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Power Generation from Waste Incineration

James O. Kolb
Kenneth E. Wilkes

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Energy Division

POWER GENERATION FROM WASTE INCINERATION

James O. Kolb
Kenneth E. Wilkes

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EXECUTIVE SUMMARY

Incineration of municipal solid wastes (MSW) with heat recovery for power generation is being used increasingly in the United States to reduce the volume of waste to be landfilled. Conventional MSW incineration is an expensive technology because of initial capital costs and high operation and maintenance costs. Revenues from electrical power sales and, in some cases, thermal energy in the form of steam are used to offset these costs and reduce the disposal fees.

In some landfills, "codisposal" has been used as a technique for disposal of hazardous chemical wastes in the past. In this technique, industrial liquid wastes were dumped into excavated pits with MSW spread over the liquids and soil finally used to cover the pits. The assumption in this disposal technique was that the MSW would absorb the hazardous liquids and prevent them from leaching from the waste pits into the surrounding soil and aquifers. In some codisposal landfills, hazardous chemicals have been detected in aquifers near the waste pits indicating dispersion of the hazardous chemicals beyond the initial waste pit areas. One such codisposal landfill site is the Denver Arapahoe Disposal Site (DADS) which has been placed on the Environmental Protection Agency (EPA) national priority list (NPL).

The Air Force is involved in several EPA and Air Force NPL landfill site restoration activities as a potentially responsible party. This study has been performed for the Air Force Regional Civil Engineers (AFRCE) to contribute to its capabilities in the economic restoration of such NPL sites.

GOALS AND OBJECTIVES

The overall goal of this study is to provide the AFRCE with analysis of the feasibility of reducing the cost of hazardous waste treatment at a codisposal site through incineration of MSW and hazardous wastes using an integrated system design at a common site. The objective of this study is to develop information for a preliminary analysis of MSW incineration coupled with heat recovery from

hazardous waste incineration for power generation in an integrated facility that could reduce the overall costs of hazardous waste treatment. In addition, the use of a large number of waste tires stored at the codisposal site is to be evaluated as a part of the integrated power generation system.

APPROACH

Analysis of hazardous waste incineration systems was performed in a companion study by the Science Applications International Corporation (SAIC). The primary tasks summarized in this report are (1) to characterize the DADS site, (2) to characterize the MSW and waste tires at the DADS site, (3) to review the current technology of large-scale MSW incineration with electrical power generation, (4) to evaluate the energy market for electricity and thermal energy at the DADS site, including the Buckley Air National Guard Base nearby, and (5) make a preliminary estimate of economic advantages and disadvantages of an integrated MSW and hazardous waste incinerator system using the results of the SAIC analyses of heat recovery from hazardous waste incineration processes.

INTEGRATED FACILITY DESIGN

Based on a preliminary site characterization study performed in 1986 for the EPA, SAIC estimated the following quantities of waste as the design basis for hazardous waste incineration processes: 380,000 tons of MSW, 52,000 tons of durable goods, and 3,900,000 tons of soil for a total of 4,332,000 tons of hazardous wastes. A processing time of 12 years was assumed for processing the hazardous waste incineration components.

A two-incinerator/boiler, conventional MSW incinerator was selected as the basis for integration with hazardous waste incinerators with heat recovery boilers. Each MSW incinerator has a 333 tons per day nominal throughput and generates 76,400 lbs/hr of superheated steam at 830°F and 865 psig.

Three types of hazardous waste incinerator systems were recommended by SAIC for development of the hazardous waste treatment portion of an integrated waste treatment facility. Rotary kiln incinerators were recommended for treatment of

contaminated MSW, contaminated soils, and durable goods. In a second option, circulating bed combustors replaced rotary kilns for treatment of contaminated soils. In a third treatment option, a fixed or multiple-hearth incinerator was used to treat contaminated durable goods.

The rotary kiln and circulating bed combustor incinerators were evaluated for heat recovery potentials, processing the contaminated MSW and contaminated soil waste streams. A single rotary kiln processing contaminated MSW at an average rate of 86 tons per day could produce 57,519 lbs/hr of turbine quality steam. Four rotary kilns processing a total of 890 tons per day of contaminated soils could produce 150,956 lbs/hr of turbine quality steam, and two circulating bed combustors processing the same rate of contaminated soils could produce 21,227 lbs/hr of steam.

These steam production rates and the associated capital and operating costs for these hazardous waste incinerators were used to develop an integrated steam power generation system for two options of contaminated soil treatment. Capital costs for the heat recovery equipment were approximately $500,000 for the MSW rotary kiln and soil circulating bed combustor systems, and approximately $2 million for the soil rotary kiln system. The cost of steam production, including capital and operating costs, range from $0.6 to $1.1 per thousand pounds of steam for these three hazardous waste heat recovery options, with the lowest for the soil rotary kiln systems and the highest for the soil circulating bed combustor systems.

Two integrated power generation system options were developed from these hazardous waste incinerator systems. Option 1 uses only rotary kiln incinerators to process contaminated MSW, contaminated soil, and durable goods. A flow of 57,500 lbs/h of turbine quality steam from the MSW rotary kiln is combined with 151,000 lbs/h of steam from the soil rotary kilns in this system. These steam flows are combined with 76,400 lbs/h of steam from one conventional MSW boiler for a total steam flow capacity of 284,900 lbs/h which is supplied to two turbine generators with 26.8 MW net electrical capacity. Option 2 of the integrated power generation systems is based on replacing the rotary kilns treating contaminated soil in Option 1 with two circulating bed combustor

incinerators, which can produce 21,200 lbs/h of turbine quality steam. The total steam flow capacity from the contaminated MSW rotary kiln, soil circulating bed combustor, and one conventional MSW incinerator/boiler is 155,100 lbs/h of turbine quality steam which is fed to one steam generator with a net electrical generating capacity of 14.4 MW.

An integrated waste incinerator power generation system at a common site creates the possibility for integrating certain operational features and sharing of support services between the two waste facilities. The most important capital cost savings from such an integrated system would result from the sharing of a common feedwater/deaerator system and steam system to circulate feedwater to boilers and then transport steam to the turbines. Other operational systems were evaluated with respect to personnel savings for the combined operation of conventional MSW and hazardous waste systems. Although some personnel savings were possible in several areas of operation, including maintenance personnel, laboratory personnel, and operating personnel in general, large reductions in operations costs were not anticipated from integrating the waste incineration systems. The operating costs reductions that were feasible would only be realized if a single operating organization was used for both conventional MSW and hazardous waste systems.

The most significant reduction in operating costs would result from the use of waste tires stored on the site in the soil rotary kiln system. The heating value of waste tires would replace a large amount of fuel oil used for auxiliary heating in the Option 1 integrated system. Approximately $2 million/yr in operating costs could be realized through the use of approximately 37 tons per day of waste tires in the soil rotary kiln system.

ECONOMIC EVALUATION

A preliminary evaluation of processing costs for hazardous waste incineration was performed based on estimated construction costs, annual operating and maintenance (O/M) costs, and revenues from energy sales. These processing costs also did not include any costs for exhuming and transporting the hazardous waste materials from the codisposal pits to the waste processing

facility. Annual O/M costs and power generation revenues from the hazardous waste incinerator systems were based on a 0.6 availability factor which was used to reflect the lower operating reliability of hazardous waste incinerator equipment compared a 0.8 availability for conventional waste incinerator systems.

Construction costs, annual O/M costs, electricity production, and annual waste processed data are summarized in Table ES.1. This table presents data for "base case" waste incineration systems that are separate facilities for conventional MSW incineration and hazardous waste incineration. The "base case" conventional MSW incineration plant has two incinerator/boilers, whereas the integrated waste facility has only one conventional MSW incinerator/boiler, which results in a reduction by one-half for the annual MSW processed between the base case and the integrated facility options. The annual electricity revenue, shown in Table ES.1, is for an electricity value of $0.045/kWh, the value of electricity purchased under PURPA regulations in the Denver area in 1986. The PURPA power market was assumed to be the primary market for energy produced by a waste incinerator plant at the DADS site.

The unit processing costs were calculated on the basis of a 10% per year financing rate applied to the construction costs. The processing cost also includes a revenue item for the annual conventional waste processing credit. This credit is based on the disposal costs for a "base case" conventional MSW incinerator plant and was $43/ton for an electricity value of $0.045/kWh. The resulting unit processing costs for a $0.045/kWh are shown in Table ES.2. The results of this analysis indicate that at the $0.045/kWh electricity value, the processing costs could be reduced by $24/ton or 13% for the higher cost Option 1 facility and by $4/ton or 3.3% for the lower cost Option 2 facility.

FINDINGS

The major findings drawn from this study and the companion study of energy recovery from hazardous waste incinerators by SAIC are summarized under the categories of technical, economic, and institutional findings.

Table ES.1. Summary data on integrated MSW and hazardous waste incineration.

	Annual Waste Processed (10^3 tons)		
		Integrated Facility	
	Base Case	Option 1	Option 2
Conventional MSW Plant	145.9	72.9	72.9
Hazardous Waste System	216.6	216.6	216.6
	Construction Cost (10^6 \$)		
Conventional MSW Plant	60.0	44.6	41.0
Hazardous Waste System,			
Option 1	24.3	23.9	
Option 2	20.7		18.8
	Annual O/M Costs (10^6 \$)		
Conventional MSW Plant	4.8	2.4	2.4
Hazardous Waste System,			
Option 1	37.4	35.4	
Option 2	24.56		24.56
	Electricity Production		
Annual Sales (10^6 kWh)	100.9	151.4	86.2
Annual Revenue (10^6 \$)	4.54	6.90	3.97
% of Power From Hazardous Waste	0	67.2	43.6

Table ES.2. Unit processing cost (\$/ton) for construction and O/M costs.[1]

	Unit Processing Cost (\$/ton) for Construction and O/M Costs[1]		
		Integrated Facility	
	Base Case	Option 1	Option 2
Conventional MSW Plant	43	43	43
Hazardous Waste System,[2]			
Option 1	184	160	
Option 2	123		119

[1]Assume 10% financing rate and a 4.5¢/kWh electricity value.

[2]Costs do not include cost of exhuming waste and transport to the treatment facility.

Technical Findings

1. Characterization of buried MSW and contaminated soil can affect the heat recovery potential from incineration of hazardous wastes at the DADS site.

2. Contaminated soil could represent the largest fraction of the DADS wastes, but the extent of soil contamination beneath the waste pits has not been verified experimentally.

3. Rotary kilns, circulating bed combustors, and fixed hearth incinerators are recommended for thermal treatment of DADS hazardous wastes.

4. Large quantities of turbine quality steam can be produced from incineration of hazardous wastes at the DADS site.

5. Waste tires stored at the DADS site could be used beneficially as supplementary fuel in rotary kilns treating contaminated soils.

Economic Findings

1. The primary market for energy recovered from incineration at the DADS site is electricity sold to the local utility at PURPA rates.

2. Integrating conventional and hazardous waste incineration facilities would produce relatively small operating cost reductions.

3. Low operating availability of hazardous waste incinerators reduces their value as revenue generators.

4. Thermal treatment is a very expensive treatment option for DADS wastes.

5. Although the cost of recovered heat from incineration of hazardous wastes appears to be attractive, integrating hazardous waste and conventional MSW incineration for power production has a limited affect on the cost of treating DADS wastes.

Institutional Findings

1. An integrated waste treatment facility would require a single operator and a unified design approach.

2. Mismatch in operating lives of conventional and hazardous waste incineration systems requires resolution for economic use of investment in the conventional waste system.

3. The viability of the integrated waste incineration facility concept for a site such as the DADS site is linked very closely with the economic viability of a conventional MSW incinerator power plant at the DADS site.

RECOMMENDATIONS

1. In order to reduce overall costs for site decontamination, AFRCE should encourage investigation of "in-situ" decontamination methods because of the high cost of exhuming and incinerating the large quantity of contaminated material - largely soil - estimated at the DADS site.

2. If incineration is selected for treatment of DADS wastes, moisture and corrosion characteristics of the buried MSW and contaminated soil should be reviewed for their effect on heat recovery before proceeding with the integrated power generation concept.

3. AFRCE should proceed with the development of an optimization model for sizing hazardous waste systems to changing hazardous waste thermal treatment scenarios.

ABSTRACT

Incineration of municipal solid wastes (MSW) with heat recovery for power generation is being used increasingly in the U.S. to reduce the volume of wastes to be landfilled. High-temperature incineration is also beginning to be used to decontaminate sites where hazardous chemicals were disposed of in the past with large amounts of heat usually wasted in such incinerators.

This study was performed for the Air Force Regional Civil Engineers (AFRCE) to assist in the restoration of National Priority List (NPL) landfill sites in which the Air Force is involved. The goal was to assess the feasibility of reducing the cost of treating hazardous wastes from a contaminated landfill by integrating heat recovery from incineration of conventional MSW and hazardous wastes in a common power plant. The NPL site selected to examine this concept was the Denver Arapahoe Disposal Site (DADS), known locally as the Lowry Landfill, that is the largest active landfill in the Denver area. This site also has a large number of waste tires stored which could be used in heat recovery incinerators to produce power.

This report presents a characterization of MSW incineration technologies, an energy market evaluation in the DADS area, an evaluation of energy recovery from waste tires, a conceptual design of an integrated incineration power plant, and an economic analysis of hazardous waste processing costs and potential savings with an integrated facility. Analyses of the amount and types of hazardous wastes, appropriate incineration technologies, a process design to size flue gas heat recovery equipment, and cost estimates for hazardous waste incinerator systems and heat recovery equipment were performed by Science Applications International Corporation (SAIC) in a companion study and used in this report.

The primary conclusion of this study is that processing cost savings with an integrated waste incinerator power plant range from 6 to 20% of costs compared to separate hazardous waste incineration. However, this result depends on the amount and moisture content of the waste material and the electricity value sold to the local utility. Other results and conclusions include the types of hazardous waste incineration technologies recommended, the market for energy products, and institutional restraints and requirements.

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POWER GENERATION FROM WASTE INCINERATION

1. INTRODUCTION

1.1 BACKGROUND

Incineration of municipal solid waste (MSW) for the purpose of reducing the waste volume is not a new technology, but has not been used extensively in the United States. Landfills are the most common method of MSW disposal. Many of the existing nation's landfills are reaching their capacity, and developing new landfills is becoming increasingly expensive. Municipalities are now investigating the use of solid waste incinerators, and some have constructed and started operation of these facilities.

Solid waste incineration is an expensive technology because of the initial capital costs and operation and maintenance costs. To help to stabilize or reduce the costs of these facilities, heat from the burning waste is used to generate steam and electricity. Some facilities recover iron and glass from the waste for additional revenue.

The type of incinerator and energy recovery equipment depends on the composition and quantity of the solid waste stream. Typically, MSW waste contains over 50% by weight combustibles having a "higher heating value" of about 4500 Btu/lb of waste. However, there can also be large quantities of a particular waste component, such as scrap tires, at a given site. This waste component has a high fuel value and can have a significant bearing on available energy recovered at an existing landfill site.

In addition to the normally expected type solid waste, there may be other waste, classified as hazardous waste, requiring treatment. In the past, disposal of industrial chemical wastes had taken many approaches, some of which have created a legacy of environmental problems for current and future generations because of insufficient long-term containment of hazardous chemical

constituents -- heavy metals, PCB's, and aromatic hydrocarbons among others. "Codisposal" was one of the disposal techniques used in which industrial liquid wastes were dumped into excavated waste pits or lagoons, MSW was next spread into the liquids, and soil was used to finally cover the pit. The assumption made in this codisposal technique was that the MSW and soil would absorb the toxic liquids and prevent them from leaching and migrating from the waste pit into the surrounding soil and aquifers.

With the passage of time, some "codisposal" sites have begun to indicate that uncontrolled dispersion of toxic chemicals was occurring, threatening local groundwater sources in the near-term and widespread contamination of large aquifers that supply raw water to major population centers in the longer term. Thus, such sites have been placed on the EPA's National Priorities List (NPL) under the EPA Superfund Program for Remedial Investigation (RI) and ultimate destructive treatment of the codisposed, mixed toxic liquid and MSWs.

High-temperature (2,200-2,400°F) incineration is the method often used for destroying (99.9999% destruction efficiency) toxic wastes and contaminated soils from codisposal-type hazardous waste sites. This incineration process requires large amounts of natural gas fuel burned relatively inefficiently with excess air to promote complete combustion of the toxic materials. Normally, the entire energy content of the fuel is wasted in quenching the off-gas stream. However, heat recovery from the high-temperature off-gas could be attractive for superheating steam and/or as an economizer for a steam cycle power plant. A hazardous waste incinerator facility could be located at an operating landfill where an MSW incinerator could also be operated to process fresh MSW from an urban area. Therefore, the collocation of both types of incinerators could provide an opportunity for effective integration of the two incinerator operations for maximum economic efficiency.

The Air Force is involved as a Potentially Responsible Party (PRP) in several EPA and Air Force NPL landfill sites. It, therefore, has an interest in contributing to the ultimate economic restoration of such sites. This study has been performed for the Air Force Regional Civil Engineer (AFRCE) to contribute to its generic capability to participate constructively in NPL site restoration efforts.

1.2 GOALS AND OBJECTIVES

The overall goal of this study is to provide the AFRCE with an analysis of the feasibility of reducing the cost of hazardous waste treatment through incineration of MSW and hazardous wastes using an integrated system design at a common site.

The specific objective is to provide a framework for performing analyses of MSW incineration for power generation, heat recovery from hazardous waste thermal treatment and other operational features that could be integrated with an MSW incinerator facility in a manner that reduces overall costs.

1.3 APPROACH

The approach taken in this study is to use a specific NPL site selected by the AFRCE as the basis for a "generic" study. The study is intended to be "generic" in the sense that the results could have applications over a range of assumed values of certain key variables. Characterization of hazardous wastes at the specific NPL site selected has only been partially completed, so that levels and volume of contamination of buried hazardous wastes are not known precisely. Thus, the study was not based on a single set of conditions to represent the specific NPL site, but it used information available from the specific NPL site as the starting point for defining ranges of values for analyses to be performed.

Analysis of thermal treatment processes of hazardous wastes was performed in a companion study by the Science Applications International Corporation (SAIC). The results of the SAIC study have been used in the analysis of integrating the hazardous waste treatment process with an MSW incinerator plant.

The primary tasks in this study are (1) to characterize an NPL landfill site with codisposed MSW and hazardous waste and a large number of scrap tires, (2) to characterize the MSW and scrap tires at the site, (3) to review the current technology of large-scale (<300 TPD) MSW incineration with electric power production, (4) to characterize the energy market for electricity and thermal energy, as steam or hot water, for the specific site selected by the AFRCE, and (5) using the results of the SAIC analyses of hazardous waste thermal treatment processes to make a preliminary estimate of the economic advantages and disadvantages of locating an MSW incinerator, a scrap tire incinerator, if required, and a hazardous waste incinerator at a common site for the most cost-effective waste treatment option.

In the following section, a brief summary of essential information is presented on the specific site used as a basis for this generic study.

2. SITE CHARACTERIZATION

2.1 GENERAL

The information presented in this section was obtained from Ref. 2.1. The characterization of the site presented in this report is restricted to general information for descriptive purposes. Hence, important considerations of site suitability from an engineering perspective of design for new plant facilities - such as local geology, hydrology, utility requirements - are not included in this study. Also, information on contamination from codisposed municipal and hazardous wastes at the Denver Arapahoe Disposal Services (DADS) site, as documented in Ref. 2.1, is discussed in a companion SAIC study report, Ref. 2.2.

2.2 LOCATION

The landfill selected by the AFRCE for this study is the DADS landfill, commonly known as the Lowry Landfill. This 2,680 acre landfill site is located in section 6 of Arapahoe County, approximately 20 miles southeast of Denver and two miles east of Aurora, Colorado, as shown on Fig. 2.1.

2.3 CLIMATE AND GENERAL PHYSICAL CHARACTERISTICS

Climate at the DADS landfill is characterized as semi-arid and low humidity with 15.3 in. average annual rainfall. Prevailing winds are generally from the south.

Surface topography is gently rolling - see Fig. 2.2 - with occasional small surface streams that flow generally north. An unnamed creek flows northward across the landfill and drains into Murphy Creek, that drains into the South Platte River, as shown in Fig. 2.1.

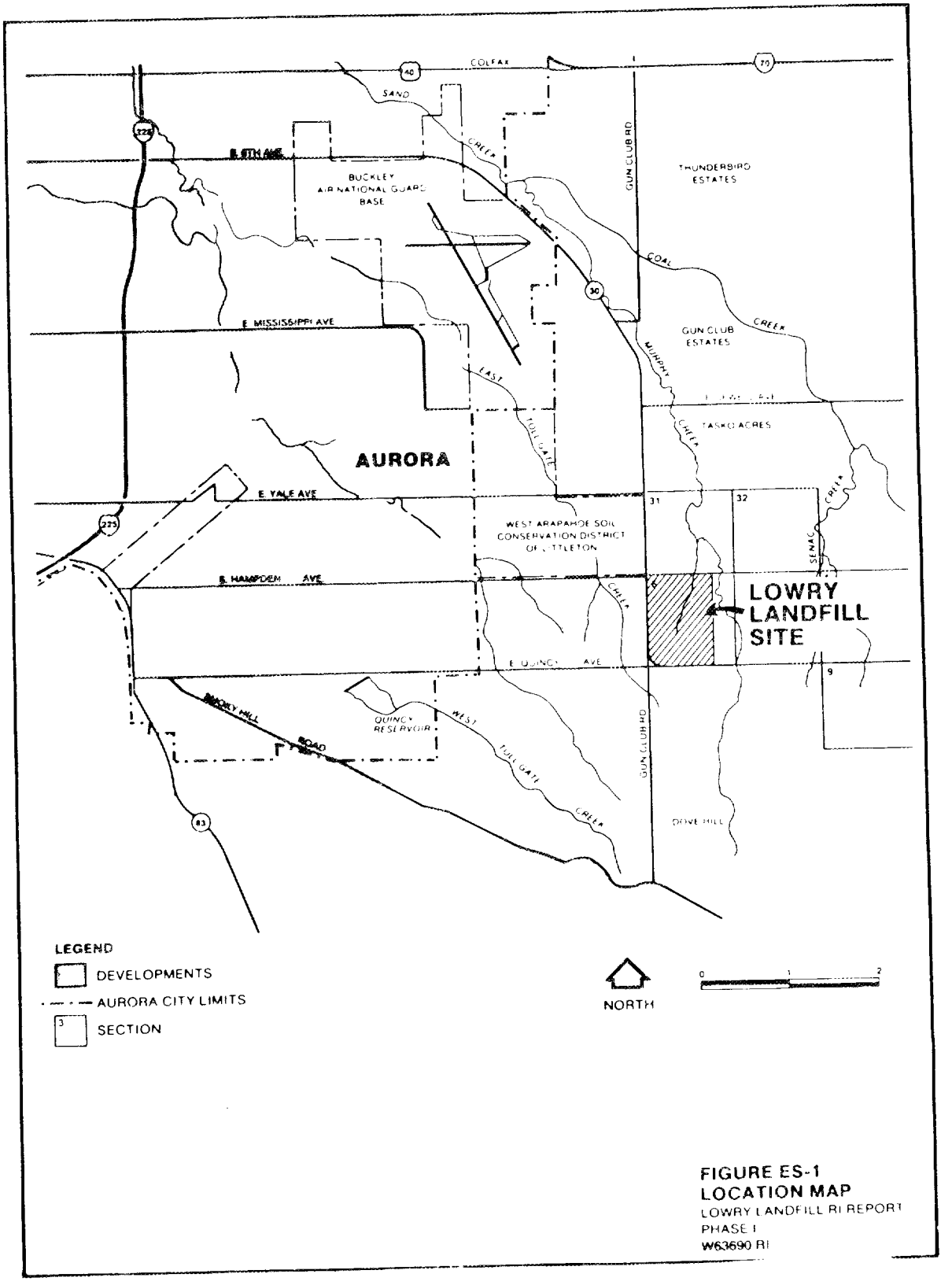


Fig. 2.1. Location map for Lowry Landfill (from Ref. 2.1).

