. Based on the optimum solid waste management plan resulting from the study, specify a viable mechanism for acquiring the required capital and associated incremental O&M costs.

Preliminary Engineering Study of HRI/Air Conditioner Coupled System

Given an overlong term for accomplishing the previous recommendation, the economic and technical feasibility of firing solid waste in smaller HRIs to power air conditioner drivers (steam turbines) should be investigated. Conceptual designs of systems for serving the Naval Station barracks and the Naval Medical Center air conditioning needs should be developed if the approach proves cost effective. Absorption process air conditioning should be brought into this analysis.

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Table 1. 1982[a] Monthly Steam Consumption by Major Guam Naval Activities Users (Ref 6)

Plant	Steam Use (MBtu/mo)			Unprocessed Solid Waste Equivalent (tpd[b])
	Average	High (mo)	Low (mo)	
Naval Station	1,276	1,548 (Sep)	909 (Jul)	7.8
Naval Medical Center	1,403	1,725 (Nov)	1,114 (Oct)	8.5
Naval Air Station	741	951 (Mar)	624 (Nov)	4.5
Naval Communications Station	602	709 (Feb)	508 (Jun)	3.7
Ship Repair Facility	674	1,261 (Jul)	362 (Nov)	4.1
Total	4,696			28.6

[a]August data not available.

[b]Assumes 76% to be recovered as 4,500 Btu/lb RDF, which is fired at 60% thermal efficiency.

Table 2. Estimated Net Present Value (NPV) Capital and O&M Costs for Waste-Fired Steam Generator Plant to Drive 600-Ton Air Conditioning System at Naval Station, Guam

Item	NPV Cost ($)
Capital Costs	
Two package units	2,970,000
Air pollution equipment	250,000
Steam turbine	25,000
New air conditioning system	150,000
Support facilities	100,000
Concrete facilities	100,000
Other erection costs	300,000
Engineering	150,000
Freight	80,000
Total	4,125,000
Annual Operating and Maintenance Costs	
Operating labor	165,000
Maintenance labor	88,000
Electricity	150,000
Auxiliary fuel	15,000
Chemicals	17,000
Repair parts	32,000
Sewer	20,500
Pest/vermin control	5,000
Ash disposal	33,000
Total	525,500

Table 3. Input Parameters and Values Used in Applying NCEL HRI Model to Waste-to-Energy System for Naval Station, Guam Air Conditioning Plant

Costing Base	Value
Assumed number of years between analysis and funding	2
Annual inflation percentage rates for:	
Capital expenditures	5
Energy	10
Landfill costs	10
All other	5
Project lead time, ending project year:	
Complete architect and engineer input	1
Complete capital payouts	2
Economic life of HRI, yr	25
Annual unit costs of consumables:	
Electricity, \$/kW-hr	0.125
Diesel fuel, \$/gal	1.21
Cost of landfill disposal, \$/ton	6.64[a]
Operating data:	
Tons of ash/ton waste burned	0.17
Thermal efficiency of fossil fuel boiler compared, %	80
Thermal efficiency of HRI, %	60
Higher heating values:	
Solid waste, Btu/lb	4,500
Auxiliary fuel, Btu/gal	130,000
HRI availability, %	85
MBtu/1,000 lb of HRI output steam	1.28

[a]1976 base year.

Table 4. Output Data from NCEL Modelling of Waste-to-Energy System for Naval Station, Guam Air Conditioning Plant

Parameter	Value
Inflated cost of disposing waste of the type generated at the site to the landfill, $/ton	16.03
Inflated cost of the fossil fuel boiler to which the HRI is being compared, $/MBtu	9.91
Tons of trash burned annually by the HRI	22,429[a]
Btus produced annually by the HRI (considering no downtime)	1.23×10^8
Thousands of pounds of steam output by the HRI per ton of waste burned	4.24
Fossil fuel offset annually by the HRI, barrels-of-oil-equivalent	24,052
Landfill space conserved annually by the HRI, tons	18,616
Cost of using a boiler to produce the annual no-downtime quantity of steam produced by the HRI and landfilling all waste, $	1,600,150
Inflated total capital cost of the HRI (includes equipment, support facilities, and construction and setup), $	5,280,890
Uniform annual cost of the HRI (the cost of capital, modifications, labor consumables, residue disposal, downtime, and other costs spread over the economic life of the HRI), $	1,518,170
Annual no-downtime cost of the HRI (the total of no-downtime costs spread over the economic life of the HRI), $	1,270,690
Discounted life cycle cost of using a boiler to produce the life cycle no-downtime quantity of steam produced by the HRI and landfilling all waste (costs discounted to the point of initial funding), $	20,569,900
Discounted life cycle cost of the HRI, $	12,301,900
Discounted life cycle cost of auxiliary fuels used by the HRI, $	108,078
Discounted life cycle cost of noncombustible waste and ash disposal, $	932,173