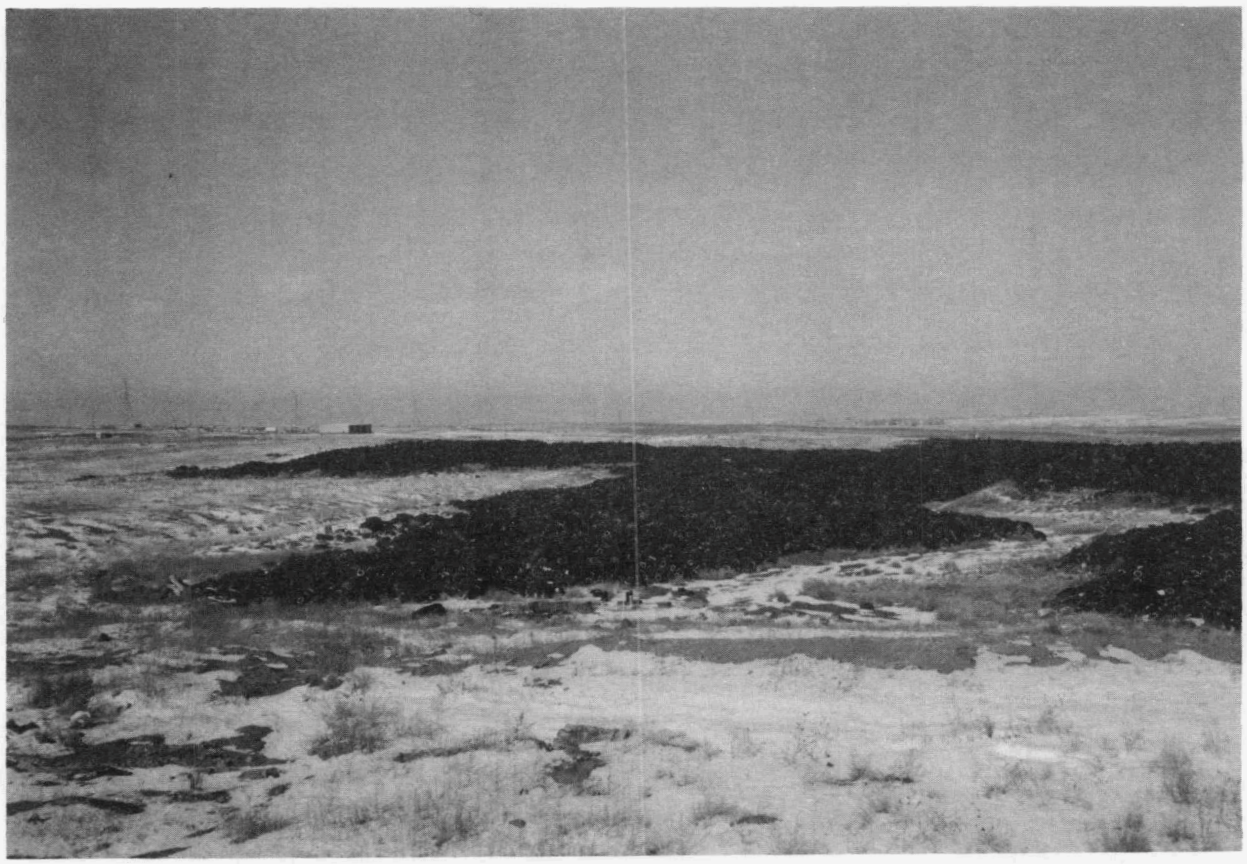


Fig. 2.2. view of Lowry Landfill, looking north, showing waste tires.

Groundwater is used extensively in the area for residential development in Arapahoe County outside Aurora. Groundwater systems are divided into (1) a shallow, discontinuous alluvial and weathered bedrock system and (2) a lower unweathered bedrock system. A summary description of groundwater flows, as excerpted from Ref. 2.1, is presented below.

- Leachate flows in the unnamed creek are continuous. These flows, measured since August 1985, vary between 24 gallons per minute in September 1985 to approximately 8 gallons per minute in May 1986.

- Data from five sets of nested groundwater monitoring wells and from a water balance calculated for the site confirm the presence of downward vertical gradients, indicating conditions in which water can potentially move from upper to lower water-bearing zones.

- Calculated estimates of groundwater velocities indicate that vertical movement of infiltrating water and, possibly, contaminants carried by the water could be as high as 20 feet per year, resulting in a 400-foot downward penetration into the unweathered lower bedrock in the 20-year history of the site.

- A lack of continuity was observed in the subsurface bedrock strata, making it difficult to draw geologic correlations across the site. Borings only several hundred feet apart encountered dissimilar lithologic bodies.

- Groundwater movement across these otherwise discontinuous lithologies may be enhanced by the presence of fractures. Fractures were found in on-site continuous core samples and in log data from on-site borrow pit excavations.

- Shallow groundwater levels appear to be increasing in certain areas of the landfill.

2.4 WASTE DISPOSAL PRACTICES

Prior to 1965, the DADS site was owned by the U.S. Air Force and was a part of Lowry Air Force Base located in Aurora, 10 miles to the west-northwest. In 1965, the site was deeded to the City and County of Denver which began using it as a landfill. Between 1965 and 1980, MSW, liquid and solid wastes, and domestic sewage sludge was codisposed by filling excavated pits about three-fourths full of waste liquids and then filling the pits with MSW. It has been estimated that 100 million gallons of waste liquid were disposed of during the 15-year period.

In addition to the wastes discussed above, a large number of scrap tires, estimated to be between 8 and 12 million, were piled on top of certain portions of the landfill, as shown in Fig. 2.3. These tires present a unique form of waste fuel for possible use in a waste-to-energy plant. However, they also hinder sampling of portions of the contaminated waste pits, located in the early landfill areas.

In 1980, Waste Management, Inc., began operating the DADS site, and only MSW has been landfilled since that time. Characterization of MSW flowing to the DADS site is presented in the following section.

Fig. 2.3. Lowry Landfill view of waste disposal activities (from Ref. 2.1).

REFERENCES FOR SECTION 2

1. Phase I Remedial Investigation - Lowry Landfill, Vol. I, performed by CH2M Hill under EPA contract No. 38.8L08.3 (September 2, 1986).

2. "Energy Recovery from Hazardous Waste Incineration," report by Science Applications International Corporation, Inc., Oak Ridge, TN, to Martin Marietta Energy Systems, Inc. (September 1987).

3. WASTE CHARACTERIZATION

3.1 GENERAL CONSIDERATIONS

MSW is viewed in various ways, depending on the perspective of the viewer, i.e., by residents near a waste landfill as a nuisance and source of disease and contamination if not disposed of properly, as a commodity and a basis for a business (trash collectors and disposal firms), and as a resource - combustion fuel and recyclable materials. It is from the latter perspective that this study considers MSW - as a fuel for an incinerator boiler/power plant for the production of electricity and saleable thermal energy.

As fuel for a large (>300 tons/day), modern incinerator plant, the most important characteristics of MSW are (1) heating value and composition, and (2) waste generation and availability. The first of these characteristics are discussed below in general terms before a more detailed discussion of waste generation and supply for the generic landfill site.

3.2 COMPOSITION AND HEATING VALUE OF MSW

The heating value of raw MSW is commonly assumed to be approximately 4,500 Btu/lb. As shown in Table 3.1, MSW's heating value is close to that of wood and about one-third that of coal. The heating value of mixed, raw MSW can range from 3,800 to 5,800 Btu/lb, depending on a wide variety of factors. The discussion that follows is presented to provide background information on such factors that can affect the heating value of MSW.

MSW can be grouped into three basic fractions - combustibles, non-combustibles, and moisture. These fractions are combined in the various components of residential and commercial wastes that significantly affect fuel

Table 3.1. Heating value of MSW and other fuels.[3.1]

Fuel	Lower Heating Value Btu/lb
Peat	3,235
MSW	4,500
Wood	4,690
Lignite	7,065
Subbituminous Coal	10,245
Bituminous Coal	12,235
Anthracite Coal	11,100
No. 2 Home Heating Oil	19,565

value. Non-combustibles include such materials as glass and metals (cans, metal appliance parts, etc.). Combustibles are represented by high fuel value plastics, used tires, cellulose materials (paper, cardboard, yard wastes, etc.), waste liquids (paints, chemicals, etc.), and high moisture content kitchen wastes. The composition in weight percent of typical MSW is shown in Table 3.2.

Table 3.2. Source components of typical MSW in weight, %.[3.2].

Combustibles	Weight, %
Paper	41.7
Yard Wastes	12.6
Food Wastes	15.0
Glass	9.9
Metals	8.8
Wood	2.2
Textiles	2.5
Leather and Rubber	1.2
Plastics	3.5
Miscellaneous	2.6
Total	100.0

Moisture content can vary considerably in several of the combustible materials listed above, such as yard and kitchen wastes. In addition, any water added to raw wastes through rainfall or seepage reduces fuel value proportionately.

Typical breakdowns of the physical and chemical composition of MSW are given in Tables 3.3 and 3.4. In the physical composition, the combustible matter includes a certain amount of ash associated with it. In the chemical composition, the inerts include the ash, ferrous metals, glass, aluminum, heavy non-ferrous material, and at least part of the miscellaneous material.

The composition of MSW can vary both locally by type of source (residential, commercial, and industrial), and also from lifestyle and seasonal variations that depend on geography and time of the year. In addition, MSW fuel value is believed to be increasing slowly from an increasing fraction of high heating value organic plastics; one source estimated that the heating value would increase at an average rate of 0.5%/year. Although the heating value of MSW can be highly variable on a microscale basis, the effect of variation in heating value from various sources can be assumed to be homogenized by the large-scale material handling systems typical of a MSW incinerator facility serving a large metropolitan area.

For this generic study, the heating value of MSW was assumed to be 4,500 Btu/lb, a typical value used for process calculations. Seasonal variations that could increase or decrease the heating value significantly are not germaine to this study, as all analyses will be performed on an annual basis.

3.3 WASTE GENERATION

Generation of MSW in a specific metropolitan area is primarily a function of the population and to a lesser degree the types of activities conducted within the area, i.e., mix of industrial/commercial/residential activity. The

Table 3.3. Typical physical composition of municipal solid waste.[3.3]

Component	Percent by Weight
Combustible matter	59.0
Moisture	25.0
Ferrous metals	5.0
Glass	6.5
Aluminum	1.0
Heavy non-ferrous	0.2
Miscellaneous	3.3

Table 3.4. Typical chemical composition of municipal solid waste.[3.3]

Component	Percent by Weight
Carbon	28.0
Hydrogen	3.4
Oxygen	20.0
Nitrogen	0.4
Sulfur	0.2
Inerts	23.0
Moisture	25.0

metropolitan area chosen as the basis for this study is the Denver metropolitan area. Therefore, information on MSW generation was obtained from the following Denver area governmental entities - the Department of Public Works (DPW) of the City and County of Denver, and the Denver Regional Council of Governments (DRCOG). The following information was extracted from studies and personal contacts with these organizations.

Estimates of future MSW generation rates are made by combining population estimates with the average per capita generation rate in pounds per day (PPD). A recent (late 1986) study by the DRCOG developed average generation rates in tons per day (TPD) for the Denver metropolitan region based on 5 PPD, the national average figure, and 9 PPD, a figure developed for the Denver region in 1981. The resulting average generation rates, presented in Table 3.5, show minimum generation rates of 5,000-6,000 TPD with 9,000-11,000 TPD rates possible at the high per capita generation rate.

Table 3.5. Metropolitan region generation rate estimates.

Year	Population	Low TPD (5 PPD)	High TPD (9 PPD)
1985	1,953,050	4,882	8,788
1990	2,179,163	5,447	9,806
2000	2,529,529	6,323	11,382

3.4 WASTE AVAILABILITY

A MSW incinerator plant must have a reliable supply of MSW to provide the energy products such as electricity, steam or hot water, upon which its economic viability depends. The scope of this study is to evaluate an incinerator plant of approximately 670 TPD capacity. The regional generation rates presented in the previous section indicate that 10-20 times as much MSW are generated than is required by an incinerator plant. However, there are several important factors to be considered with regard to the availability of MSW at a specific landfill location where an incinerator plant could be sited.

3.4.1 Specific MSW Flow

The first and most important factor affecting MSW availability is the flow of MSW being delivered to the specific landfill where an incinerator plant could be located. The landfill of interest for consideration as a site for an incinerator plant in this study is the DADS/Lowry Landfill. This landfill is located in Araphoe County, approximately 20 miles southeast of Denver and two miles east of Aurora, Colorado (see Sect. 2 for additional description).

From information supplied by the DRCOG, there were eight landfills operating in the Denver metropolitan area. The DADS landfill was one of two publicly-owned landfills, and also had the largest MSW flow, approximately 3,000 TPD, and the greatest remaining capacity, 37% of the total capacity estimated in 12/86. Thus, MSW flow to the DADS landfill would appear to provide a very adequate flow for a MSW incinerator plant of approximately 450 TPD capacity.

3.4.2 Reliability of MSW Flow

Coupled in importance with the amount of MSW flow to a specific site is the question of control over the MSW flow to guarantee that a reliable flow will be available for an incinerator plant. Flow of MSW to the various landfills available is usually controlled by (1) public haulers operating under contract with specific landfills and disposal or "tipping" fees and (2) private haulers who are free to choose where to dispose of MSW based on their hauling cost and the tipping fee at specific publicly- and privately-operated landfills. Thus, the most desirable source of MSW for an incinerator plant is the public hauler with a contractual obligation to dispose of MSW at a specific landfill.

In the case of the Denver metropolitan area, the DADS landfill is one of two publicly-owned landfills. Since it is owned by the city of Denver, DADS receives all residential waste collected in Denver, estimated to be

approximately 600 TPD. In addition, DADS receives some publicly-collected wastes from the city of Longmont plus MSW from area private haulers to yield the 3,000 TPD total estimated flow to DADS.

The city of Denver is currently studying, with the city of Aurora, the feasibility of operating a 450-TPD incinerator plant near a site being considered for a relocated Stapleton Airport, the major commercial airport serving the Denver metropolitan area. Denver would be obligated to supply one-half of the MSW for this proposed incinerator plant or 225 TPD. Hence, the current 600-TPD flow of publicly collected MSW from Denver to DADS could be reduced to approximately 375 TPD when and if the Stapleton incinerator project occurs.

Approximately 300 TPD of additional MSW flow would have to be guaranteed to reach the 670-TPD level of guaranteed MSW flow for an incinerator plant at DADS. Therefore, a reliable supply of 670 TPD of MSW would appear to be attainable in the future from either growth in the residential waste collected in Denver or by initiating a contractual agreement with private haulers to supply the relatively small amount of MSW required.

3.5 SCRAP TIRE RESOURCE

In addition to the MSW flow, the DADS site contains a unique waste resource in the form of a large number of scrap tires. These tires were accumulated between 1966 and 1980 when the landfill was operated by the City and County of Denver.

Estimates of the number of tires by local officials varies from 4-12 million tires with a probable number of approximately 8 million. An additional uncertainty exists in the number of tires that could be reclaimed because the bottom layer of tires may be in contact with contaminated soil from the waste pits used for disposal of hazardous liquids. An official of Waste Management of Colorado, the current DADS operator, estimated that no more than

10% of the tires stored at the DADS site would require decontamination. Therefore, a value of 8 million tires is used in this study to represent the useable DADS tire resource.

The potential fuel value of 8 million tires is estimated on the basis of 15,000 Btu/lb fuel value and an average tire weight of 20 pounds. This combination yields a maximum potential fuel value of 2.4×10^6 million Btu, equivalent to approximately 400,000 barrels of oil.

REFERENCES FOR SECTION 3

3.1 Vence, T. D., and D. L. Powers, "Resource Recovery Systems - Part I: Technological Comparison," Solid Waste Management, May 1980.

3.2 T. A. Sladek, et al., DEUS IV: "Refuse Combustion for Power and Thermal Energy," Department of Public Works, City and County of Denver, February 1986.

3.3 D. J. Smith, "Waste Fuels, Refused-Derived Fuels, and Cogeneration," Power Engineering, pp. 40-46, April 1986.

4. MSW INCINERATOR SURVEY

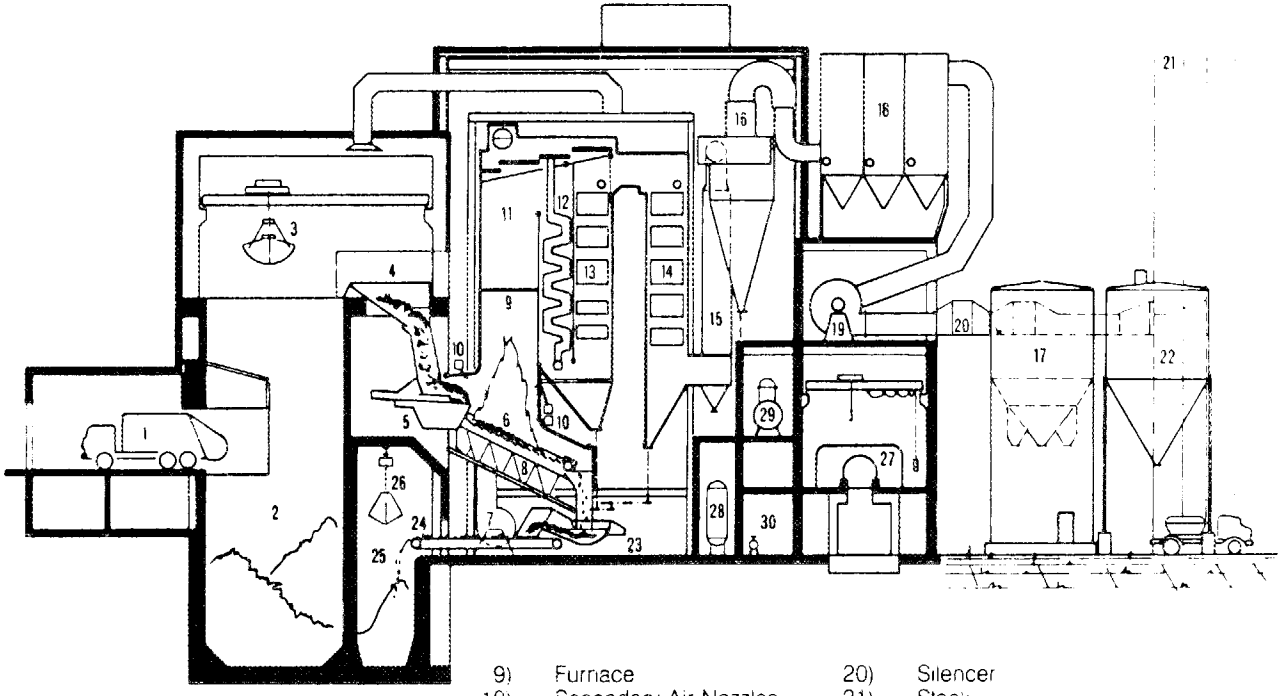
4.1 INTRODUCTION

Two general methods are used for burning MSW: mass burning and refuse-derived fuel (RDF). With the mass burning method, the waste is burned as it is received without any processing other than the removal of bulky items such as refrigerators, stoves, engine blocks, etc. With the RDF method, noncombustible materials are separated out and the combustible material is shredded into small pieces before burning. RDF systems tend to be more cost effective for plants handling 1500 TPD or more, while mass burning systems are more cost effective for smaller plants.[4.1] Each of these methods is discussed separately below.

4.2 MASS-BURN INCINERATION TECHNOLOGY

4.2.1 General System Description

A typical mass burning plant is shown schematically in Fig. 4.1. Refuse is delivered to the plant by trucks (1), which enter an enclosed receiving area and dump their load into a storage pit (2). The storage pit is usually large enough to hold about three days worth of waste material. In this way, the plant can be run on weekends (and holiday weekends) when no waste is delivered. This size of pit also acts as a buffer during down times of equipment for maintenance. Both the receiving area and the storage pit are enclosed to prevent blowing of dust and debris and to reduce emissions of noise and odors from the plant. Also, air for combustion in the furnaces is drawn from these areas so that the odors are destroyed by the combustion process. By drawing air from these areas, a slightly reduced pressure is maintained so that the odors do not escape from the plant.



1) Refuse Collection Vehicle
2) Refuse Storage Pit
3) Refuse Handling Crane
4) Feed Hopper
5) Feeder
6) MARTIN® Reverse-Acting Stoker Grate
7) Forced-Draft Fan
8) Undergrate Air Zones
9) Furnace
10) Secondary Air Nozzles
11) Boiler
12) Evaporator
13) Superheater
14) Economizer
15) Conditioner
16) Cyclone Reactor
17) Reagent Additive Silo
18) Fabric Filter Baghouse
19) Induced-Draft Fan
20) Silencer
21) Stack
22) Fly Ash Silo
23) MARTIN® Residue Discharger
24) Residue Conveyor
25) Residue Pit
26) Residue Handling Crane
27) Turbine Generator
28) Feedwater Treatment Plant
29) Feedwater Storage Tank
30) Boiler Feed Pump

Fig. 4.1. Schematic of mass-burning system.

Source: Ogden-Martin Systems, Inc. literature.[2]

An overhead crane (3) is used to separate large bulky items such as appliances and engine blocks. It is also used to mix the remaining waste in the pit and then to transfer the waste to feed hoppers (4). The material falls by gravity through the feed hoppers and then hydraulic ram feeders (5) charge the material onto the stoker grate (6). The ram feeders are controlled to charge the grate at the desired rate.

The waste material is then burned as it moves across the grate. The grate is usually inclined and consists of sections that are either stationary or move in such a fashion as to agitate the waste material and keep it moving down the grate. Generally, the thickness of the layer of waste material decreases as the waste moves along the grate and is burned. Primary combustion air is supplied to the burning layer of waste by forced-draft fans (7) through the undergrate air zones (8). The air supplied through the undergrate air zones also acts to cool the grate and decrease corrosion and wear of the grate materials. Air passages through the grates are small enough that the grate forms a higher resistance to air flow than does the layer of burning refuse. This promotes a more uniform distribution of air flow through the grate.

The residue left after burning on the grate is quenched by water in the residue discharger (23) and is carried by a conveyor (24) to the residue pit (25). Siftings, i.e., fine materials that fall through the grate, are also collected by this system. Residues may be magnetically separated to remove ferrous metals and the remainder is hauled to a landfill.

In addition to the primary combustion air supplied below the grate, secondary combustion air is injected through nozzles (10) above the grate to promote turbulence for mixing and complete combustion of the volatile gases in the furnace (9).

There are two basic types of furnaces: waterwall and refractory lined. In the waterwall furnace, water tubes from the boiler extend into the combustion zone and provide a cooled wall, while extracting heat from the combustion process. The tubes are coated with a protective material to reduce corrosion. In the refractory-lined furnace, the boiler and furnace are separated and there are no boiler tubes in the furnace. To prevent excessive heat losses from these types of furnaces, they are lined with refractory bricks.

Heat is extracted from the combustion gases and generates steam as it passes through a boiler system. In the system shown in Fig. 4.1, the hot gases pass sequentially through four sections of the boiler (11). The first section is the waterwall section where the hot gases are initially cooled primarily by radiation. In the second section, water is evaporated to form saturated steam, while in the third section, the steam is superheated. The fourth section is the economizer where the boiler feedwater is initially heated.

In the system shown in Fig. 4.1, the water circulating through the boiler is used to generate electricity. Steam exiting from the superheater is sent to a steam turbine which drives an electrical generator (27). The steam leaving the turbine is condensed and combined with makeup water from the feedwater treatment plant (28). It is stored in a feedwater storage tank (29) before being pumped by a boiler feed pump (30) into the economizer section of the boiler. As an alternative, or in combination with electric generation, the steam generated by the boiler may be used directly for district heating or industrial process heat.

The combustion gases carry flyash along with them. The flyash can be deposited on the surfaces of the boiler tubes, decreasing their efficiency in extracting heat from the gases. To prevent excessive buildups of flyash, the boiler tubes are cleaned using soot blowers. The flyash falls into hoppers at the bottom of the boilers and is conveyed to the residue discharger.

After leaving the boiler, the flue gases are treated before being discharged by an induced draft fan to the environment through the stack (21). Various combinations of pollution control devices are used. Generally, these devices can be divided into two groups: (1) those for removal of acid gases and (2) those for removal of particulate material. In the system shown, after leaving the boiler system, the flue gases enter a conditioner (15) where water is added to cool the gases. The gases then flow into a cyclone reactor (16) where a reagent of fine lime dust [stored in the silo (17)] is blown in. Acid gases in the flue gas are bound to the lime particles and are neutralized. The flue gases then pass through the fabric filter baghouse (18) where both the reacted lime dust particles and flyash are removed. The fabric bags are shaken mechanically or pneumatically and the particulate material drops into hoppers and is conveyed to a storage silo (22) where it awaits disposal in a landfill.

An alternative device for removing particulate material from the flue gases is the electrostatic precipitator. With this device, the particles are electrically charged, while the plates of the precipitator are oppositely charged. The particles are thus attracted to the plates and are collected on them. The plates are mechanically rapped and the particles fall into hoppers as with the baghouses. Electrostatic precipitators are not usually used in combination with the dry gas scrubbers (lime dust reactors) as fabric filter baghouses are.

4.2.2 System Capacities - Installations

A recent survey has identified 194 facilities in the United States for producing energy from MSW that are in an advanced state of planning, under construction, operational, and/or shut down.[3,4] A breakdown of the status of these facilities is given in Table 4.1. About one-third of the facilities are operational.

Table 4.1. Status of planned or existing resource recovery projects in the U.S.[4]

Status	Number of Projects
Advanced Planning	72
Construction	25
Shakedown	7
Operational	63
Shutdown Temporarily	8
Shutdown Permanently	19
Total	194

Of these facilities, 41% are mass burning systems and 21% utilize refuse-derived fuel. Modular systems account for 33% of the total number, and other types of technology account for 8%. The modular systems are generally used for industrial on-site heat-recovery incineration systems which are generally smaller than facilities for handling MSW.

The total design capacity for all existing plants is 34,564 TPD. Planned projects would add another 98,954 TPD capacity. A breakdown of planned and existing facilities by size is given in Table 4.2.[4] An earlier survey[5] showed that 47 mass-burn plants were operational and another 14 plants were under construction. The total capacity of operational plants was 16,820 TPD, while the total capacity of the plants under construction would be 5,655 TPD. These plants ranged in size from 7 to 2250 TPD, with an average size of 368 TPD. Table 4.3 lists eight mass burning facilities that are being built or have been built by Ogden Martin Systems, Inc. These facilities span the range from 550 to 2362 TPD. Each facility consists of two or three separate units that range in size from 275 to 787 TPD.

Table 4.2. Size of planned or existing resource recovery facilities.[4]

Size, Ton/Day	Number of Facilities
50-100	42
101-300	42
301-600	28
601-900	19
901-1200	20
1201-1500	8
1500+	35
Total	194

Table 4.3. Capacities of mass-burning facilities by Ogden Martin Systems, Inc.[2]

Plant Location	Plant Capacity tons/day	Number of units	Capacity per Unit, tons/day
Hillsborough Co., FL	1200	3	400
Alexandria, VA	975	3	325
Bristol, CT	650	2	325
Marion Co., OR	550	2	275
Stanislaus Co., CA	800	2	400
Tulsa, OK	1125	3	375
Indianapolis, IN	2362	3	787
Babylon, NY	750	2	375

4.2.3 Mass-Energy Balances

As was mentioned in the system description, energy from burning waste is used to produce steam which is then either used to generate electricity or to provide steam for district heating, or industrial processes, or both. The energy production for the eight mass-burning plants that have been built or are being built by Ogden Martin Systems, Inc. are summarized in Table 4.4. For each of these systems, the steam temperature is between 700°F and 830°F, with most of the systems operating nearer 700°F. Steam temperatures are limited to these values to lessen the effects of corrosion and slagging of the boiler tubes.

An estimate of the overall efficiency of the plants may be obtained by using the typical higher heating value of 4500 Btu/lb[1] for MSW along with the conversion factor of 3413 Btu/kW-hr. For the plants that generate electricity only, overall efficiencies are calculated to range from 17.0 to 18.7%, and to average 17.8%.

By dividing net the electricity generated by the plant capacity, an energy production factor can be obtained. For the six plants listed in Table 4.4 that produce electricity only, this factor ranges from 18.7 to 20.5 kW/TPD, with an average of 19.5 kW/TPD.

The total residual material from a mass burning facility is expected to be approximately 23% of the input stream. This figure is a weight percentage, and since the bulk density of the residual material is much higher than that of the input stream, the volume of material to be removed to a landfill is reduced to approximately 10% of the original volume.[4.6]

4.2.4 Costs

The cost of a facility may be broken into two parts. The first is the capital cost, which includes the cost of design and construction, and the costs of financing. The second is the recurring expenditures for operating and maintaining the facility. These costs are offset by revenues generated through the sale of electricity or steam and the disposal or "tipping" fee.

Table 4.4. Energy production for mass-burning systems by Ogden Martin Systems, Inc.[2]

Plant location	Plant capacity ton/day	Steam pressure psig	Steam temperature °F	Electricity generated, net MW	Steam generated lb/hr
Hillsborough Co., FL	1200	615	750	23	--
Alexandria, VA	975	600	700	20	--
Bristol, CT	650	865	830	13	--
Marion Co., OR	550	655	700	11	--
Stanislaus Co., CA	800	865	830	15	--
Tulsa, OK	1125	630	700	16.5	240,000
Indianapolis, IN	2362	510	710	--	500,000
Babylon, NY	750	655	700	14	--

Design and construction costs for eight mass burning facilities being built or built by Ogden Martin Systems, Inc. are listed in Table 4.5. These costs do not include the costs of financing. The costs for these plants range from $48 million to $84 million. Normalized costs (cost divided by capacity) vary from $35,500 to $111,900 per TPD. The lowest normalized cost is for the Indianapolis plant (planned for completion in late 1988), which will produce only steam and does not produce electricity. Excluding this plant, the normalized costs would range from $66,700 to $111,900 per TPD. Another plant planned for completion in late 1988 (Babylon, NY) and a plant planned for completion in early 1989 (Stanislaus Co., CA) will have normalized costs of $111,900 and $102,800 per TPD, respectively.

Operating and maintenance costs include the following: operating labor, salaries and benefits, maintenance, equipment replacement, taxes and licenses, insurance, professional services, overhead (administrative and support), costs for water, electricity, and fuel consumed by the plant, and costs for disposal of residue. The average operating and maintenance costs obtained from the recent survey are $22/ton.[4] This figure is in line with a value of about $25/ton (1980 dollars) that is given for a 720 TPD mass burning plant.[7]

4.3 REFUSE-DERIVED FUEL (RDF) TECHNOLOGY

4.3.1 General System Description

With the RDF system, the waste material is processed before it is introduced to the furnace for burning. A schematic of the fuel preparation is shown in Fig. 4.2.

The waste is delivered to the facility and is unloaded onto the floor of an enclosed receiving area. As with the mass burn system, large bulky items such as appliances are separated out first. The remaining waste is loaded onto a conveyor which feeds it to a flail type primary shredder. This shredder breaks open bags containing waste, breaks glass, and exposes the material for further processing. The material then goes to a separation system where ferrous metals are removed magnetically and diverted for further processing.

Table 4.5. Design and construction costs for mass-burning facilities at Ogden Martin Systems, Inc.[2]

Plant Location	Plant Capacity ton/day	Design and Construction cost (millions)
Hillsborough Co., FL	1200	$80
Alexandria, VA	975	75.9
Bristol, CT	650	58.8
Marion Co., OR	550	47.7
Stanislaus Co., CA	800	82.2
Tulsa, OK	1125	75.5
Indianapolis, IN	2362	83.8
Babylon, NY	750	83.9

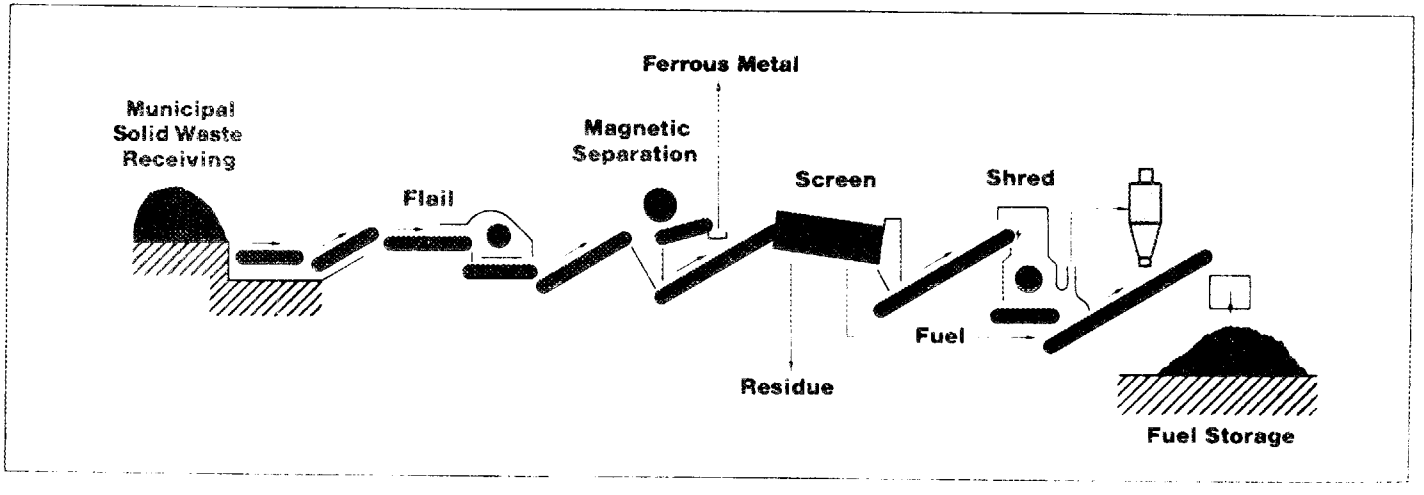


Fig. 4.2. Schematic of fuel preparation for RDF facility.

Source: Combustion Engineering, Inc. literature.[8]

The remaining waste is then fed to a trommel, which is a large rotating drum with holes, where noncombustible materials, like glass, sand, and dirt, are removed for disposal. The remaining combustible material, consisting mostly of paper and cardboard is sent to another shredder where it is reduced to pieces that are a few inches in size. The shredded material is then separated from the air stream in which it is conveyed by a cyclone separator and is then taken to a fuel storage area.

Figure 4.3 shows a schematic of the rest of an RDF facility. The prepared fuel is pneumatically fed into a waterwall furnace. Part of the fuel burns while it is suspended, while the rest falls onto a grate where burning is completed. The grates used in RDF systems are much different from those used in mass burning systems. The grate moves horizontally from the back of the furnace toward the front (where the fuel distributors are located). Combustion air is supplied both above the grate and below it. At the front of the furnace, the grate drops ash to an ash discharger.

Remaining parts of the RDF system are similar to those described for the mass burning system. One additional feature shown in Fig. 4.3 is a heat recovery system in which the air for combustion extracts heat from the flue gases before the combustion air is injected into the furnace.

4.3.2 System Capacities-Installations

Of the 194 plants identified in Sect. 4.2.2 that are in advanced planning, under construction, operational, and/or shut down, 21% are RDF facilities. The earlier survey[4.4] showed that 12 RDF plants were operational and another 3 were under construction. The total capacity of the 12 operational plants was 15,120 TPD, which is only slightly lower than the 16,820 TPD total capacity reported for 47 operational mass-burning plants. The total capacity of the 3 RDF plants under construction was 3600 TPD, compared to the 5655 TPD total

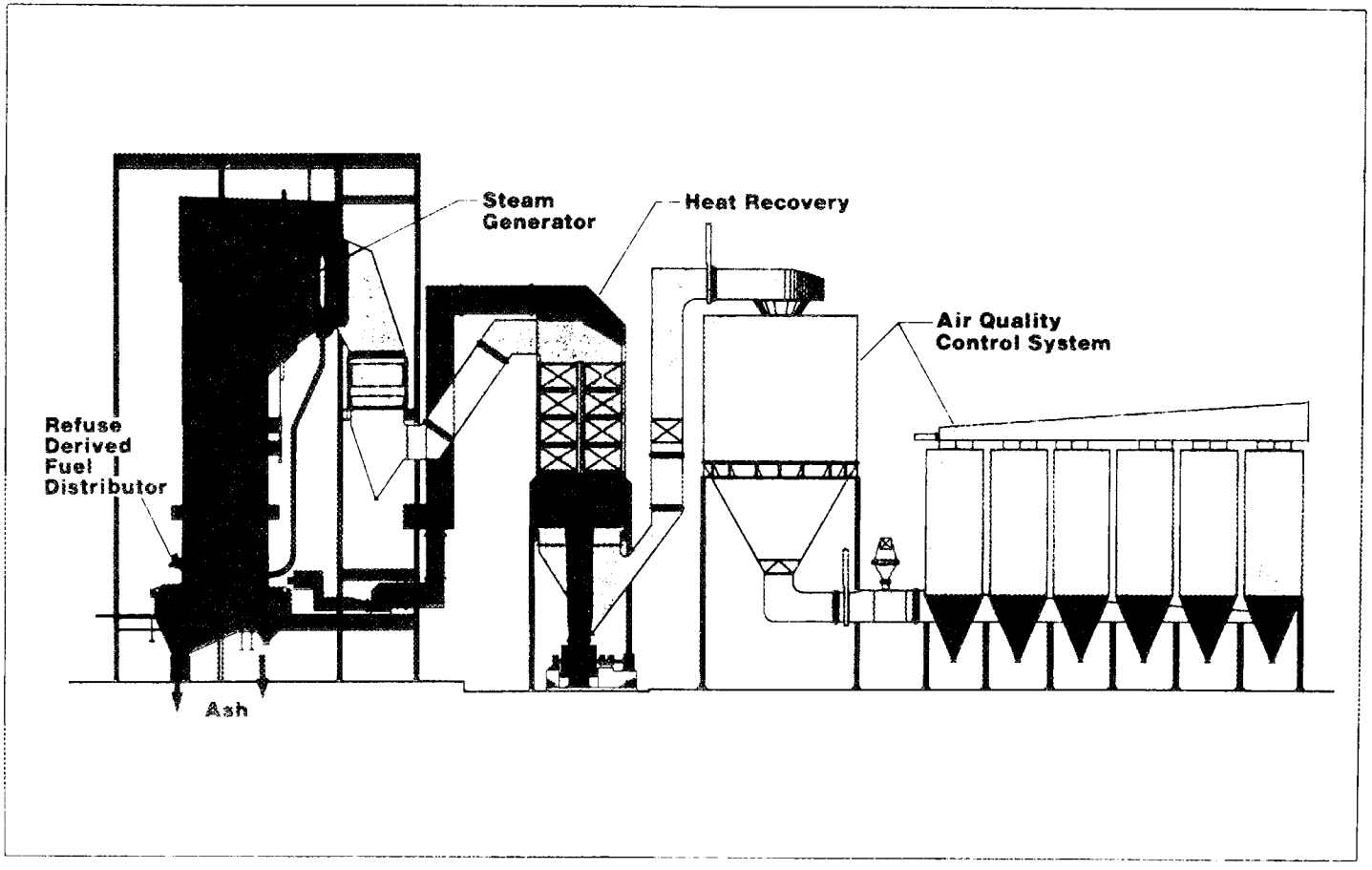


Fig. 4.3. Schematic of refuse-derived fuel facility.

Source: Combustion Engineering, Inc. literature.[8]

capacity for 14 mass-burning plants under construction. The size of the RDF plants ranged from 400 to 3000 TPD. The average size of an RDF plant was 1248 TPD, which is more than three times as large as the average mass-burning plant.

Four RDF plants to be built by Combustion Engineering, Inc. are summarized in Table 4.6. These are all large plants with capacities over 2000 TPD. As with mass-burning plants, RDF plants consist of two or three units.

4.3.3 Mass-Energy Balances

Energy productions for the four RDF plants to be built by Combustion Engineering are given in Table 4.6. Each of these plants will produce electricity, while the Detroit plant will also produce steam for district heating.

Using the electrical generation rates, plant capacities, a higher heating value of 4500 Btu/lb, an estimated internal usage of 12%, and a conversion factor of 3413 Btu/kW-hr, the overall efficiencies of the three plants that will produce only electricity are 27.4%, 21.1%, and 16.6%.

The energy production factor obtained by dividing the estimated net electric generation rates by the plant capacities are 30.1, 23.2, and 18.3 kW/TPD for the three electric-only plants.

The typical physical composition of municipal solid waste was given in Table 3.3. The typical chemical composition of MSW, given in Table 3.4, listed inerts (residual) as about 23% of the input stream. This figure should hold for RDF plants as well as for mass-burning plants. The main difference is the location where the residuals are removed. In the RDF plant, the 5% of the input stream that consists of ferrous metals is removed first. Then, most of the glass, aluminum, heavy non-ferrous materials, and miscellaneous materials (or about 11% of the input stream) are removed before the remainder is sent to the furnace.

Table 4.6. Capacities and energy production of refuse-derived fuel plants by Combustion Engineering, Inc.[8]

Plant Location	Plant Capacity ton/day	Numbered of units	Electricity Generated, gross MW***	Steam Generated lb/hr
Hartford, CT	2000	3	68.5	692,000*
Detroit, MI	4000	3	65**	550,000**
Honolulu, HI	2160	2	57	500,000*
San Mateo, CA	3850	3	80	--

*Steam used for electricity generation.

**Both steam for district heating and electricity are generated.

***Estimated internal electrical requirements are about 12 percent.

Table 4.7. Typical chemical composition of refuse-derived fuel.[1]

Component	Percent by Weight
Carbon	33.4
Hydrogen	4.0
Oxygen	25.0
Nitrogen	0.4
Sulfur	0.2
Inerts	14.0
Moisture	23.0

The typical chemical composition of the refuse-derived fuel that is introduced to the furnace is given in Table 4.7. About 14% of the fuel is inert material and is removed from the furnace as ash. Assuming that the ferrous metals are reclaimed and sold, about 18% of the input stream is left to be disposed of in a landfill.

4.3.4 Costs

An RDF plant of a given capacity appears to cost somewhat more than a mass-burning plant of the same capacity. An example is given in the literature for a 720 TPD plant.[7] For a mass-burning plant, the capital cost in 1980 dollars was estimated to be $75.7 million, while the cost for a similar RDF plant was estimated to be $83.1 million, or about 10% more. Also, operating costs were estimated at $30/ton for a RDF plant compared to about $25/ton for a mass-burning plant. Differences are at least partly due to the extra cost of building and operating the facility to prepare the refuse-derived fuel.

The estimated costs for the Detroit and Honolulu plants being built by Combustion Engineering have been given as $230 million[8] and $145 million.[1] By dividing these costs by the plant capacities, normalized costs of $57,500 and $67,130 per TPD are obtained.

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5. MARKET CHARACTERIZATION

5.1 INTRODUCTION

This section presents a discussion of markets for products from a typical 300-450 TPD MSW incinerator plant with electric power generation. The primary markets considered are for electricity and thermal energy in the form of steam or hot water. Recovered materials such as metals and glass also have some economic value, usually of minor importance compared with other sources of revenue.

The site of the MSW incinerator plant is assumed to be at the DADS (or Lowry) Landfill described in Sect. 2. This site is currently isolated from urban development, so there are no energy markets readily available other than the electric power grid of the Public Service Company of Colorado.

As the site for a generic study of integrating MSW and hazardous waste incineration for cogeneration, there is probably no site that is truly generic because of the wide diversity of conditions existing at Superfund type sites. The DADS site has several characteristics that may represent some Superfund sites and also contribute to energy markets for energy products from a waste-fueled power system. These attributes are (1) the presence of an "anchor" customer for power from the system at the Buckley Air National Guard (ANG) Base and (2) the possibility of commercial and light industrial development in the vicinity of the site. These markets are discussed in the following sections.

5.2 ELECTRIC ENERGY MARKETS

Markets for electricity produced from an MSW incinerator power plant include the local electric utility under provisions of the Public Utility Regulatory Policies Act (PURPA) and any special markets for electricity. These markets are discussed below in the general context of an MSW incinerator plant at the DADS site.

5.2.1 Local Electric Utility

Under PURPA regulations, local electric utilities are required to negotiate with small power producers (<80 MWe) and cogeneration plants for purchasing power to be resold by the utility. Such electricity purchases are to be priced on the "avoided costs" of the local utility. The value of such avoided costs to a generating utility includes not only the fuel and capacity savings to the utility, but also the availability - time of day - and reliability of the purchased power. Thus, the value of power purchased by a utility under PURPA depends on the specific characteristics of both the purchasing utility and the power producer.

The electricity rate being offered by Public Service Company of Colorado under PURPA was $0.045/kWh in February of 1987. The rate for a specific power producer such as an MSW incinerator power plant could differ from this rate because of availability and reliability factors mentioned above. Also, the value of future power sources supplied under PURPA regulations to other utilities will vary because of the individual characteristics of each utility. PURPA rates are generally highest in the Northeast where high fuel cost, oil-fueled generation is the basis for PURPA rates. Therefore, the rate of $0.045/kWh used for PURPA sales of electricity in this study would apply to the Public Service Company of Colorado service area and other utilities with similar power generation costs.