Continued

Table 4. Continued

Parameter	Value
Discounted life cycle cost of HRI downtime, $	64,553
Discounted life cycle savings of the HRI, $	13,047,900
HRI savings-to-investment ratio	+2.73
Payback period (includes project lead time), yr	10.1

[a]This figure takes into account an HRI capability to increase its combustion rate following a failure so as to burn waste stored during the failure.

Table 5. Estimated Net Present Value (NPV) Capital and O&M Costs for Guam Turbo-Electric Plant Firing All-Island Solid Wastes

Item	NPV Cost ($)
Capital Costs	
Equipment and instrumentation for two boilers	4,700,000
Air pollution equipment, ductwork and common stack	650,000
Two steam turbine-generators:	
Systems and switch gear	825,000
Support facilities	260,000
Concrete structures	800,000
Other erection costs	1,500,000
Engineering	950,000
Freight	150,000
	9,835,000
Annual O&M Costs	
Operating labor	330,000
Maintenance labor	102,000
Electricity	255,000
Auxiliary fuel	12,500
Chemicals	28,000
Repair parts	63,000
Sewer	41,000
Pest/vermin control	10,000
Ash disposal	68,000
	909,500

Table 6. Input Parameters and Values Used in Applying NCEL HRI Model to Waste-to-Energy System for Guam All-Island Waste Disposal Plant

Costing Base	Value
Assumed number of years between analysis and funding	2
Annual inflation percentage rates for:	
Capital expenditures	5
Energy	10
Landfill costs	10
All other	5
Project lead time:	
Complete architect and engineer input	3
Complete capital payouts	4
Economic life of HRI, yr	25
Annual unit costs of consumables:	
Electricity, $/kW-hr	0.125
Diesel fuel, $/gal	1.21
Cost of landfill disposal, $/ton	6.64[a]
Operating data:	
Tons of ash/ton waste burned	0.17
Thermal efficiency of fossil fuel boiler compared, %	80
Thermal efficiency of HRI, %	70
Higher heating values:	
Solid waste, Btu/lb	4,500
Auxiliary fuel, Btu/gal	130,000
HRI availability, %	85
MBtu/1,000 lb of HRI output steam	1.18

[a]1976 base year.

Table 7. Output Data from NCEL Modelling of Waste-to-Energy System for Guam All-Island Waste Disposal Plant

Parameter	Value
Inflated cost of disposing waste of the type generated at the site to the landfill, $/ton	17.64
Inflated cost of the fossil fuel boiler to which the HRI is being compared, $/MBtu	10.90
Tons of trash burned annually by the HRI	45,712[a]
MBtus produced annually by the HRI (considering no downtime)	2.94×10^8
Thousands of pounds of steam output by the HRI per ton of waste burned	5.36
Fossil fuel offset annually by the HRI, barrels-of-oil-equivalent	57,978
Landfill space conserved annually by the HRI, tons	37,941
Cost of using a boiler to produce the annual no-downtime quantity of steam produced by the HRI and landfilling all waste, $	4,045,330
Inflated total capital cost of the HRI (includes equipment, support facilities, and construction and setup), $	13,855,600
Uniform annual cost of the HRI (the cost of capital, modifications, labor consumables, residue disposal, downtime, and other costs spread over the economic life of the HRI), $	3,650,760
Annual no-downtime cost of the HRI (the total of no-downtime costs spread over the economic life of the HRI), $	3,139,630
Discounted life cycle cost of using a boiler to produce the life cycle no-downtime quantity of steam produced by the HRI and landfilling all waste (costs discounted to the point of initial funding), $	49,638,900
Discounted life cycle cost of the HRI, $	26,992,600
Discounted life cycle cost of auxiliary fuels used by the HRI, $	231,286
Discounted life cycle cost of noncombustible waste and ash disposal, $	1,994,680

Continued

Table 7. Continued

Parameter	Value
Discounted life cycle cost of HRI downtime, $	171,385
Discounted life cycle savings of the HRI, $	35,142,100
HRI savings-to-investment ratio	+2.81
Payback period (includes project lead time), yr	10.7

[a]This figure takes into account an HRI capability to increase its combustion rate following a failure so as to burn waste stored during the failure.

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