5.2.2 Marketing Electricity to Specific Customers

The presence of a specific market or markets for sale of electricity generated by an MSW incinerator power plant has both advantages and disadvantages for the economics of the project. One advantage is that a specific market can provide a reliable source of revenue to the project through a long-term contract for power. A second advantage is that the rate for power negotiated through such a contract can be higher than rates to the local utility under PURPA regulations.

There are also disadvantages to be recognized in selling power to specific markets, however. First, the purchaser may require a put-or-pay type contract whereby the supplier of power would pay a penalty if unable to provide power as specified in the contract. For an MSW-fueled power plant, a backup source of steam to the turbine may be desirable or required when maintenance and unscheduled outages occur. Secondly, the cost of transformers, power transmission lines, and rights-of-way would have to be born by either the supplier or purchaser of power. Finally, entering the market as a supplier of electricity could result in the MSW plant being classified as a public utility and thereby subjected to regulation by the State Public Utility Commission.

These general considerations are discussed relative to a specific electricity market, the Buckley ANG Base - or Buckley - for the DADS site of an MSW power plant.

5.2.3 Buckley Base Characteristics

The Buckley Base is located approximately five miles northwest of the DADS site, as shown in Fig. 5.1. This base has several characteristics that make it attractive as a potential purchaser of electric power from a power plant located at the DADS site.

Buckley's location relative to the DADS site lends itself to easy right-of-way for transmitting power between the two sites. A transmission line could be routed along an existing highway - Gun Club Road - passing east of the DADS site and then passing to the north of Buckley. Therefore, no rights-of-way over private property would be involved in this transmission route, which would reduce the cost of installing a power transmission line.

The electric load shape of Buckley is another desirable feature as a specific purchaser of power. Information on the current electrical load of Buckley was obtained from the Base's engineering staff. The load has two primary

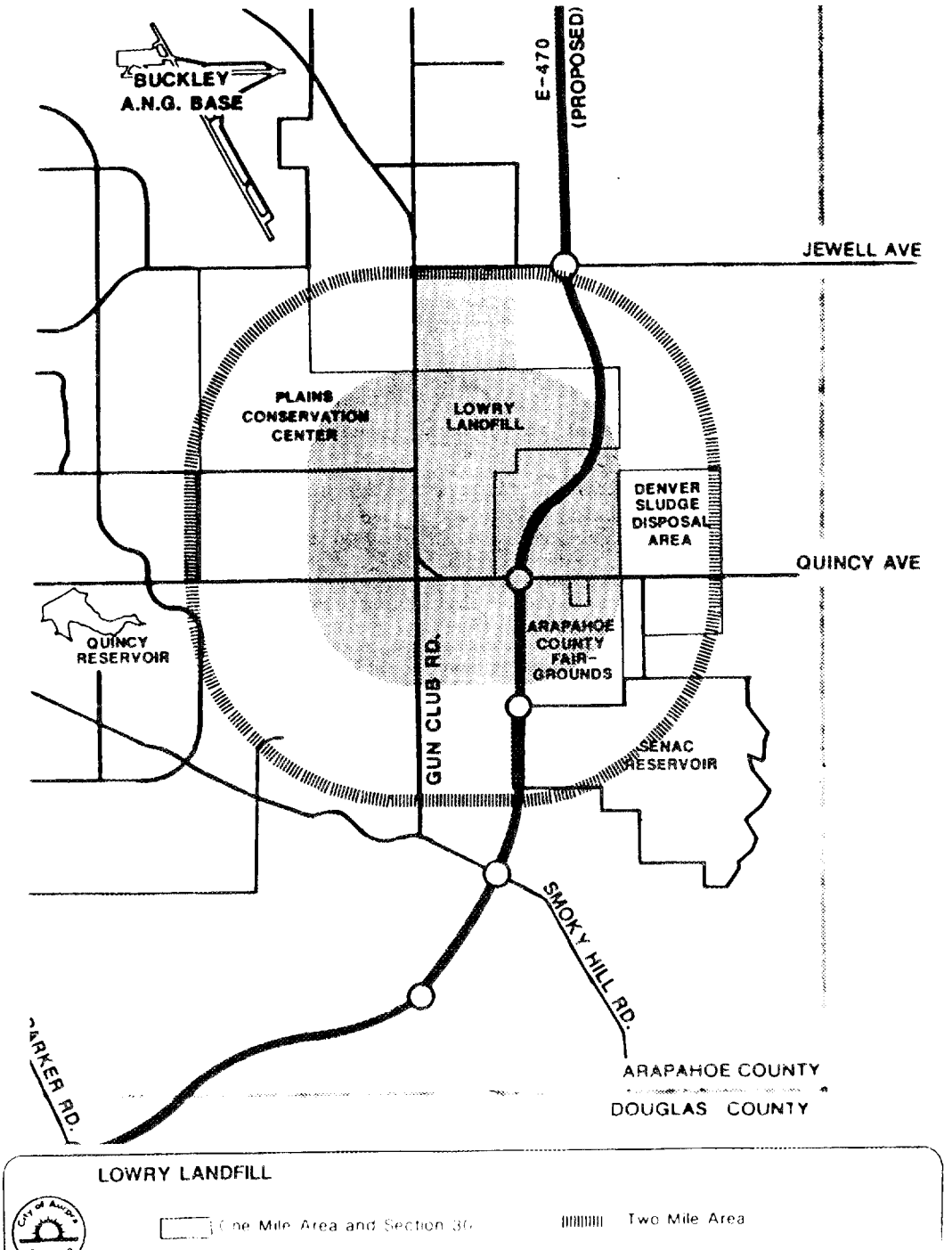


Fig. 5.1. Lowry Landfill and Buckley Air National Guard Base (Ref. 5.1).

components: (1) the normal load of the base for building space conditioning, domestic water heating, lighting, and other miscellaneous loads - office equipment, appliances, etc. -, and (2) a special "superimposed" load of 4,000 kW, generally between the daytime hours of 0900 and 1600, although the period can be extended at times.

The normal load shape of the base, estimated from 1986 data on maximum and minimum loads, is shown in Fig. 5.2 for summer and winter seasons. The summer load, which includes air conditioning, peaks at about 1,800 kW, whereas, the winter peak was about 1,200 kW. The superimposed load is also shown in Fig. 5.2. The resultant combined peak load was 5,600-5,800 kW in the summer and 5,200 kW in the winter.

The high superimposed load during the daytime hours of peak rates makes the Buckley Base a possible customer for direct power sales. The Public Service Company of Colorado rate for power in 1986 was $0.051/kWh during peak load hours compared with $0.035/kWh during off-peak hours. In addition, Buckley has added on-site, diesel power generation equipment capable to provide the 4,000 kW superimposed load. The on-site diesel generators are used for five months, from May through September, to increase reliability during the period of electrical storms. Therefore, the diesel generators could possibly be used to provide a backup to power purchased from a generation facility at the DADS site, thereby reducing the need to provide additional backup capacity.

5.3 FUTURE URBAN DEVELOPMENT

Urban development of land adjacent to the DADS site is one possible source of a market for thermal energy from an MSW incinerator plant.

5.3.1 Development Plans

The DADS site is currently several miles from any residential or commercial development. However, the City of Aurora plans to expand to the east of its present boundaries by annexing land that would include the DADS site.

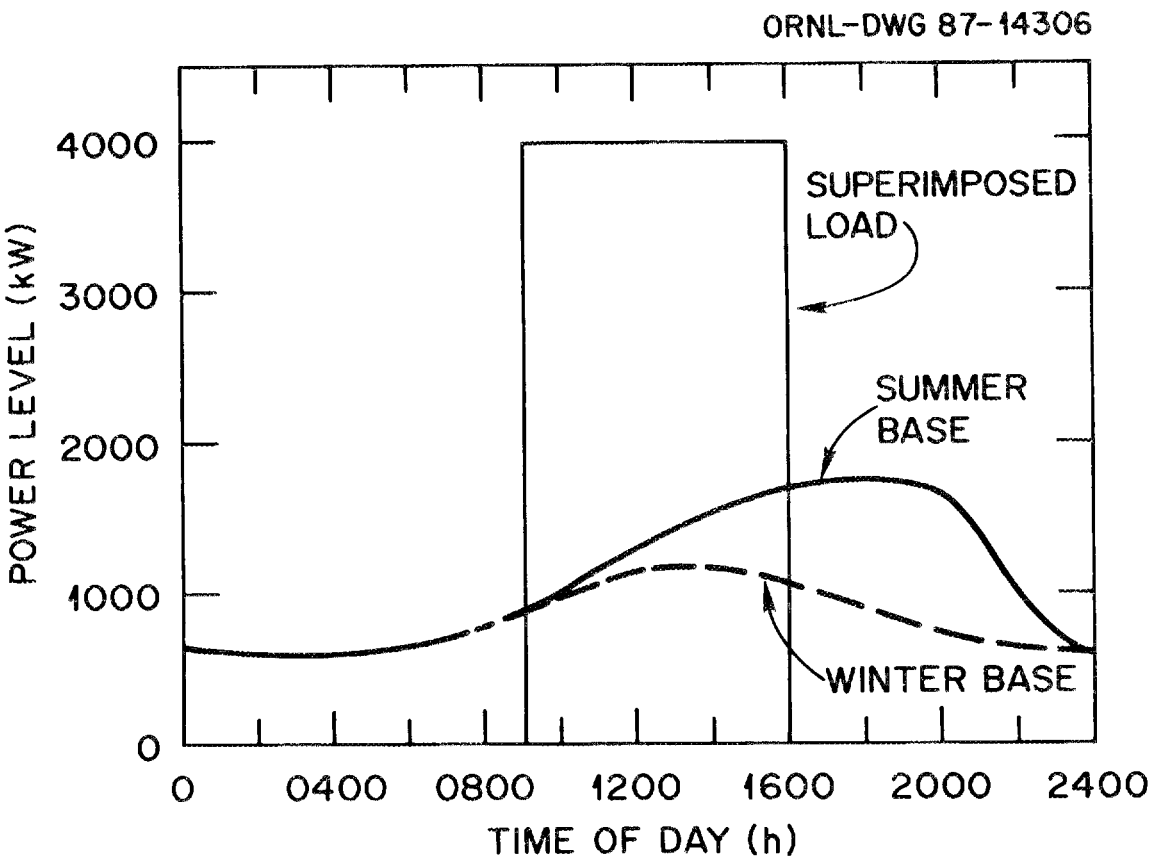


Fig. 5.2. Electrical loads estimated for Buckley Air National Guard Base.

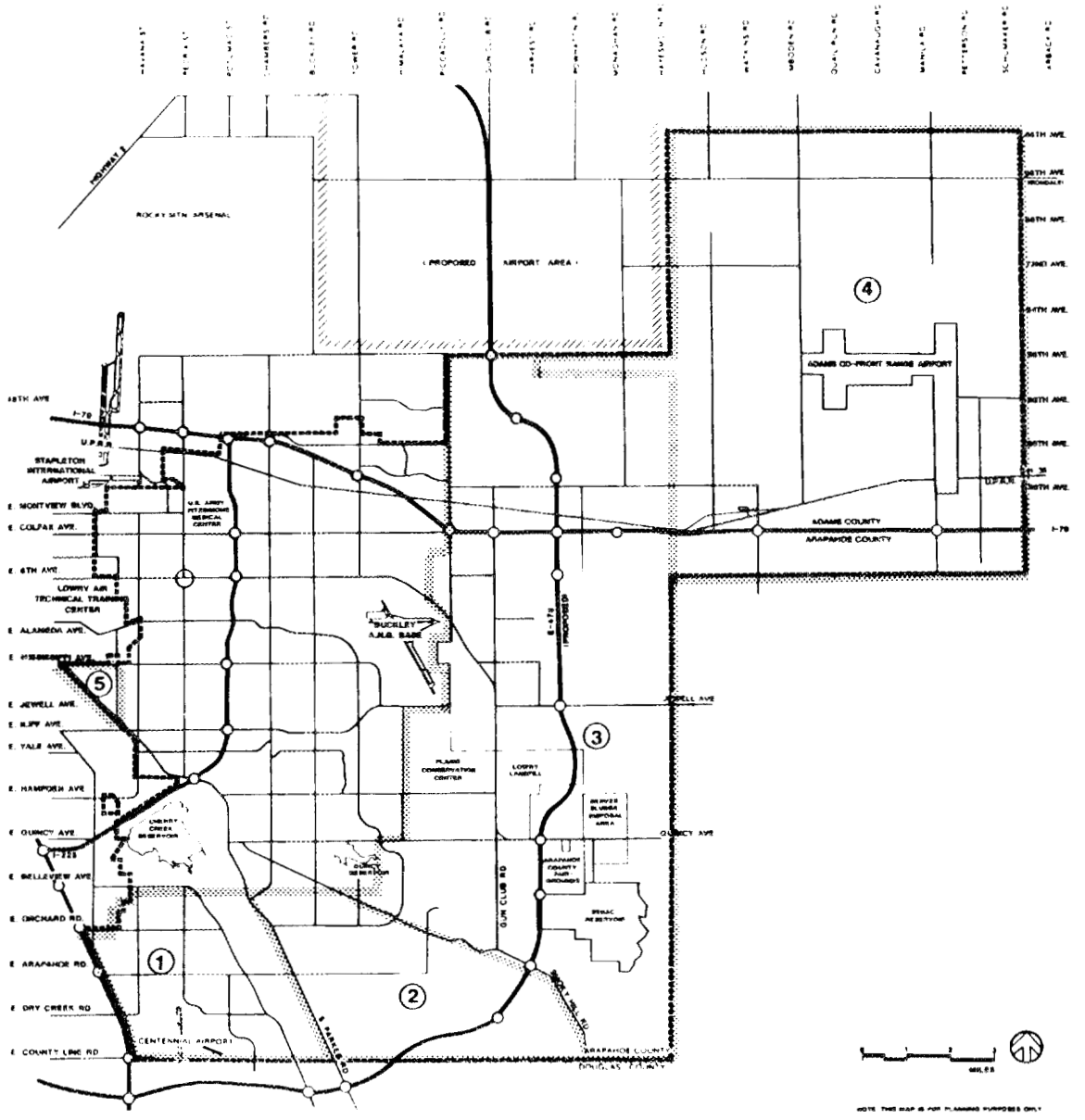
Figure 5.3 from the Draft 1986 Comprehensive Plan of the City of Aurora (Ref. 5.1) shows the long-range annexation boundaries for development past the year 2010. Annexation could include land approximately three miles west of the DADS site according to this development plant.

Of even greater significance to the development of energy markets near the DADS site is the possible location of a new north-south interstate connector called E-470, as shown on Fig. 5.3. This freeway would be expected to result in commercial and light industrial development to the east of the DADS site, as shown in Fig. 5.4. According to Ref. 5.1, such development would exclude residential and "people-intensive" land uses within a two-mile distance of the DADS site at least until that site is decontaminated (see Fig. 5.1).

5.3.2 Future Thermal Energy Markets

Commercial and industrial development along the proposed E-470 corridor would create demand for space heating, domestic hot water heating, and space cooling. All these energy demands could be served from a district heating system providing medium-pressure steam (100 psig), and all demands except space cooling could be provided by a system providing low-temperature hot water (max. 250°F). Steam extracted from a cogeneration turbine in the MSW power plant would be the source of thermal energy or these energy markets.

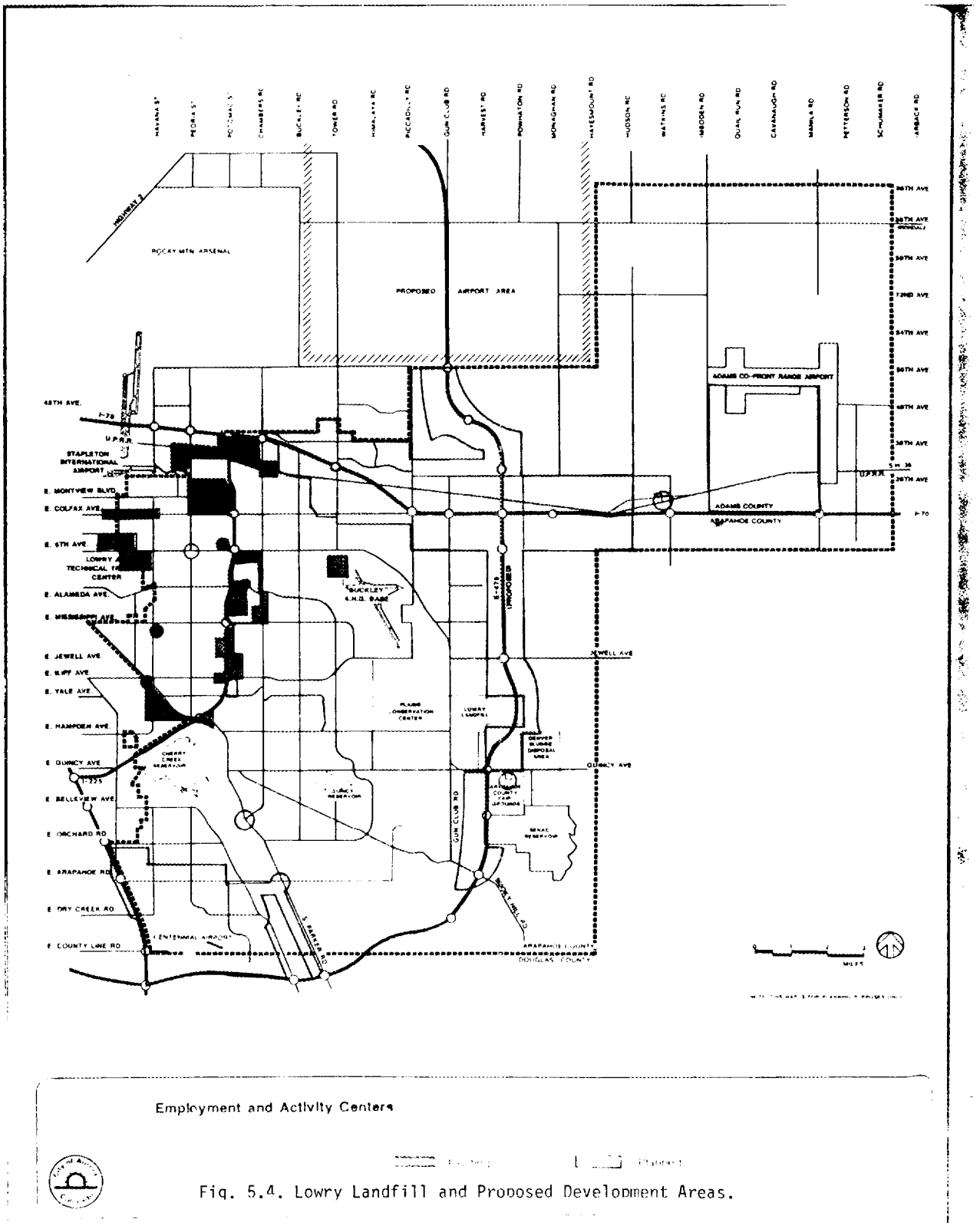
An estimation of future thermal energy markets for a potential MSW incinerator plant in the Denver area was performed by the Department of Public Works of the City of Denver (Ref. 5.2). This study used thermal energy consumption estimation procedures for the International District Heating Association as adapted to Denver climate conditions. Annual thermal energy consumption for new commercial and institutional buildings was estimated to be 80,000 Btu/ft^2 for space heating and domestic hot water. Industrial buildings would have thermal energy consumption at least as high and higher than commercial buildings.



Annexation Area

1. West of Parker Rd.
2. East of Parker Rd. to Smoky Hill Rd.
3. East Aurora
4. Front Range Airport Area
5. West of Dayton to Parker Rd. (Parker Triangle)

Fig. 5.3. Lowry Landfill and Proposed E-470 Freeway.



Employment and Activity Centers

Fig. 5.4. Lowry Landfill and Proposed Development Areas.

Thermal energy consumption could be increased if space cooling were provided by steam or hot water absorption chillers. However, most cooling is currently supplied by electric chillers. Therefore, the 80,000 Btu/ft^2/yr figure can be used for a first estimate of total building space served by a district heating system supplied by steam from an MSW incinerator plant.

5.3.3 Time-Phasing of Future Thermal Energy Market Development

Since the construction of the E-470 connector is at this time only a possibility, commercial/industrial development in the vicinity of the DADS site is highly conjectural. Even less predictable is the time-phasing of any such development if the E-470 connector were constructed. The most likely scenario leading to development along the E-470 connector would appear to be (1) adoption of a remedial action plan for decontamination of the DADS site, (2) begin DADS decontamination, and (3) planning, designing, and completion of the E-470 connector. Commercial/industrial development along E-470 would probably not occur until well after DADS site decontamination was in progress.

Another factor to be considered for planning to supply energy markets from an MSW incinerator plant at the DADS site is the possible development schedule for such an incinerator plant relative to decontamination of the DADS site. Since there is currently no plan to locate an MSW incinerator at the DADS site, this is also a hypothetical concept at this time. The primary site being considered for an MSW incinerator in the Denver area is the vicinity of the Stapleton International Airport (Ref. 5.2). Hence, interest in the Stapleton incinerator project could delay interest in another MSW incinerator project in the Denver area. However, for the purposes of this generic study, we have assumed that an MSW incinerator would have been constructed concurrently with any hazardous waste incinerator facilities at the DADS site in order to make integration of energy produced from the two incinerator facilities feasible.

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6. ENERGY RECOVERY FROM WASTE TIRES

6.1 INTRODUCTION

Waste tires represent a growing waste disposal problem in most areas of the U.S. for a variety of reasons. First, the increased use of steel-belted tires has reduced the tire retreading and, consequently, the life of a tire carcass. Secondly, the economics of recovering materials from used tires for recycling into new tires compared with using new materials - carbon black, steel - favors use of new materials over recycled materials. Thirdly, although waste tires have been used extensively in other countries as a supplemental fuel for cement kilns and industrial boilers, this application in the U.S. has been limited by low coal prices.

Therefore, waste tire piles have become common near many metropolitan areas, including Denver at the Lowry Landfill, where a large number of used tires, estimated at about 8 million, were accumulated during the 1970's. The goal of storing waste tires above ground rather than disposing them in the landfill, as is often done, was to ultimately process them for either material recycling or energy recovery. Unfortunately, a "tire pile" can present certain problems, including: (1) a breeding site for rodents, snakes, and mosquitoes - especially the tiger mosquito in hot climates, and (2) the possibility of fire started by lightning or vandals. Hence, methods for using waste tires, either for their fuel value or as a source of recycled materials, have been receiving increased attention by waste management officials.

This section presents a summary description of energy recovery systems that could be used to process the waste tires at the DADS site (Lowry Landfill). This information was developed in a recent study of disposal techniques for waste tires at the DADS site by the Department of Public Works of the City and County of Denver.[1] This study concluded that the tires stored at the DADS site would have to be moved to allow exhuming material in waste pits beneath the tire

piles; therefore, the waste tires should be shredded into a coarse size for interim storage in a more compact and safe configuration. Shredded tires would make a more flexible fuel form for use in either MSW or hazardous waste incinerators. However, the recommendation to shred the waste tires at the DADS site may not be followed. So, in the interest of this "generic" study, it will be assumed that the waste tires are stored away from contaminated waste pits as whole tires.

Energy recovery systems described below have been selected on the basis of integration with an MSW incinerator and a hazardous waste (HW) thermal treatment system(s) assumed to be located at the DADS site. The MSW incinerator system would include a steam turbine for power generation. Also, the HW treatment systems would include at least a rotary kiln unit and possibly a fixed hearth HW incinerator or a circulating bed incinerator based on analysis of thermal treatment requirements of the hazardous wastes at the DADS site.[2]

6.2 ENERGY RECOVERY SYSTEMS FOR WASTE TIRES

Energy recovery systems for waste tires can be classified as either "dedicated" or "supplemental" tire-fueled systems. Dedicated systems can use tires as the only type of fuel, whereas, supplemental systems can combine waste tires with MSW as fuel. A further classification of energy recovery systems exists - i.e., those that can use whole tires and others that require tires to be shredded into nominal 2-in. size pieces, or tire-derived fuel (TDF). This variation will be treated within the discussion of the dedicated and supplemental types of systems.

6.2.1 Dedicated Tire-Fueled Systems

This type of energy recovery system could be used to process the waste tires stored at the DADS site plus any waste tires brought to the DADS site for disposal.

6.2.1.1 Pyrolysis

Pyrolysis processes use temperatures in the 1,000-1,800°F range to thermally decompose shredded tires in the absence of oxygen. Primary products are a liquid fuel oil (~125 gal/ton of tires) and carbon black (~700 lb/ton of tires) with some additional combustible gas that is often consumed as fuel for the process. The ash residue contains 50 wt.% Zn oxide that has some market value.

Tire pyrolysis processes have been developed by several firms in the U.S. with seven pyrolysis processes on the market for waste tires and several other processes under development.[1] One of the larger development programs was conducted by the Tosco Corp. and the Goodyear Tire Corp. in the 1970's.[2] This program came to the conclusion that tire pyrolysis plants would have to be large (~9 million tires/year) to be profitable. Therefore, this process has not been widely applied, primarily because of economic conditions that have restrained revenues and the large amount of capital investment at risk.

In general, a tire pyrolysis plant could be considered as a candidate to process the waste tires at the DADS site plus the current stream of tires from the Denver area. However, this option was not recommended by the Denver study of the DADS waste tire pile because of the uncertain economics and high capital investment requirements.[1] In addition, the primary products from this process, fuel oil and carbon black, are not required by the MSW and HW incinerators assumed to be at the DADS site. Therefore, pyrolysis was removed from the processes considered for removing the waste tires at the DADS site.

6.2.1.2 Traveling Grate Incinerator

The traveling grate (TG) incinerator is one of the basic types of mass-burning incinerators described in Sect. 4.2. Whole tires have been burned in a few incinerators of this type as a normal constituant of MSW because the agitation of the traveling grate promotes relatively complete combustion. However, most TG incinerators have used tires that have been shredded, or TDF, as supplemental fuel with MSW (see Sect. 6.2.2.2).

A special, whole-tire-burning incinerator was developed by Gummi Mayer in Germany with operation of such an incinerator since 1971.[1] With this incinerator, whole tires are fed into a refractory-lined furnace where they travel through the primary combustion zone on a reciprocating grate. The hot combustion gases pass through a boiler section where steam is produced either for direct use or passed through a turbine to generate electricity. This incinerator therefore uses the refractory-lined, traveling-grate type boiler adapted for whole tires as the primary fuel.

Oxford Energy, Inc. has licensed this technology in the U.S. and has sold its first system in Modesto, CA. This $38 million plant has a capacity for 4.5 million tires/year and will produce 4.5 MW of electricity.[1] Oxford Energy has developed plant designs ranging from 14-28 MW of electricity output, and has proposed plants in Derry, NH and Sterling, CN.

6.2.1.3 Rotary Kiln System

The rotary kiln system is basically the same as is used for hazardous waste treatment described in Ref. 3. However, a special system for whole tire incineration is marketed by Combustion Technologies, Inc. (CTI). This system has a variable speed feeder that can charge whole or shredded tires plus MSW into the kiln. A CTI system, rated at 12,200 passenger tires/day - 4.4 million tires/year, max., could generate 63,000 lb/hr of steam or 5.5 MW of electricity from a condensing turbine generator.[1] The capital cost of a CTI rotary kiln tire incinerator capable of producing 50,000 lb/hr of steam was estimated to be approximately $8 million, not including a turbine generator.

6.2.2 Supplemental Fuel Systems

Waste tires can be a supplemental fuel for two types of incinerator systems of special interest to this study, the rotary kiln system and the traveling grate, mass-burn type incinerator. These systems could be included at the DADS site for treatment of hazardous wastes and MSW, respectively, and therefore may not require construction of a separate waste tire facility.

Another potential use of waste tires as a supplemental fuel is in cement kilns in the vicinity of a waste tire pile. This method for recovering the fuel value of waste tires has been used extensively in Japan and Germany, and thus is technically feasible. Most U.S. kilns would require shredded tires rather than whole tires, raising the cost of using waste tires above that of low-cost coal. Therefore, domestic economics has prevented any significant use of waste tires in the U.S. cement industry.[1] Hence, this option for energy recovery from waste tires was not considered in this study.

6.2.2.1 Rotary Kiln System

The rotary kiln incinerator also has the capability to use waste tires as a supplemental fuel when treating low Btu content hazardous wastes or MSW. This feature adds to the versatility of this system since the energy content of waste tires can directly offset the requirement for adding supplemental oil or natural gas fuels. Each passenger tire, with a conservatively estimated 200,000 Btu, could replace 200 cu. ft of natural gas or 1.4 gal. of distillate oil fuels.

Another feature of the rotary kiln system that could be attractive for processing the waste tires at the DADS site is the capability of processing whole or shredded tires that are contaminated by contact with contaminated soils. Thus, a rotary kiln unit assumed to be located at the DADS site for decontamination of soils could also be used to incinerate contaminated tires stored above ground plus waste tires exhumed from the contaminated waste pits.

6.2.2.2 Traveling Grate Incinerators

Several mass-burn, TG type incinerators, described in Sect. 6.2.1.2, have accepted waste tires as a normal component of MSW without shredding to improve combustion. However, most TG incinerators that dispose of waste tires accept shredded tires or TDF since tire combustion is much more uniform and complete in

this form, reducing particulate emissions and "hot spots" in the combustion zone. TG incinerators that use shredded tires with MSW are located in Dyersburg, TN, Tuscaloosa, and AL, Harrisburg, PA. In addition, several supplemental tire-fueled incinerators are being constructed in Maine. Therefore, ample demonstration exists for the use of shredded tires as supplemental fuel for TG incinerators.

6.3 DISCUSSION OF PREFERRED WASTE TIRE ENERGY RECOVERY SYSTEMS

As a result of this review of energy recovery options for waste tires stored at a landfill such as the DADS site, two energy recovery systems appear to have significant advantages for integration with other waste energy recovery systems being considered for the DADS site. These systems are the rotary kiln incinerator system and the TG, mass-burning incinerator. The primary advantage of these systems is that both would be present as constituants of the waste treatment systems if there were no stored waste tires as a part of the waste stream. Therefore, capital costs would be minimized by including the capability for processing waste tires in the same types of equipment that is used to process MSW and hazardous wastes. The size of the units selected may have to be increased to accommodate the increased mass flow from the waste tires.

An advantage of both of these systems is the flexibility to use either whole tires or shredded tires in the same basic type of combustion unit. It would, however, be important to identify whole tires as a significant type of waste to be processed by the TG incinerator and rotary kiln units so that specific units could be selected with this capability.

Finally, the capability to use whole tires in the two waste energy recovery systems proposed would reduce the importance of installing a tire shredder at a generic site as has been recommended for the waste tires at the DADS site. If it is determined that tire shredding is desirable because of reduced storage problems at the generic site, then the shredded tires are even easier to use as a high-Btu content fuel for a mass-burning, MSW incinerator or a rotary kiln unit(s).

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7. HEAT RECOVERY FROM HAZARDOUS WASTE INCINERATION PROCESSES

7.1 INTRODUCTION

This section presents an evaluation of potential processes for recovering heat from HW incineration for integration with MSW incineration processes at a common site to produce electricity and thermal energy. Information on HW incineration processes and heat recovery, plus other non-energy related integration possibilities, has been developed in a companion study by the Science Applications International Corporation (SAIC).[1]

The SAIC study developed several HW incineration process designs based on the characteristics of buried solid and liquid wastes and soil contamination as presently determined at the DADS site. Heat recovery from the high-temperature off-gases of these processes was analyzed for production of steam at conditions to match steam produced by MSW incineration boilers.

7.2 HAZARDOUS WASTE INCINERATION PROCESSES

7.2.1 Process Design Basis

There are three types of wastes at the DADS site that could be decontaminated by thermal treatment (or incineration) processes. These waste types are (1) contaminated MSW that would be exhumed from buried waste pits, (2) contaminated durable goods such as appliances and other bulky non-combustible items that would also be exhumed from the waste pits, and (3) contaminated soil from liquid wastes that drained or leached from the waste pits. Free-standing liquids containing organic contaminants in the waste pits are indicated to be highly aqueous and therefore more amenable to chemical decontamination than thermal treatment. Therefore, no liquid wastes are assumed to be treated by incineration in the process designs developed in this study.

SAIC estimated the following quantities of wastes for the design basis of incineration processes - 380,000 tons of MSW, 52,000 tons of durable goods, and 3,900,000 tons of soil. These quantities contain uncertainties because of the preliminary information on which they are based.[2] Subsequent site investigations should provide better estimates of both the quantities of wastes and levels of contamination, and may therefore significantly modify the quantities of wastes assumed for decontamination by incineration. The soil quantity may be the most suspect as it was based on a calculated leaching rate of contaminated liquids into soil beneath the waste pits.

The other variable necessary to size equipment modules was the assumed processing period for decontaminating the quantities of wastes listed above. Because of the potentially large quantities of wastes that may require decontamination, a processing period in the range of 10-15 years was indicated as possible in discussions with Region 8 EPA officials. A 12-year processing period was therefore selected on the basis of a total period of 15 years, including two years for construction and shakedown and one year for equipment removal and project closeout. A shorter processing period would result in higher processing rates and therefore higher capital costs for the processing system, and a longer processing period would reduce processing rates and capital costs.

Auxiliary fuel for afterburners and supplementary heating was assumed to be No. 2 fuel oil with a lower heating value of 18,000 Btu/lb and a cost of $0.141/lb ($1/gal.).

7.2.2 Summary of Hazardous Waste Incineration Systems

7.2.2.1 Candidate Hazardous Waste Incineration Systems

In its study of hazardous waste incineration technologies, SAIC evaluated four technologies in depth for consideration as candidate systems for treating the DADS hazardous wastes. These technologies were rotary kilns, circulating bed combustors or fluidized beds, multiple hearth incinerators, and electric infrared incinerators. The first three technologies were selected as candidates

for a preliminary process design on the basis of a wide range of criteria, including: completion of RCRA trial burns, state of development, feed capability, versatility of treating waste types, and auxiliary fuel cost. These same technologies - rotary kilns, multiple hearth incinerators, and circulating bed combustors - were listed in Ref. 3 as currently developed thermal treatment technologies as opposed to "emerging" technologies that are still in various stages of development.

7.2.2.2 Rotary Kiln Incineration

Rotary kiln incineration is a preferred method for treating mixed hazardous solid residues because of its ability to handle waste in any physical form and because of its high incineration efficiency. Rotary kilns can incinerate solids, liquids, or gases independently or in combination, and they can accept waste feed without any preparation. Because of their versatility, rotary kilns are used by most commercial incinerator operations, despite very high capital costs and operating costs from less-than-optimum energy efficiency.

Rotary kilns allow for complete manipulation of the essential requirements for combustion: retention time, turbulence, air supply, and temperature. Although liquid wastes are frequently incinerated in rotary kilns, and kiln operating conditions allow for treatment of hazardous gaseous wastes, the kilns are designed primarily for the combustion of solid wastes. They are exceedingly versatile in that they can handle slurries, sludges, bulk solids of varying size, and containerized wastes. The only wastes that create problems in rotary kilns are aqueous organic sludges that become sticky on drying and form a ring around the kiln's periphery, and solids that tend to roll down the kiln (e.g., drums) and are not retained as long as bulk solids. To reduce this problem, drums and other cylindrical containers usually are not introduced to the kiln when it is empty. Other solids in the kiln help to impede the rolling action. The numerous hazardous wastes that have been treated in rotary kilns include PCBs, tars, obsolete munitions, polyvinyl chloride wastes, and bottoms from solvent reclamation operations.

Rotary kiln incinerators have at least two combustion chambers - the rotating kiln and an afterburner. The rotary kiln is a slowly rotating, cylindrical, horizontal, refractory-lined shell mounted at a slight incline. The incline facilitates ash and slag removal. The kiln rotates from less than one to seven times per minute. Rotary kilns can be fueled by natural gas, oil, or pulverized coal. Fuels can be fed into the kiln, the afterburner section, or both. The afterburner section can handle only gaseous or low-viscosity liquid fuels. Most of the heating of the waste results from heat transfer between the combustion product gases and the walls of the kiln.

Solid and semisolid wastes are ignited on traveling grates before they reach the kiln. The rotation of the kiln mixes the waste with combustion air as the waste passes through. Liquid residues are burned in suspension. Following the kiln, the gas stream enters the afterburner section, where product gases and combustible carry-over particulates undergo complete combustion.

A typical rotary kiln incinerator is shown in Fig. 7.1. Solid waste is charged at the higher end and travels the length of the kiln because of its evolving and tumbling motion. Liquid and gaseous wastes can also be added through auxiliary nozzles. Unlike the liquid injection incinerator, the rotary kiln burning liquid wastes in conjunction with solids may be fired at either the feed or discharge end of the unit. Both concurrent and countercurrent firing designs are widely used. The discharge end of the rotary kiln is hooded so that collected combustion gases are exhausted to a secondary combustion chamber (afterburner), a quench chamber, and the air pollution control equipment.

Waste undergoes combustion as it passes through the kiln, and the noncombustible waste drops out the lower end. The tumbling action of the rotary kiln results in continuous removal of ash and continuous exposure of new surfaces for oxidation. The rotation also creates turbulence and improves combustion.

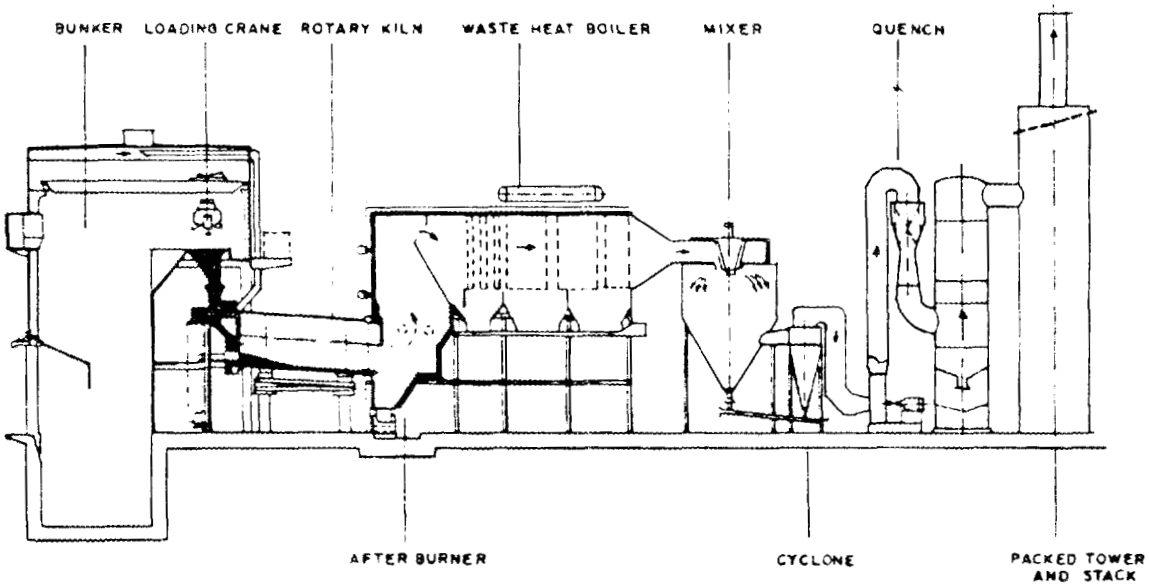

Fig. 7.1. Example of modern hazardous waste rotary kiln incinerator with waste heat recovery and high-efficiency wet/dry flue-gas scrubber (Biebesheim, West Germany). (Reproduced courtesy of Von Roll A.G.) Source: Proctor and Redfern, Ltd., Weston Designers-Consultants, and Ontario Research Foundation, Generic Process Technologies Studies, System Development Project, Ontario Waste Management Corporation, August 1982.

Rotary kilns can provide the retention times and temperatures necessary to combust any organic hazardous waste. Retention times can range from a few seconds to an hour or more for bulk solids and can be controlled by varying the rotational speed of the kiln. Retention time of the gas stream, which includes any liquid or gaseous wastes and the oxygen supply, is varied as required by the air supply controls. Combustion temperatures range from 1,500 to 3,000°F. A relatively constant temperature can be maintained by varying the feed rate of waste and by directly controlling the auxiliary burners. Mixing of the combustion gases is achieved through the tumbling action of the kiln and the turbulence caused by directional changes as the gas stream travels from the kiln to the secondary combustion chamber. Since the requirements of combustion (retention time, turbulence, air supply, and temperature) are all controllable, they can be manipulated as required for complete combustion.

To ensure complete waste combustion, rotary kiln incinerator designs always include an afterburner. The primary function of the kiln section is conversion of solid wastes to gases, which occurs through a series of volatization, destructive distillation, and partial combustion reactions. However, an afterburner is almost always required to complete the gas-phase combustion reactions. The afterburner is connected directly to the discharge end of the kiln, where the gases exiting the kiln turn from a horizontal flow path to a vertical flow path upward to the afterburner chamber. The afterburner itself may be horizontally or vertically aligned.

The primary chamber of rotary kiln incinerators may be operated in either a starved air mode or an excess air mode. Smaller kilns are generally operated in a starved air mode, and larger units are always operated using excess air. Because rotary kiln incinerators are always equipped with an oxidizing secondary combustion chamber, there is always overall excess air usage. Rotary kilns operate at a slight vacuum maintained by an induced draft blower in the combustion chambers. As a result, air may enter through charging doors, seals, and ports, as well as combustion air forced-draft blowers. Allowances for air entering through leaks are incorporated in kiln designs.

Waste loading systems for rotary kilns are often the most complex of all hazardous waste incinerator types. Solid, liquid, and containerized wastes are often fed to a rotary kiln simultaneously, and liquid wastes may be injected at several locations.

Solid wastes are loaded into the kiln at the high end and are passed through the combustion zone as the kiln rotates. Whole drums of solid waste, tires, and/or sludge can be pack-fed into the upper end of the kiln. Containers as large as 55 gallon drums may be fed through loaders equipped with air locks and hydraulic drum dumpers.

7.2.2.3 Circulating Bed Combustors

The circulating bed combustor is a special kind of fluidized bed incinerator that operates at higher turbulence and combustion particle burnup rates. Figure 7.2 shows the basic components of a circulating bed combustor. Combustible waste and limestone are fed into the combustion loop along with recirculated bed material from the hot cyclone. Both the bed material and the waste travel at high velocity through the combustion chamber reaction zone to the hot cyclone. Solids are separated from the hot combustion gas and injected into the combustion chamber. Hot flue gas passes through a convective gas cooler and a baghouse filter before it is exhausted to the atmosphere. The high gas velocity and circulating solids create a highly turbulent combustion zone and result in a uniform temperature (within 50°F) around the entire combustion loop.

The circulating bed combustor does not require an afterburner or a wet scrubber. The recirculating solids volatilize the injected waste, and the fine circulating limestone absorbs most of the acid gases to form the respective calcium salts. The emissions of carbon monoxide and nitrogen oxides are kept low by effective mixing, staged combustion, and relatively low combustion temperatures (1,450 to 1,800°F). Even with these low combustion temperatures,

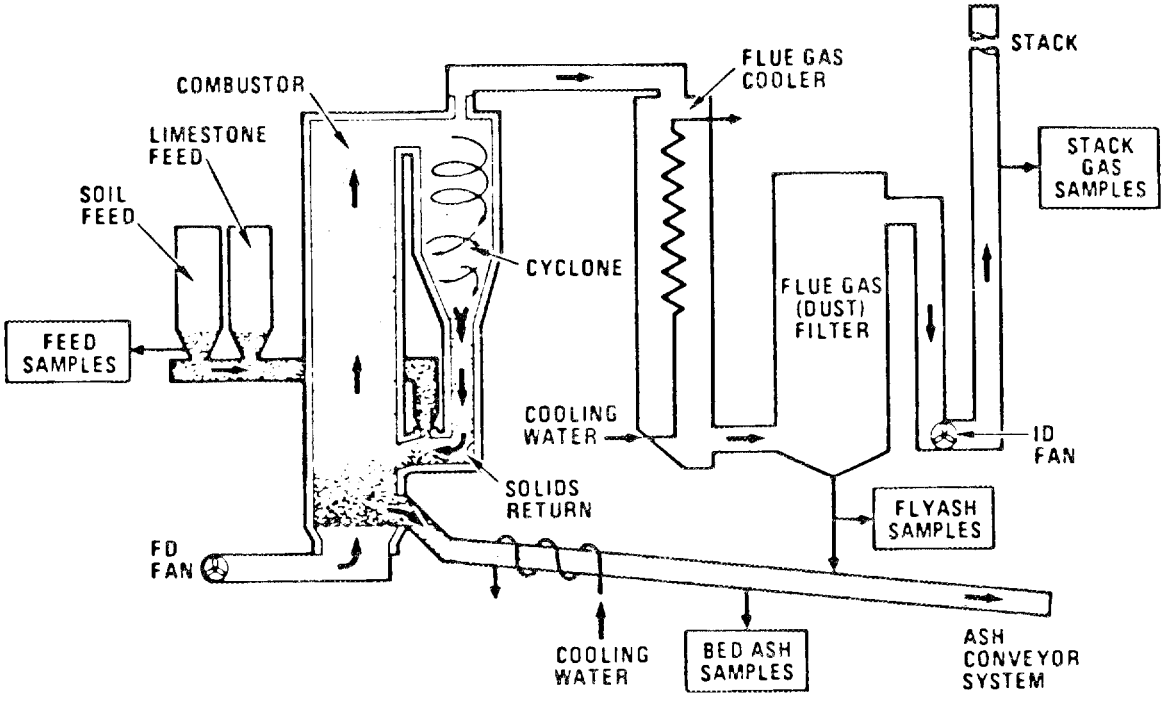

Fig. 7.2. Diagram of circulating bed combustor for soil treatment.

Source: Jenson and Young, 1986.[4]

one manufacturer reports test burn results of better than 99.99% destruction and removal efficiency for chlorinated hydrocarbons and better than 99.9999% destruction and removal efficiency for PCBs.[5]

The circulating bed combustor can accept solids, liquids, sludges, and slurries directly into the combustor loop; multiple feed ports or atomizers are not needed. The inherently high levels of turbulence and mixing ensure good distribution. Energy is recovered in both the combustor zone and the flue gas cooler. The heat exchange surface in the combustor removes the thermal energy released during the combustion reactions. Heat transfer in the combustor is enhanced by convection and solid particle conduction. Conventional heat exchangers located between the cyclone and the baghouse filter remove sensible heat from the flue gas. The flue gas coolers are not subjected to the high acid gas concentrations prevalent in some waste incinerators because acid gas scrubbing takes place within the combustion chamber. The limestone in the combustor is effective in removing the acid gases. Approximately 80% of the required heat is recovered in recuperation or in energy conversion. This high efficiency results from a high combustion efficiency, operation at low excess air, and low heat loss from the unit.

7.2.2.4 Multiple Hearth Incinerators

Hearth incinerators generally consist of two interconnected refractory-lined chambers, a primary or ignition chamber, and a secondary or afterburner chamber. The primary chamber is divided into a combustion section and an ashpit. The ashpit is positioned by the hearth or grate on which the refuse is burned. The gaseous and particulate products of complete or partial combustion are entrained in the flue gas and flow to the secondary chamber where combustion is completed. Liquid wastes can be injected into either the primary or the secondary chamber.

Hearth units equipped with a grate introduce combustion air both above (overfire air) and below (underfire air) the grate. Units without grates generally use a hydraulic ram to push the solid waste along the floor of the hearth in order to ensure complete burning.

The combustion process in a hearth incinerator proceeds in two stages: primary or liquid/solid fuel combustion occurs in the primary chamber, followed by secondary or gaseous-phase combustion in the secondary combustion chamber. Ignition and combustion of the liquid or solid wastes occur in the primary chamber under started-air conditions. Excess air rates range from 30 to 200% in the primary chamber at temperatures of 1,200 to 1,800°F. Excess air rates of 50 to 80% are most typical (Oppelt 1987).

As burning proceeds, the moisture and volatile components of the fuel are vaporized and partially oxidized in passing from the primary chamber to the secondary chamber, where additional air is introduced along with auxiliary fuel. Typical excess air rates in the secondary chamber range from 200 to 400% at temperatures of 1,400 to 2,200°F. The residence time that is critical to hazardous waste destruction is based entirely on the period of time the flue gases spend in the secondary chamber. Typical residence times are 1.5 to 2.5 seconds. The combustion at adequate temperature and additional air, augmented by secondary burners as necessary, assists in initiating the second stage of the combustion process. Turbulent mixing, resulting from the restricted flow areas and abrupt changes in flow direction, furthers the gaseous-phase reaction and final oxidation of combustible components.

The flue gas then leaves the secondary chamber and flows to the quench chamber and to air pollution control equipment. An example of a hearth incinerator unit is shown in Fig. 7.3.

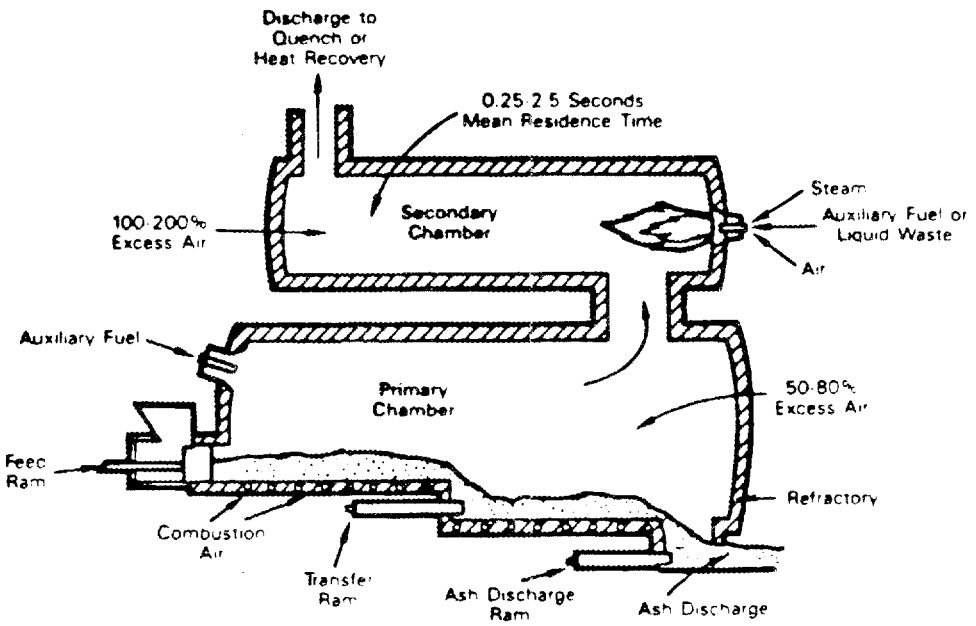

Fig. 7.3. Diagram of a hearth incinerator.

Source: Gardner, et al., 1979.[6]

7.2.3 Incineration Facility Conceptual Design

The three types of hazardous wastes to be treated were assigned to the candidate technologies on the basis of their processing characteristics as follows: rotary kiln for MSW, soil, and durable goods; circulating bed combustors for soil; and multiple hearth incinerators for durable goods. These assignments were used to develop the incineration facility conceptual designs described below. It should be noted that the use of circulating bed combustors to decontaminate soils depends on the specific types of contaminants present since the decontamination factor achievable with the circulating bed combustor may not meet RCRA standards for some chlorinated hydrocarbons.

The conceptual layout of an incineration facility is shown in Fig. 7.4. Exhumed MSW and contaminated soil would be brought by truck to an unloading area where it would be transferred to a sorting area by conveyors and front-end loaders. The durable goods portion would be separated from the MSW at the sorting area where liquid runoff would also be collected for transfer to the storage area. The three waste fractions - MSW, soil, and durable goods - would be transferred to the incineration area by truck or conveyors, as appropriate.

Three conceptual designs for incineration of hazardous wastes were developed for preliminary evaluation of heat recovery potential from treatment of the DADS hazardous wastes. These system options, summarized in Table 7.1, combine the treatment capabilities of the three incineration technologies with processing rates in TPD for the three types of solid wastes to be treated. The processing rates are average daily rates for 365 days/year over a 12-year period.

The first incineration system option employs rotary kilns for all waste types - four units to process 890 TPD of soil, one unit to process 86 TPD of MSW, and one unit to process 11.9 TPD of durable goods. The second system option uses two circulating bed units in place of the rotary kilns to process

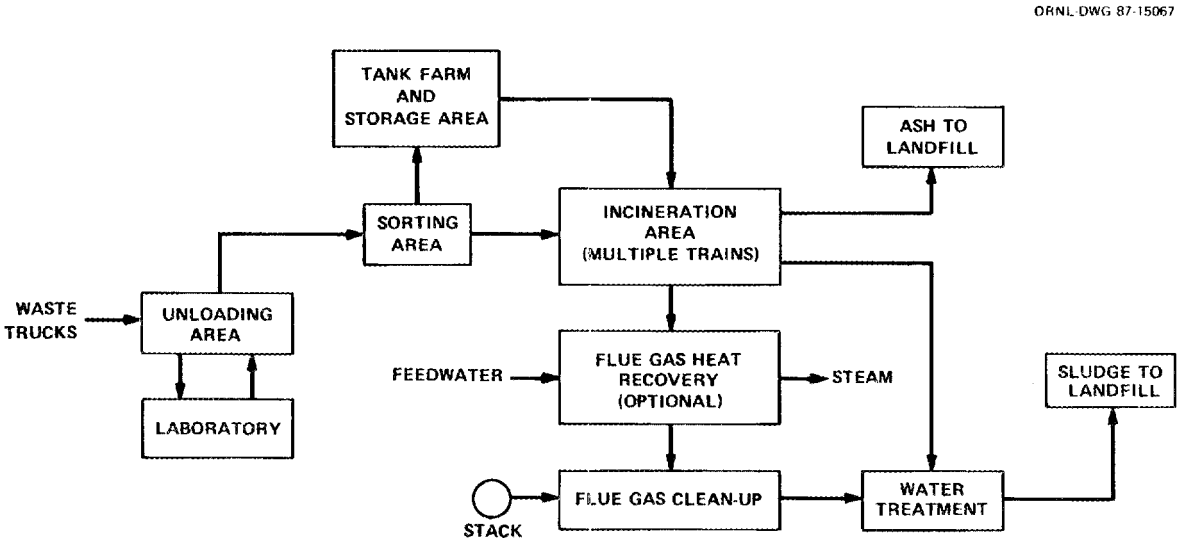

Fig. 7.4. Conceptual layout of hazardous waste incineration facility.

Table 7.1. Summary of hazardous waste incineration system options.

Waste Type	Soil	MSW	Durable Goods
System Option 1			
Technology	Rotary Kiln	Rotary Kiln	Rotary Kiln
No. of active units	4	1	1
No. of spare units	0	1	0
Unit processing rate - TPD	222.5	86	11.9
System Option 2			
Technology	Circulating Bed	Rotary Kiln	Rotary Kiln
No. of active units	2	1	1
No. of spare units	0	1	0
Unit processing rate - TPD	445	86	11.9
System Option 3			
Technology	Rotary Kiln	Rotary Kiln	Multiple Hearth
No. of active units	4	1	1
No. of spare units	0	1	0
Unit processing rate - TPD	222.5	86	11.9

the 890 TPD of soil, and the third system option is the same as the first option except for using a multiple hearth incinerator unit in place of a rotary kiln for durable goods treatment.

After incineration, the flue gas flows through a heat-recovery heat exchanger and/or a quench tank to reduce the gas temperature. Additional treatment steps include a Venturi scrubber, a caustic absorption unit, a mist eliminator, and a fabric filter baghouse before venting through a stack. Ash from the incinerator units and sludge from the water treatment system would be sampled and disposed of in a landfill in an appropriate manner. (More detailed descriptions of these processes are provided in Ref. 1.)

7.3 HEAT RECOVERY FROM HAZARDOUS WASTE SYSTEMS

7.3.1 Heat Recovery Conditions

Flue gas temperatures are nominally 1,800°F from hazardous waste rotary kilns and 1,500°F from circulating bed combustors. Such high temperatures allow the possibility of producing high-quality energy in the form of superheated steam for power production rather than preheating of combustion air and solids. Therefore, steam conditions from a flue-gas heat recovery boiler were chosen to match the highest superheat temperatures used in current mass-burning MSW incinerator power plants. These conditions were 830°F, 865 psig steam - see Table 4.4 - with an enthalpy of 1,413 Btu/lb.

A cogeneration steam turbine using these steam conditions in an MSW incinerator power plant was also selected for preliminary power system integration evaluations. Table 7.2 lists the primary characteristics of this turbine and its associated MSW boilers.

Table 7.2. MSW incinerator power system characteristics.

Turbine/Generator	
Maximum steam flow, lb/h	152,800
Throttle steam temperature, °F	830
Throttle steam pressure, psig	865
Net generator output - full condensing, MW	14.4
Net generator output - cogeneration, MW	2.7
Extraction steam flow, lb/h	116,000
Boiler	
No. of units	2
Total MSW throughput	
@ 4800 Btu/lb, tons/day	625
@ 4500 Btu/lb, tons/day	666
Gross heat release, million Btu/h	250
Overall boiler efficiency, %	70

Source: Ogden Martin Systems, Inc.

7.3.2 Potential Heat Recovery and Costs

Heat recovery from off-gas flows was estimated for the three hazardous waste systems described in Sect. 7.2.2 used to process the MSW and the contaminated soil: (1) the 86 TPD MSW rotary kiln used in all three system options, (2) the 890 TPD soil rotary kilns used in the first and third system options, and (3) the 890 TPD soil circulating beds used in the second system option. These systems are shown schematically in Fig. 7.5. The durable waste incinerator was not included in the heat recovery analysis because of the relatively small size of this incinerator unit.

Preliminary calculations were performed to indicate the magnitude of heat that could be recovered for several energy uses such as pre-heating combustion air, producing turbine quality superheated steam, and adding to steam superheat. These calculations indicated that only the second option, production of turbine quality steam, would provide a useful flow of energy to match process flow requirements.

Analysis of steam production was based on a three-stage heat exchange process from the high-temperature incinerator off-gas to feedwater and steam, as shown in Fig. 7.6. A suitable acid-gas corrosion resistant material such as Hastelloy C was assumed as the heat exchanger material. Heat transfer areas for the three heat exchange stages were calculated for the off-gas flows of each of the incineration systems, and the corresponding capital costs in 1987 dollars were estimated based on standard cost estimating procedures. The results of these calculations are presented in Table 7.3. The total capital costs for the heat recovery systems range from approximately one-half to two million dollars for the three hazardous waste incinerator systems considered.

The total off-gas flow rates and steam production rates of 830°F/835 psig steam calculated for the three incinerator systems is shown in Table 7.4. The total steam production cost in $/lb is also shown with its primary components,

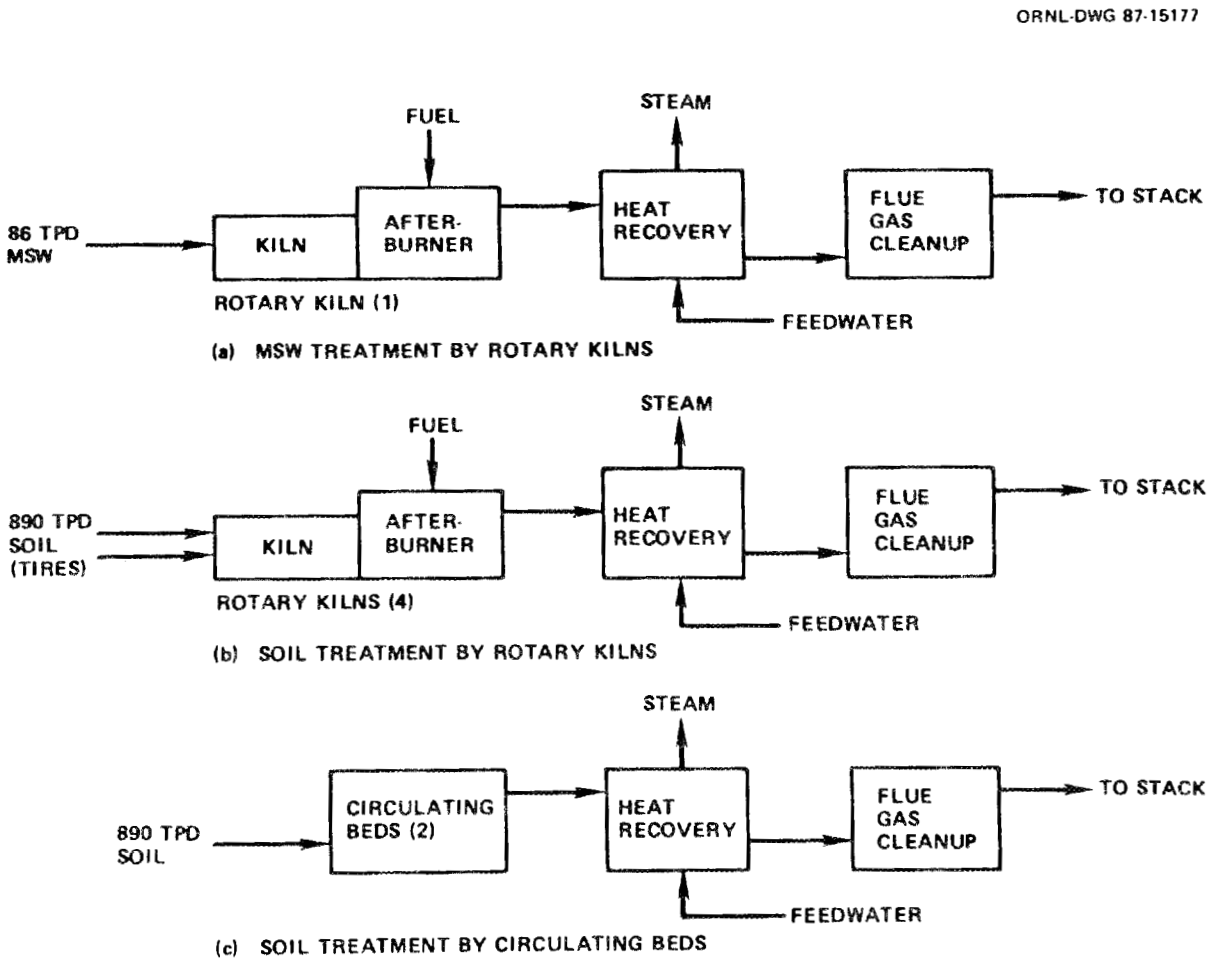

Fig. 7.5. Schematics of hazardous waste heat recovery systems.

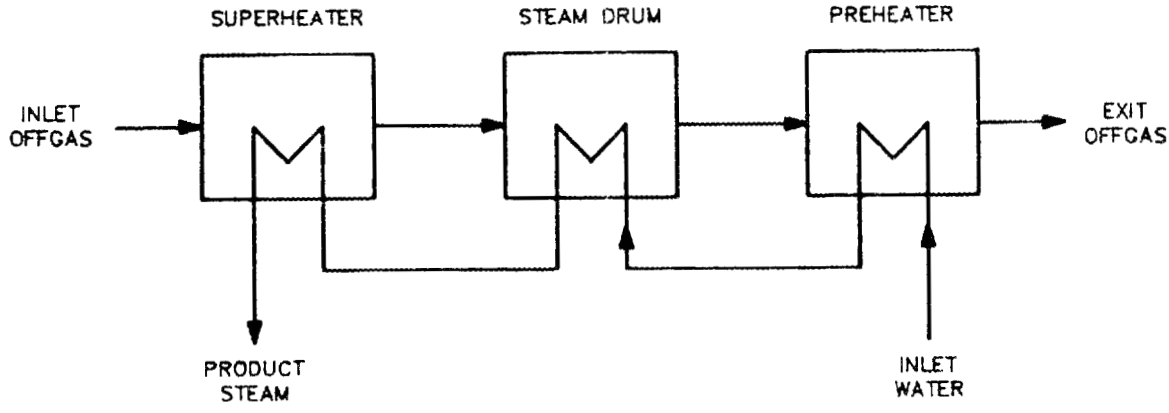

Fig. 7.6. Steam generation from off-gas heat recovery.

Table 7.3. Capital cost estimates for heat recovery systems.

	Steam Superheater		Steam Generator		Water Preheater		Total
	Area (sq ft)	Capital ($)	Area (sq ft)	Capital ($)	Area (sq ft)	Capital ($)	Capital ($)
MSW Kiln	618	98,000	3,722	56,250	4,619	392,900	547,150
Soil Kiln	1,622	181,300	9,769	846,250	12,122	1,042,700	2,070,250
Soil Circulating Bed	315	60,450	1,903	226,670	2,102	241,800	528,920

Table 7.4. Heat recovery system flow rates and steam costs.

	Off-Gas Flow (lb/h)	Steam Flow (lb/h)	Steam Cost ($/10^3 lb)		
			Total	Fuel	Heat Recovery
MSW Kiln	176,426	57,519	7.60	6.90	0.70
Soil Kilns (4)	461,358	150,956	13.60	13.0	0.6
Soil CBCs (2)	75,233	21,227	13.30	12.20	1.10

the fuel cost and heat recovery cost components. The heat recovery cost was based on the total installed cost of the heat exchange equipment levelized over 12 years with a 7% discount rate.

The total steam cost is predominantly the fuel cost which would be experienced whether or not heat was being recovered. Therefore, the "heat recovery" cost is a truer indicator of the economic value of producing turbine-quality steam from hazardous waste incinerator systems. The "heat recovery" steam costs of approximately $0.6-1/thousand lbs appears to be attractive for such high-quality energy.

The next section will evaluate power production options for utilizing steam produced by heat recovered from such incinerator systems.

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8. INTEGRATION OF CONVENTIONAL AND HAZARDOUS WASTE INCINERATION SYSTEMS FOR POWER GENERATION

8.1 INTRODUCTION

This section describes the conceptual integration of steam production from incineration of conventional and hazardous wastes for power generation. Two integration options are presented based on the estimated steam production from hazardous waste incineration systems developed in Sect. 7. Operational features that could benefit from integration of the two incineration processes are also discussed. Finally, several issues are discussed that are important to the integration concept.

8.2 INTEGRATION OPTIONS FOR POWER GENERATION

There are potentially a large number of combinations of conventional MSW boilers and steam turbines that could be integrated with a steam-producing hazardous waste facility. However, only one conventional MSW incinerator power plant was used for this preliminary evaluation of the concept because of limited information available on detailed plant designs.

The two hazardous waste system options considered are examples of a large number of equipment sizes and treatment process combinations that could be selected for the hazardous wastes assumed for thermal treatment at the DADS site. The two options differ only in the treatment process used for decontaminating the soil fraction. The first option uses rotary kilns to decontaminate the soil; rotary kilns have relatively high processing costs, but have a good destruction efficiency rating for difficult organic wastes such as PCBs. The second option uses circulating bed combustors to decontaminate the soil because they have relatively low processing costs but also have a lower destruction efficiency rating for some chloronated organic wastes. Therefore, these two options are intended to serve only as examples of integration options rather than "optimal" system configurations.

8.2.1 Conventional MSW Incinerator Power Plant

The conventional MSW incinerator power plant selected for integration with a hazardous waste incineration facility is shown schematically in Fig. 8.1. Mass-burning boilers of the traveling-grate type and each firing 333 TPD of 4,500 Btu/lb MSW produce 76,400 lb/h of steam at 830°F/865 psig. (A more detailed system schematic is shown in Fig. 4.1.) The two boilers feed up to 152,800 lb/h of steam (250,000 Btu/h) to an 18.2 MW rated extraction/condensing turbine with a net generator output of 14.4 MW in the full condensing mode and 2.7 MW in the maximum extraction mode for cogenerated steam. Additional turbine and boiler data are shown in Table 7.2.

This MSW incineration plant with mass-burning, traveling-grate type boilers was chosen because the steam flow from each boiler, 76,400 lb/h, was of a magnitude that allowed several reasonable combinations with the steam flows from the hazardous waste heat recovery boilers being considered. Also, the mass-burning type boiler predominates over the refuse-derived fuel type of MSW boiler in the 300-400 TPD size range used in this study.

From data in Sect. 4.2, the design and construction cost of such an MSW incinerator power plant is approximately $60 million.

8.2.2 Integrated Power Generation with All-Rotary Kiln Hazardous Waste Incinerator System

This integrated power generation option is based on the hazardous waste incineration option No. 1 described in Sect. 7.2.3 (see Table 7.1) and shown schematically in Fig. 8.2. Contaminated MSW is incinerated in an 86-TPD rotary kiln that produces 57,500 lb/h of turbine quality steam. Contaminated soil is processed at a rate of 890 TPD in four rotary kilns that produce 151,000 lb/h of turbine quality steam. These steam flows are combined with 76,400 lb/h of steam from one 333 TPD conventional MSW boiler, shown in Fig. 8.1, to produce a total

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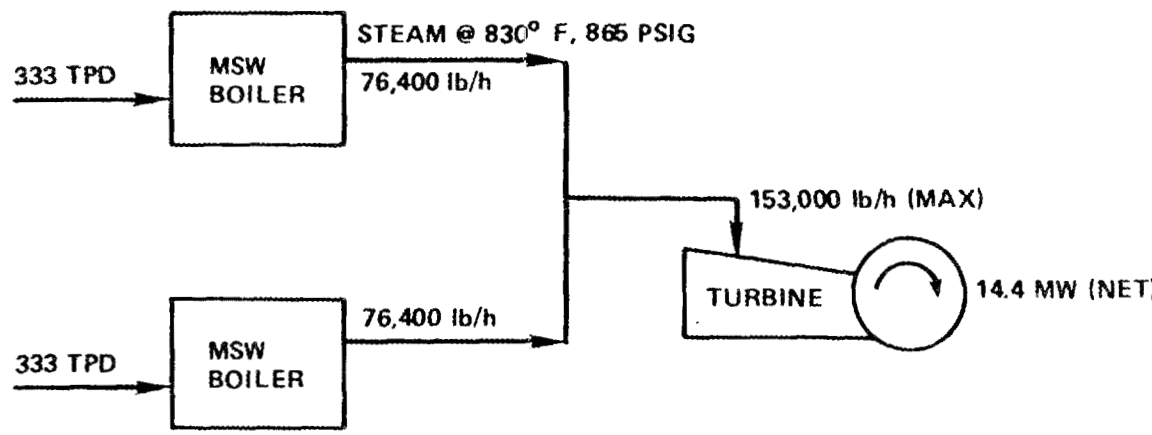

Fig. 8.1. Conventional municipal solid waste power generation system.

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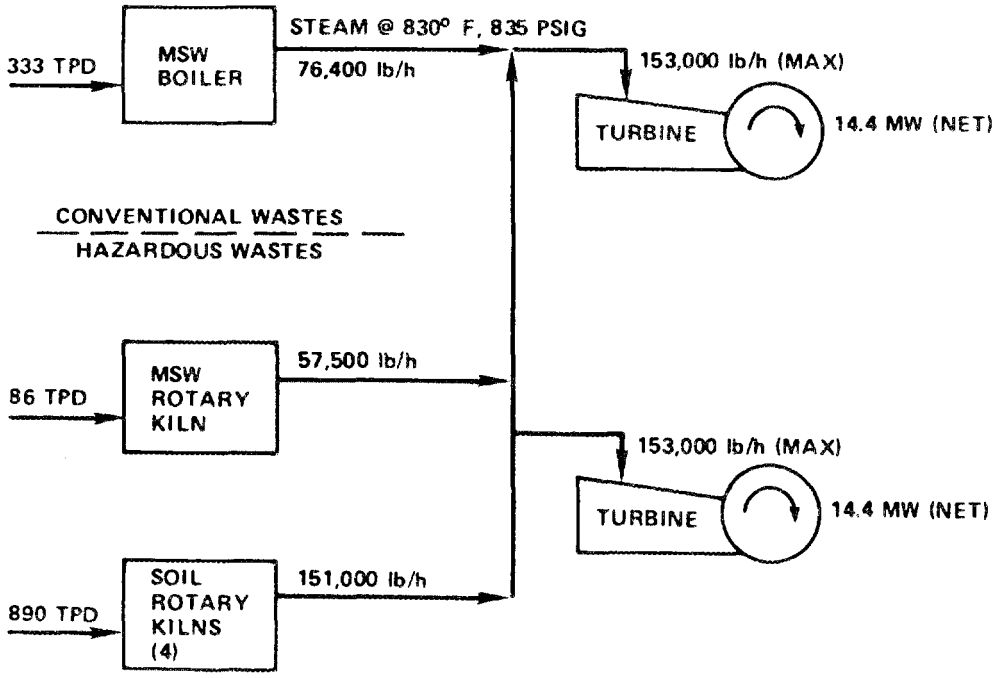

Fig. 8.2. Combined conventional and hazardous waste power generation system - option 1.

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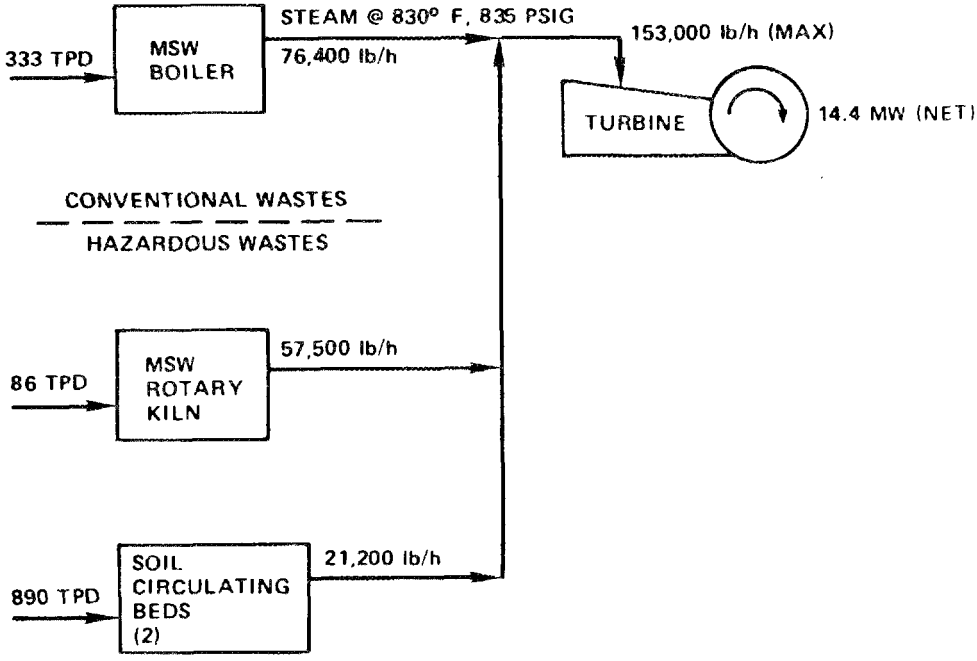

Fig. 8.3. Combined conventional and hazardous waste power generation system - option 2.

steam flow capacity of 284,900 lb/h from the conventional and hazardous waste incinerators. (A single rotary kiln treating 11.9 TPD of durable waste is not shown since heat recovery from this small unit is not included.)

In order to utilize the combined steam flow of 284,900 lb/h, a second turbine/generator of the same size as used in the conventional incinerator power plant is added to give this conceptualized power generation system a maximum turbine throttle steam flow of 306,000 lb/h. The maximum exportable power from the two turbine/generators would be 26.8 MW with equal steam flows of 142,450 lb/h to each turbine.

Adding a second turbine contributes operating flexibility and efficiency to the power generation system by allowing each turbine to be operated at a greater fraction of its rated capacity. A single turbine with a throttle steam flow capacity of 306,000 lb/h would have a lower capital cost than the two 153,000 lb/h turbines, so a design study for such a system might select a single, larger turbine as the most economical choice. For this conceptual study, it was desirable to utilize the same equipment sizes as used in the conventional MSW incinerator plant for comparison purposes.

In summary, this option for an integrated conventional and hazardous waste power generation system modifies the conventional MSW system described in Sect. 8.2.1 in the following ways: (1) adds five hazardous waste rotary kilns as turbine-quality steam sources and deletes one of two conventional MSW boilers, and (2) adds a second turbine/generator unit to accept the increased steam-generating capacity, primarily of the soil rotary kilns.

8.2.3 Integrated Power Generation with an MSW Rotary Kiln and Soil Circulating Beds Hazardous Waste Incinerators

Another option for power generation from incineration of conventional and hazardous wastes is based on the hazardous waste option No. 2 described in Sect. 7.2.3 (see Table 7.1) and shown schematically in Fig. 8.3. In this

system, contaminated soil is treated in two circulating bed combustors (CBCs) capable of producing 21,200 lb/h of turbine quality steam with heat recovery boilers. Contaminated MSW is treated in a single rotary kiln with heat recovery producing 57,500 lb/h of turbine quality steam, identical to the system in option No. 1 described above.

The steam flows from the hazardous waste heat recovery boilers are combined with steam produced by one conventional MSW boiler to feed up to 155,100 lb/h of 830°F/835 psig steam to a single turbine/generator, assumed to be the same size as in the conventional MSW incinerator power plant in Fig. 8.1. (Although the total steam flow from the combined steam generators is slightly higher than the 153,000 lb/h maximum capacity of the turbine/generator, it is considered to be a reasonable match for this preliminary conceptual evaluation.) This integrated power generation system option therefore consists of a replacement of one conventional MSW boiler with the combined heat recovery boilers of the hazardous waste treatment system.

8.3 INTEGRATING OPERATIONS AND SUPPORT SERVICES

Colocating a conventional MSW incinerator facility with a hazardous waste incineration facility at a common site creates the possibility of integrating certain operational features and also sharing support services between the two facilities.

8.3.1 Integrated Operations

The conceptual integrated power generation systems described in Sect. 8.2 indicated the desirability of a common feedwater/deaerator system and steam system to circulate feedwater to the boilers and then transport steam to the turbine(s). Thus, colocating the two waste incinerator systems could eliminate the need for separate feedwater/deaerator systems for the conventional and hazardous waste treatment systems. In addition to reducing capital costs, a common feedwater/deaerator system would reduce maintenance personnel requirements and costs.

Wastewater treatment may be a common requirement of both incinerator systems. The potential for combining wastewater treatment in one system would primarily depend on the characteristics of wastewater from the MSW incinerator facility. If treatment were required for the MSW wastewater, then a combined treatment system would be possible. Savings of one operating staff person could result from combined wastewater treatment for both waste incineration facilities.[1]

Handling and codisposal of solid residuals such as fly ash, bottom ash, and scrubber sludge from both types of waste treatment systems were evaluated by SAIC. Fly ash is currently defined as non-hazardous by the EPA. However, it was considered to be the residual most likely to be listed as hazardous because of heavy metals content. This waste stream could therefore be considered for a single codisposal operation. Bottom ash, including incinerated soil and scrubber sludge, should be delisted as nonhazardous unless heavy metals content is unacceptably high. Therefore, these waste streams could also be combined in a codisposal operation.

The potential for significant savings on equipment costs for handling of solid residuals may be minimal because additional waste handling equipment may be required to combine the waste streams from the two treatment systems.[1] However, there are potential operating cost savings from colocating the two waste treatment facilities if a single operating organizations were performing solid residual disposal. Operating costs would be reduced from having a single management structure and by making more efficient use of operating personnel in performing similar operations.

A final system considered for integration was the air emission controls for the stack handling flue gases from the two incineration facilities. However, it was concluded that flue gases from the two incineration facilities should be released separately because RCRA regulations of emissions from hazardous waste incinerators require automatic feed cutoff from stack emission monitors.[1]

8.3.2 Common Support Services

A single site with both conventional and hazardous waste incineration treatment could conceivably share many common support services required by both types of facilities. The most important condition affecting the possible sharing of support services is the type of operational administration selected for the colocated waste treatment facilities. This aspect is discussed in the following section.

Assuming that a suitable administrative situation existed, the following common support services could be shared by both types of facilities:

1. Administration building services - offices, conference rooms, food services, personnel services (locker rooms, etc.);
2. Site maintenance - lawn, road, and building maintenance, snow removal; and
3. Facility maintenance - skilled craftsmen such as pipefitters, mechanics, and electricians.

The number of support personnel saved through a common facility has not been quantified. From the several types of support services listed above, however, significant operating cost savings could be realized through a sharing of these services.

An additional support service that is unique to waste incineration facilities is laboratory analysis of the various effluent streams to satisfy EPA and state environmental control requirements. SAIC analyzed the types and frequency of samples required from each facility and the possibility for sharing analytical laboratory services.[1] SAIC concluded that the volume of samples from the conventional MSW incinerator would not justify operation of an on-site laboratory, but would be analyzed by a contract laboratory. The sampling requirements of the hazardous waste incineration system could justify the operation of a

small, on-site laboratory staffed by two technicians. With colocated waste incineration facilities, the hazardous waste laboratory could analyze the conventional MSW samples either on a contract basis or as a combined management service arrangement.

Either situation could reduce sampling technician time by only one day per week. Therefore, the primary economic gain with regard to laboratory services for colocated facilities appears to be from a higher utilization of the hazardous waste laboratory equipment and personnel and the consequent cost reduction that could be realized. Such savings could be most easily realized with joint administration of the colocated waste treatment facilities.

8.4 INTEGRATION ISSUES

With the descriptions of potentially viable scenarios of power generation with integrated conventional and hazardous waste systems as a basis, several issues are discussed below that strongly influence the economic viability of such an integrated waste treatment/power generation system.

8.4.1 Operating Organization

Large quantities of turbine quality steam can be produced from the hazardous waste heat recovery options described in this section. Steam used to drive power generating turbines in an integrated system would be produced in both conventional waste boilers and hazardous waste heat recovery boilers.

It would be very desirable for all of the steam/feedwater and power generation equipment to have the same operating organization to coordinate operation of this critical equipment. Such combined operation would facilitate planning and scheduling of planned equipment maintenance outages and also would allow the most efficient response to unscheduled equipment outages.

Although not as important as for the steam and power generation equipment, the same concept of a single operating organization could also be desirable for the operation of the MSW and hazardous waste incinerators. The single operating organization could be a private company that specializes in waste management and disposal under contract to operate the waste treatment facility. Since there are several such companies in the U.S., this operational approach would appear to have validity for an integrated waste treatment facility.[2]

Another type of operating organization could be a public, not-for-profit corporation formed as a contract operator of the entire facility. Such a corporation could also participate as an owner of the facility. Examples are (1) the Nashville Thermal Corporation that owns and operates the MSW incinerators and district heating and cooling system serving Nashville, TN, and (2) District Energy St. Paul, Inc. that owns and operates the district heating system serving St. Paul, MN.

These examples of operating organizations are given to indicate a few of the many types of options that exist for structuring the combined operation of an integrated waste treatment facility that would increase operating efficiency and reduce operating costs.

8.4.2 Coordination Requirements

Colocating two waste treatment systems that both produce turbine quality steam for shared power generating equipment adds certain coordination requirements that would not exist with separately sited systems. The most obvious requirements are for an integrated design and construction plan and for a coordinated operating period.

Both integrated power generation options described in this section have one less conventional MSW boiler than would be provided with a separate conventional MSW facility. The turbine/generator would be sized for a much higher steam flow

from the combined waste boilers. Therefore, an integrated design and construction plan is required because the two waste treatment systems should become operational at a similar time period to make maximum use of the investment in the power generation equipment.

An example of this situation is if the conventional MSW boiler and a turbine were constructed and operated for a period of time before the hazardous waste treatment system were constructed. The full power generation capacity of the turbine/generator would not be used until a hazardous waste incinerator with heat recovery were constructed, and revenues to the project would be reduced in the interim period. It would therefore be advantageous to construct at least part, if not all, of the hazardous waste incinerators and heat recovery boilers in concert with the conventional MSW boiler. (It should be noted, however, that the construction phasing of hazardous waste incinerators, if chosen for site decontamination, would be dictated by many site-specific conditions that may not allow the optimum power generation construction schedule to be followed.)

The "coordinated operating period" is the overall time period between initial startup and final shutdown that the waste treatment systems produce steam for a shared power generator. This issue is raised relative to the integrated waste treatment concept investigated in this study because the two waste treatment systems would normally have different operating periods. The conventional waste treatment system would be expected to have an operating period of approximately 30 years, whereas the hazardous waste treatment system would have a shorter operating period, such as the 12 years assumed in this study. For smaller quantities of contaminated MSW and soil than are assumed in this study, the disparity in operating periods would be even greater. If the hazardous waste treatment system were to stop operating while the conventional MSW treatment system continued, power production would be reduced by more than one-half in the system options presented in this section, and project revenues would be reduced proportionally.

In order to improve utilization of the capital invested in the power generation equipment and hazardous waste treatment system, this system could continue to operate on other sources of waste from the area after the contaminated MSW and soil from the DADS site has been processed. Fresh MSW, waste tires, and even hazardous organic liquid wastes could be incinerated with heat recovery in the rotary kilns and circulating bed combustor units of the hazardous waste treatment system. Thus, continued use of the hazardous waste treatment system at the integrated waste treatment facility could continue to generate revenues from disposal fees and power sales. Such a strategy would therefore reduce the need for constructing waste incinerators at other sites and also utilize the special features available for decontaminating certain hazardous wastes.

Another strategy that could alleviate the miss-match in operating periods between the conventional and hazardous waste treatment systems would be to extend the decontamination of hazardous wastes at the DADS site over the 30-year operating period of the conventional MSW incinerator plant. This approach could reduce the size of the hazardous waste incinerators and annual costs by up to 50%. However, the size of turbine/generator equipment would have to be re-evaluated for the integrated power plant since steam flows from the hazardous waste incinerators would be reduced relative to the conventional MSW incinerator.

8.4.3 Ownership Implications

The brief discussion presented here is intended only to indicate the need for more extensive planning to implement an integrated waste management approach. The coordinated operating period and the integrated design and construction plan discussed above would add complexity to the planning, financing, and possibly public support for an integrated waste treatment facility.

These project management issues could be most readily addressed by a single owner and/or operator type of management structure. The owner of the hazardous waste treatment system may represent a consortium of public and private interests as required for funding the decontamination of the DADS site under RCRA regulations. The conventional MSW incinerator system would normally be owned by a public agency, representing local governments and possibly private partners such as a privately-owned operating contractor. Thus, forming a single owner partnership to represent all equity interests in the conventional and hazardous waste treatment systems would appear to be a formidable task. Therefore, the structure of owner partnership(s) to represent all interests will require additional analysis to indicate feasible approaches that could be considered.

8.4.4 Power Plant Availability

An important assumption in estimating annual revenues from the sale of electricity from a power plant is the plant availability, which is the fraction of time the plant is producing its rated output. The availability fraction therefore excludes the time any of the entire chain of equipment, from incinerator through turbine/generator, is unavailable to perform at rated capacity because of planned or unplanned reasons.

For a conventional MSW incinerator power plant, including the turbine/generator unit, availability was assumed to be 0.80. This value is based on availability values for mass-burning incinerator power plants of the same type as assumed in this study.

For hazardous waste incinerators, there is little experience to base an estimation of availability over a long period of time such as the 12-year operating period assumed in this study. Maintenance requirements are known to be greater for hazardous waste incinerators than for conventional MSW incinerators because the higher temperatures employed increases degradation of equipment

seals and refractory liners. An availability of 0.60 was selected for all the hazardous waste units included in this study - i.e., rotary kilns, circulating bed combustors, and fixed hearth incinerators. This lower availability value reflects the generally lower value of hazardous waste incinerators as sources of thermal energy for electricity production. At a 0.60 availability factor, the amount of hazardous waste at the DADS site would require 20 years for decontamination with the equipment sizes described in Sect. 7 unless more units were added for redundancy.

REFERENCES FOR SECTION 8

1. "Energy Recovery from Hazardous Waste Incineration," Sect. 4 report by Science Applications International Corporation, Oak Ridge, TN, to Martin Marietta Energy Systems, Inc. (September 1987).

2. D. H. Graham, "Management, Operation, and Management Systems for Waste Facilities," pp. 157-176, in Proceedings of 1986 National Waste Processing Conference, June 1-4, 1986, American Society of Mechanical Engineers (1986).

9. ECONOMIC EVALUATION

9.1 INTRODUCTION

The overall goal of this study is to explore possible scenarios for reducing waste treatment costs by integrating hazardous waste incineration with heat recovery with a conventional MSW incineration power plant. To that end, economic data are presented in this section on construction costs, annual operation and maintenance (O/M) costs, and revenues from energy sales for separate waste treatment facilities and the two options for integrated power generation systems developed in Sect. 8. All costs are presented in 1987 dollars.

9.2 CONSTRUCTION COST ESTIMATES

Construction cost estimates have been estimated for the conventional and hazardous waste incineration systems developed in this study. The term construction cost is defined to be the bid price of a contractor firm for design and construction of the system or facility. Costs not included are direct costs for site acquisition and development - roads, utilities, etc. - and indirect costs for construction insurance, contingencies, administration, and financing costs for debt service, interest during construction, and bond underwriting. Indirect costs can be very site specific, and financing costs are very unpredictable for hazardous waste treatment facilities because very few facilities of the size and complexity as envisioned in this study have been financed from capital markets. Therefore, construction costs are a more reliable indicator of capital costs for the comparison purposes of this study.

The construction cost estimates in this section were developed from published data and general cost estimating information rather than detailed cost estimates. Therefore, the construction cost data presented in this section are very preliminary in nature and are intended only to indicate the general level of construction costs.

9.2.1 Conventional MSW Incinerator Plant

The construction cost of the 666 TPD capacity conventional MSW incinerator plant was assumed to be $60.0 million from data in Sect. 4. This plant includes an 18.8 MW capacity turbine-generator and two 333 TPD mass-burning incinerator/boilers, each with associated feed equipment, air emission controls, and ash handling equipment. Since the integrated waste treatment facility options are based on variations of the conventional MSW incineration plant with one incinerator/boiler, the cost of an incinerator/boiler plus associated feed and effluent handling equipment was estimated in the following manner.

First, the installed cost of an 18.8 MW turbine/generator was based on a unit cost of $190/kW.[1] The construction cost of two incinerator/boilers was estimated to be $28.0 million,[2] and the cost of each air emission control system to be $5.0 million.[3] The resulting cost breakdown of the $60.0 million total construction cost is shown in Table 9.1.

9.2.2 Hazardous Waste Incinerator Plant

Construction costs were estimated by SAIC[4] for the two hazardous waste incinerator plant options described in Sect. 7.2. The "base case" cost shown in Table 9.1 does not include the cost of a water treatment and deaerator system or heat recovery equipment. The cost of water treatment and deaerator system, from Ref. 9.3, was added in Table 9.2 to give the total construction costs without heat recovery.

9.2.3 Integrated Waste Incinerator Plant

Construction costs for the conventional incinerator portion of the integrated incineration facility were based on modifying the "base case" cost elements shown in Table 9.1. The number of conventional boilers was reduced from two to one, and the number of turbine/generators increased to two in

Table 9.1. Summary of construction cost estimates.[1]

Conventional MSW Incinerator Plant	Cost in 10^6 1987 $		
	Base Case	Integrated Facility	
		Option 1	Option 2
Boilers + Emission Controls (No.)	38.0 (2)	19.0 (1)	19.0 (1)
Turbine/Generator (No.)	3.6 (1)	7.2 (2)	3.6 (1)
Balance of Plant	18.4	18.4	18.4
Total Construction Cost	60.0	44.6	41.0
Hazardous Waste System, Option 1			
Waste Treatment System	21.3	21.3	
Water Treatment/Deaerator	3.0	-	
Heat Recovery Equipment	-	2.6	
Total Construction Cost	24.3	23.9	
Hazardous Waste System, Option 2			
Waste Treatment System	17.7		17.7
Water Treatment/Deaerator	3.0		-
Heat Recovery Equipment	-		1.1
Total Construction Cost	20.7		18.8

[1]Note: Option 1 uses rotary kilns to decontaminate soils; option 2 uses circulating beds.

Table 9.2. Annual operating costs (in 10^6 \$/year) for hazardous waste system options.[1]

	Option 1 Feed Stream		
	MSW	Soil	Durable Goods
Labor	1.71	6.84	0.31
Water	0.03	0.08	-
Ash disposal	0.18	14.04	0.18
Fuel	2.11	10.5	0.14
Maintenance	0.29	0.94	0.05
TOTAL	4.32	32.4	0.68

	Option 2 Feed Stream		
	MSW	Soil	Durable Goods
Labor	1.71	3.42	0.31
Water	0.03	0.01	-
Ash disposal	0.18	14.04	0.18
Fuel	2.11	1.37	0.14
Maintenance	0.29	0.72	0.05
TOTAL	4.32	19.56	0.68

[1]Note: Option 1 uses rotary kilns for decontaminating soils; option 2 uses circulating beds.

Option 1 with appropriate cost adjustments. The cost of the "balance of plant" was assumed to be the same for the integrated options as for the base case. The total construction cost for the conventional incinerator portion decreases for the integrated options because one less boiler unit is included.

Construction costs for the hazardous waste systems, shown in Table 9.1, include the cost of heat recovery equipment estimated by SAIC.[5] For both options of integrated facilities, the cost of a water treatment system and deaerator, estimated at approximately $3.0 million, is not included as this service is assumed to be provided by a comparable system in the conventional incinerator portion of the plant. Thus, the construction cost for the hazardous waste portion of an integrated facility is slightly lower than for the "base case" costs.

9.3 OPERATING AND MAINTENANCE COSTS

Operating and maintenance (O/M) costs are a significant portion of the total costs for waste treatment systems because of the large volumes of materials handled and the several operations included in the overall system. O/M costs include labor, fuel, utilities - electricity, water - ash disposal, administration, maintenance, miscellaneous services, such as laboratory analyses.

9.3.1 Conventional MSW Plant

Total O/M costs were estimated from information in a financial feasibility analysis of the same type of mass-burning incinerator power plant used for estimating construction costs.[6] The annual O/M costs are estimated to be $4.8 million in 1987 dollars.

9.3.2 Hazardous Waste Incinerator Plant

O/M costs for the two hazardous waste system options were estimated by SAIC.[5] SAIC's costs for water, ash disposal, and fuel were reduced by 40% to account for an assumed 60% operating factor. The adjusted O/M costs are presented for each feed stream in Table 9.2. Fuel costs are based on a No. 2 oil cost of $1/gal. The total O/M annual costs, shown in Table 9.3, are $37.4 million and $24.56 million for options 1 and 2, respectively, of which $14.04 million is for ash disposal for the soil rotary kiln.

9.3.3 Integrated Waste Incinerator Plant

O/M costs for the conventional incinerator portion of the integrated plant were assumed to be one-half of the costs for the "base case" since the number of incinerator/boilers was reduced from two to one. Since these O/M costs include operation of the turbine/generators, this reduction is somewhat generous. However, there would be compensating operating cost reductions for administration, labor, and laboratory services - as discussed in Sect. 8 - from combined operations of the conventional and hazardous waste treatment systems.

For the Option 1 hazardous waste system, annual O/M costs were reduced by $2.0 million to reflect the potential savings in fuel oil cost by using 37.5 TPD of waste tires as auxiliary fuel for the soil rotary kilns. Waste tires could also be used as auxiliary fuel for the MSW rotary kiln; however, any appreciable use would significantly reduce the capacity to process hazardous MSW. The Option 2 O/M costs were assumed to be the same as for the "base case" since waste tires are not appropriate as auxiliary fuel for circulating bed combustors unless in shredded form. Table 9.3 summarizes the total annual O/M costs estimated in this study.

Table 9.3. Summary data on integrated MSW and hazardous waste incineration.[1]

	Annual Waste Processed (10^3 tons)		
		Integrated Facility	
	Base Case	Option 1	Option 2
Conventional MSW Plant	145.9	72.9	72.9
Hazardous Waste System	216.6	216.6	216.6
	Construction Cost (10^6 \$)		
Conventional MSW Plant	60.0	44.6	41.0
Hazardous Waste System,			
Option 1	24.3	23.9	
Option 2	20.7		18.8
	Annual O/M Costs (10^6 \$)		
Conventional MSW Plant	4.8	2.4	2.4
Hazardous Waste System,			
Option 1	37.4	35.4	
Option 2	24.56		24.56
	Electricity Production		
Annual Sales (10^6 kWh)	100.9	151.4	86.2
Annual Revenue (10^6 \$)	4.54	6.90	3.97
% of Power From Hazardous Waste	0	67.2	43.6

[1]Note: Option 1 uses rotary kilns to decontaminate soils; option 2 uses circulating beds.

9.4 REVENUES FROM POWER SALES

Revenues have been estimated for electricity sold from a conventional MSW incinerator power plant as a base case and from an integrated MSW and hazardous waste power plant. Electricity production was estimated for maximum electric output with no cogenerated steam extracted since the market for thermal energy was assumed to be insignificant in the area around the DADS site. The results of the annual electricity production and revenues are presented in Table 9.3 with the percentage of power generated from hazardous waste.

9.4.1 Electricity Values

Electricity values were assumed for two power markets: (1) the local utility under PURPA regulations, and (2) sale to the Buckley Air National Guard base at peak rates during the day. From information obtained during this study, the current PURPA electricity rate was estimated to be 0.045 $/kWh. The peak rate during the 8:00 a.m. to 6:00 p.m. period was assumed to be 0.06 $/kWh. This value was arrived at considering that it should be comparable to cost of peak daytime power from the local utility, 0.051 $/kWh in 1986. The basis for using the utility peak rate rather than the cost of Buckley's on-site power was that Buckley requires the 4 MW block of power to be generated on-site for about one-half of the year for reliability reasons. The 0.06 $/kWh is therefore considered to be a generous estimate of a rate that might be negotiated between the power plant owners and Buckley Air National Guard base.

9.4.2 Revenues from a "Base Case" Conventional MSW Incinerator Plant

As a basis for comparison, revenues from electricity sales were estimated for the conventional MSW incinerator plant described in Sect. 8.2. The 14.4 MW of power for sale would produce annually 100.9 million kWh at an 0.80 availability factor, and annual revenues would be $4.54 million at a rate of 0.045 $/kWh.

9.4.3 Revenues from Option 1 of an Integrated Incinerator Plant

Annual power production for this integrated power plant, described in Sect. 8.2, was based on two turbines, each producing a net 13.4 MW 60% of the time when the conventional MSW and hazardous waste incinerators are operating, and one turbine producing a net of 6.0 MW 20% of the time from the conventional MSW incinerator. The two-turbine operation would produce 140.9 million kWh and the one-turbine operation, 10.5 million kWh for a total of 151.4 million kWh annually.

Electricity revenues for this option were based on the sale of 4.0 MW for eight hours per day for 182 days, or one-half of the year, to the Buckley Air National Guard base at 0.06 $/kWh. Thus, 5.82 million kWh would generate a revenue of $349,200. The remaining 145.58 million kWh would be sold to the local electric utility at 0.045 $/kWh for an annual revenue of $6,551,000. The total annual revenue would therefore be $6.9 million for this option of an integrated incineration plant. At a differential of 0.015 $/kWh, the sale to Buckley Air National Guard base increases the revenue by $87,300, only 1.3% of the total revenue.

9.4.4 Revenues from Option 2 of an Integrated Incineration Plant

Annual power production for this option was based on 14.4 MW of net power generation 60% of the time when all incinerator units are assumed available, producing 75.5 million kWh, and 6.0 MW produced 20% of the time from the conventional incinerator, adding 10.5 million kWh. The total annual production of electricity would be 86.2 million kWh for this integration option.

Revenues for this option would be $349,200 from the sale to Buckley Air National Guard base - same as for Option 1 - and $3,617,000 from the sale of 80.38 million kWh to the local electric utility at 0.045 $/kWh, yielding a total annual revenue of $3,966,000.

9.5 UNIT PROCESSING COST FOR CONSTRUCTION AND O/M COSTS

A simple calculation of processing cost in $/ton of waste processed was performed as a way of evaluating any cost benefit of integrated conventional and hazardous waste incineration vs separate waste treatment. The processing cost was calculated using the equation

Cost ($/ton) = [(financing rate) x (construction cost) + (annual O/M cost) - (annual electricity revenue) - (annual conventional MSW processing credit)]/(annual waste processed, tons).

This processing cost includes the financing cost, assuming a 10%/yr interest rate, for only the construction cost portion of the total capital cost of the plant. Also, the cost of exhuming the buried MSW and contaminated soil and hauling to the treatment facility is not included in this cost calculation.

The processing cost is in current (1987) dollars with no inflation included. It is therefore intended only to indicate the relative costs between an integrated waste treatment facility and separate facilities which are comprised of the "base case" conventional MSW incinerator power plant and "base case" hazardous waste systems with no heat recovery or power generation.

The revenue item, "annual conventional waste processing credit," is included to represent the value of disposing of conventional MSW based on the operating costs of a "base case" conventional MSW incinerator plant. For a 0.045 $/kWh electricity value, the "base case" conventional MSW plant has a $43/ton processing cost or disposal cost for the 145,900 tons of MSW processed annually. The "annual conventional waste processing credit" for the integrated options is therefore ($43/ton) x 72,900 tons or $3,134,000.

Cost and revenue data in Table 9.3 were used to calculate the processing costs in Table 9.4, assuming a 10% financing rate. The "base case" processing costs of $184/ton and $123/ton for Options 1 and 2 of the hazardous waste treatment system are the costs with no revenue from electricity sales. This analysis indicates that at a 0.045 $/kWh electricity value, an integrated waste treatment facility could reduce costs by $24/ton - 13% - for the higher cost, Option 1 and by $4/ton - 3.3% - for the lower cost Option 2.

To indicate the sensitivity to electricity value, the same procedure was followed for electricity values from 0.02 to 0.09 $/kWh with the results shown in Fig. 9.1. The conventional MSW disposal cost ranges from $60/ton at 0.02 $/kWh to $11.9/ton at 0.09 $/kWh. Sensitivities of the integrated processing cost to electricity value is 4.714 $/ton and 1.36 $/ton decrease per 0.01 $/kWh increase in electricity value for Options 1 and 2, respectively.

9.6 DISCUSSION OF RESULTS

The economic data and evaluation of processing costs for "base case" or separate waste treatment facilities and integrated waste treatment facilities presented in this section lead to several observations on the overall feasibility of the integrated waste treatment concept.

9.6.1 Importance of Future Energy Markets for Project Revenues

The analysis of waste processing costs for an integrated incinerator facility and disposal cost for a conventional incinerator indicate the importance of having as high a valued energy market as possible to reduce the respective processing and disposal costs. The energy market for the DADS site appears for the forseeable future to be limited to the sale of electricity to the local utility at rates that are currently moderate - 0.045 $/kWh. Unless the value of non-utility generated electricity increases significantly in the Denver region, a disposal cost of about $40/ton for a conventional MSW incinerator would be

Table 9.4. Unit processing cost ($/ton) for construction and O/M costs.[1]

	Unit Processing Cost ($/ton) for Construction and O/M Costs[1]		
		Integrated Facility	
	Base Case	Option 1	Option 2
Conventional MSW Plant	43	43	43
Hazardous Waste System,[2]			
Option 1	184	160	
Option 2	123		119

[1]Assume 10% financing rate and a 4.5¢/kWh electricity value.

[2]Costs do not include cost of exhuming waste and transport to the treatment facility.

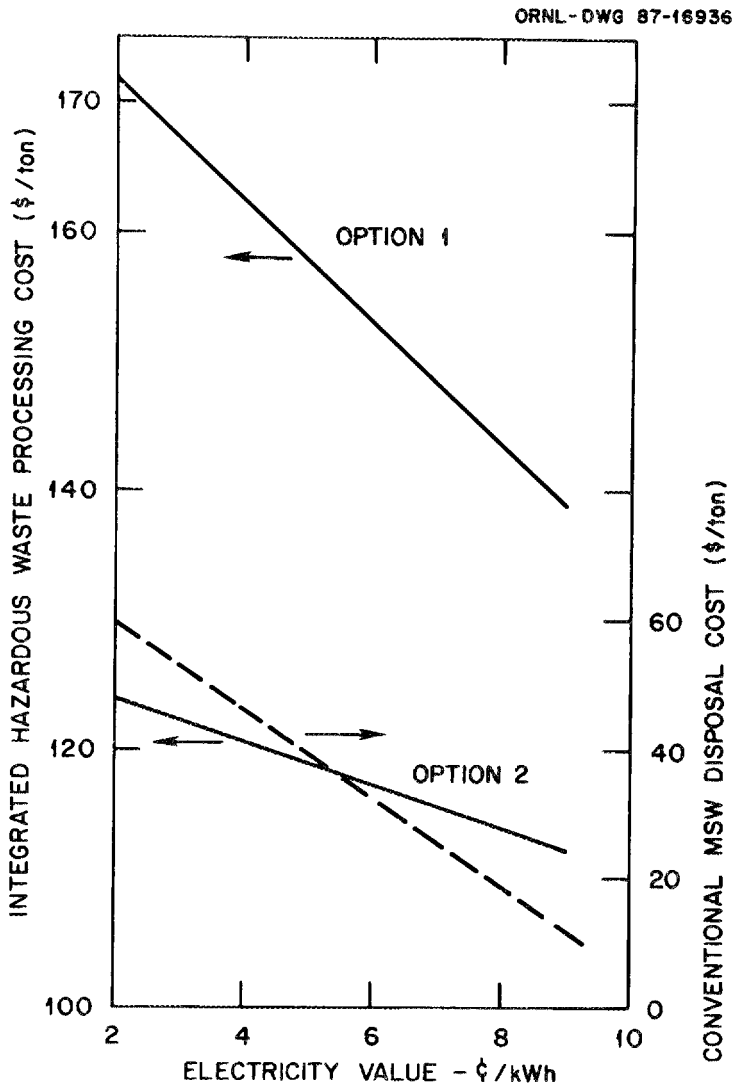

Fig. 9.1. Unit cost for processing hazardous waste and disposing of conventional MSW vs electricity value.

relatively unattractive compared to the cost of landfilling at about $10/ton, the current cost in the Denver area. However, landfilling costs could escalate significantly in the near future from local pressures to restrict landfilling as the sole method for disposing of MSW. Thus, the fate of conventional MSW incineration at the DADS site appears to be tied to how future market values develop from the present situation.

9.6.2 Potential for Cost Reduction from Integrated Waste Treatment

The simplified analysis of processing costs for integrated waste treatment performed in Sect. 9.4 indicates that the integrated approach can reduce processing costs for hazardous wastes from the cost of separate treatment without heat recovery. The magnitude of such cost reductions, indicated in Fig. 9.1, are greater for integration Option 1 than for Option 2 because of the larger steam production capability and corresponding revenues from electricity sales with that option. However, the most desirable treatment option is Option 2 with processing costs that are lower than Option 1 by 30-50 $/ton with electricity values between 0.07 and 0.02 $/kWh. Therefore, the cost reduction from integrated waste treatment for the lower cost hazardous waste treatment option is only $7/ton or 5.7% at a 0.07 $/kWh value for electricity.

REFERENCES FOR SECTION 9

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10. FINDINGS AND RECOMMENDATIONS

10.1 FINDINGS

The major findings drawn from this study and the companion SAIC study of energy recovery from hazardous waste incinerators have been organized under the categories of technical, economic, and institutional findings.

10.1.1 Technical Findings

1. Characterization of buried MSW and contaminated soil can affect the heat recovery potential from incineration of hazardous wastes at the DADS site. Additional characterization studies of the DADS hazardous wastes are important in identifying two areas that can influence the heat recovery potential. One area is the degree of soil contamination by halogens such as chlorine that could affect corrosion of heat recovery equipment. No serious corrosion problems have been indicated by the first phase of site characterization, but this tentative conclusion should be monitored in successive characterization studies.

   A second area of concern is the moisture content of the buried MSW. If the moisture content of the contaminated MSW significantly exceeds the 15% by weight, as delivered to the hazardous waste incinerator and as assumed by SAIC in their study, then less thermal energy would be produced than was estimated in this study. Thus, these two areas could impact the economics of steam production from recovered heat and the amount of heat recoverable.

2. Contaminated soil could represent the largest fraction of the DADS wastes, but the extent of soil contamination beneath the waste pits has not been verified experimentally. The total amount of DADS wastes estimated for this study was 4,332,000 tons of which 3,900,000 tons was contaminated

soil. Since the extent of soil contamination has not been characterized, the amount of soil to be treated could vary significantly from this estimate which would affect the amount of energy available for use in an integrated power system.

3. Rotary kilns, circulating bed combustors, and fixed hearth combustors are recommended for thermal treatment of DADS hazardous wastes. At this time, no decisions or recommendations have been made with respect to the use of thermal treatment of hazardous wastes at the DADS site. Assuming that thermal treatment is ultimately selected in the remedial action plan for the DADS site, three types of incinerators are recommended for consideration as possible methods of thermal treatment. Rotary kilns are appropriate for all types of wastes - municipal solid wastes (MSW), soils, and durable goods. Circulating bed combustors are especially suited for soil decontamination at lower cost than a rotary kiln. Finally, fixed hearth incinerators can handle large, bulky durable goods items at lower cost than a rotary kiln.

4. Large quantities of turbine quality steam can be produced from incineration of hazardous wastes at the DADS site. Steam flows from heat recovery boilers added to hazardous waste incinerators of contaminated MSW and soil are comparable to the 77,000 lb/h of 830°F, 865 psig steam from a conventional MSW incinerator of about 330 ton/day capacity. Steam flows estimated for hazardous waste incinerators depend on the total quantity of waste to be treated and the assumed operating period, 12 years in this study. The largest flow of steam - 151,000 lb/h - was from rotary kilns treating soils followed by rotary kilns treating MSW - 57,000 lb/h.

5. Waste tires stored at the DADS site could be used beneficially as supplementary fuel in rotary kilns treating soils. Since rotary kilns can be designed to accept whole tires, the waste tires at the DADS site could be used at a rate of 37.5 ton/day or 1.37 million tires/year if rotary kilns are used for soil treatment. Annual savings in fuel oil costs at $1/gal would amount to $2.0 million.

10.1.2 Economic Findings

1. The primary market for energy recovered from incineration at the DADS site is electricity sold to the local utility at PURPA rates. Sale of cogenerated steam to a district heating system and of electricity to the Buckley Air National Guard base were evaluated as possible markets to increase project revenues. The district heating market was considered very speculative since there is no commercial development in the area and little prospect for such development until decontamination of the DADS site is well along. Sale of electricity to Buckley Air National Guard base during daytime peak rate periods at rates above the current PURPA rate of 0.045 $/kWh generated only a small additional revenue.

2. Integrating conventional and hazardous waste incineration facilities would produce relatively small operating cost reductions. Operating costs would be reduced with an integrated facility through more efficient use of maintenance personnel and sharing of common support facilities. However, such cost savings would be small compared with other labor costs associated with the conventional MSW and hazardous waste incinerator operations.

3. Low operating availability of hazardous waste incinerators reduces their value as revenue generators. Increased downtime for maintenance of hazardous waste incinerators reduced their assumed availability to 60% compared with 80% for conventional MSW incinerator power plants. During periods of reduced steam production from the hazardous waste heat recovery boilers, return on the investment in turbine/generator equipment will be low. The value of electricity sold under PURPA regulations could also be reduced because of low reliability of production.

4. Thermal treatment is a very expensive treatment option for DADS wastes. If thermal treatment is selected, treatment costs - without the cost of exhuming and transporting wastes to the treatment facility - range from

$120 to 180/ton for no heat recovery in the system. Treatment cost is highest for an all rotary kiln system (Option 1). In Option 2 with circulating bed combustors treating the large amount of contaminated soil, the treatment cost is reduced to about $120/ton.

5. Although the cost of recovered heat from incineration of hazardous wastes appears to be attractive, integrating hazardous waste and conventional MSW incineration for power production has a limited affect on the cost of treating DADS wastes. With an integrated power plant, waste processing costs are reduced relative to separate treatment, depending on the value of the electricity produced. A preliminary analysis of waste processing costs was performed assuming a 10%/year financing rate. For the higher cost, all rotary kiln system (Option 1), the cost reduction was estimated to be up to $36/ton or 20% for a 0.07 $/kWh electricity value. For the lower cost Option 2 treatment system, the corresponding cost reduction was only $7/ton or 5.7%.

10.1.3 Institutional Findings

1. An integrated waste treatment facility would require a single operator and a unified design approach. A single operator would facilitate efficient operation of turbine/generators supplied by both conventional MSW boilers and hazardous waste heat recovery boilers. In addition, any savings in operating and maintenance labor could only be realized with a single operator. A unified design, required for an integrated waste incineration facility, indicates the need for early planning of such a facility.

2. Mismatch in operating lives of conventional and hazardous waste incineration systems requires resolution for economic use of investment in the conventional waste system. Operating lives of conventional waste systems are about 30 years compared with shorter operating lives for hazardous waste systems, dictated by the time required to decontaminate a

site, 12-20 years assumed in this study. This mismatch could possibly be approached in two ways. One approach would be to continue to use the hazardous waste incinerators for either hazardous or non-hazardous wastes after the DADS hazardous wastes have been treated.

A second approach would be to plan for an extended operating period for treating the DADS wastes to coincide with the 30-year operating life of the conventional waste system. This approach would also reduce annual costs for treating the DADS wastes. It would require a different sizing of hazardous waste incinerators and associated equipment and a re-analysis of the integrated power plant configuration. However, the unit processing cost in $/ton of waste may change little from the costs developed in this study because O/M costs dominate the unit processing costs.

3. The viability of the integrated waste incineration facility concept for a site such as the DADS site is linked very closely with the economic viability of a conventional MSW incinerator power plant at the DADS site. A significant portion of the revenues for an integrated incinerator power plant at the DADS site would come from the disposal cost or "tipping fee" for conventional MSW processed. With electricity sold under current PURPA rates as the other main source of revenue, MSW disposal costs of about $40/ton are indicated. Since this disposal cost is much higher than current landfill disposal fees in the Denver area, a significant accommodation between incineration disposal costs and landfill disposal fees is indicated before incineration of MSW is economically viable at the DADS site.

10.2 RECOMMENDATIONS

In view of the conclusions of this study presented above, the following recommendations are made for the Air Force Regional Civil Engineers relative to remedial actions to be taken at the DADS site.

1. In order to reduce overall costs for site decontamination, AFRCE should encourage investigation of "in-situ" decontamination methods because of the high cost of exhuming and incinerating the large quantity of contaminated material - largely soil - estimated at the DADS site. For the 4,332,000 tons of contaminated material estimated in this study, the cost of incineration alone could range from $520-780 million for unit processing costs of $120-180/ton. In-situ treatment methods should be evaluated in order to reduce the amount of material treated at such high costs.

2. If incineration is selected for treatment of DADS wastes, moisture and corrosion characteristics of the buried MSW and contaminated soil should be reviewed for their effect on heat recovery before proceeding with the integrated power generation concept.

3. AFRCE should proceed with the development of an optimization model for sizing hazardous waste systems to changing hazardous waste thermal treatment scenarios. As more detailed information is developed on hazardous waste characteristics and treatment options at the DADS site, thermal treatment equipment sizes and corresponding processing costs could differ significantly from this study. The analytical capability of an optimization model would allow for a rapid economic analysis of changing waste remedial plans, and provide AFRCE with a sound basis for contributing to the development of a business plan for remedial actions.

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