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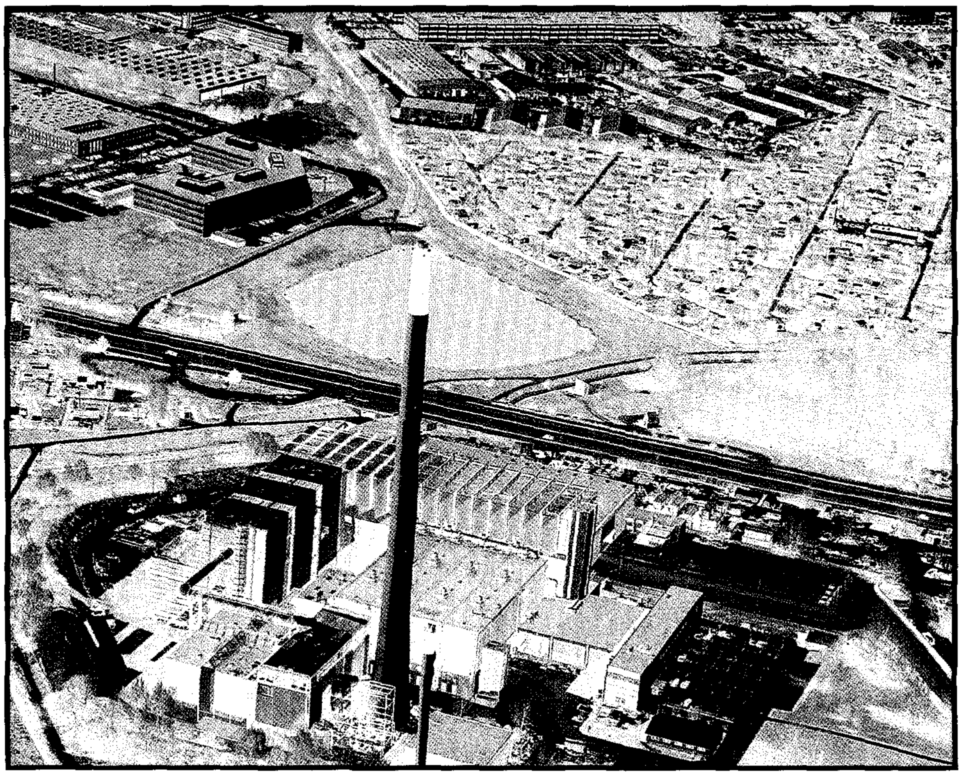
Municipal Solid Waste Incineration

Requirements for a Successful Project



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Foreword

Solid waste management is in crisis in many of the world's largest urban areas as populations attracted to cities continues to grow. This has led to ever increasing quantities of domestic solid waste while space for disposal decreases. Municipal managers are looking to the development of sanitary landfills around the periphery of their cities as a first solution. However, siting and preparation of a landfill requires the acquisition of large areas as well as good day-to-day operation in order to minimize potential negative environmental impacts. Another approach that has recently caught the attention of decision makers is mass burn incineration similar to systems found in the OECD countries. However, capital and operating requirements for these plants are generally an order of magnitude greater than required for landfills. Project developers armed with rosy financial forecasts can be found in all corners of the globe encouraging municipal officials to consider incineration.

In order to assist local officials with developing cost-effective strategies for dealing with solid waste management, the World Bank has begun a program of providing high-level advice on approaches that are basically financially self-supporting, socially and environmentally responsible. This *Technical Guidance Report* provides the foundation for such a detailed evaluation of solid waste incineration systems. A document for making a more preliminary assessment is the accompanying *Decision Maker's Guide to Incineration of Municipal Solid Waste.*

This report should be used with caution since both technical and financial feasibility are very site-specific. Readers with general interest and technical specialists will find this report useful in making their assessments. A comprehensive solid waste management program may include several options phased in over a long period of time during which refuse quantities, constituents, and the overall economic picture may change significantly. This uncertainty and associated risks must be incorporated into the planning process.

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Abbreviations and Symbols

A	Ash content per kg of dry sample
APC	Air pollution control
BO	Build and operate
BOO	Build, own, and operate
BOOT	Build, own, operate, transfer
C	Combustion fraction
°C	Degrees Celsius
CBA	Cost benefit assessment
CHP	Combined heat and power
DBO	Design, build, and operate
DC	Direct current
DS	Dry substance
EA	Environmental assessment
EIA	Environmental impact assessment
ESP	Electrostatic precipitator
EU	European Union
GDP	Gross domestic product
GR	Growth rate
GWh	Gigawatt hour
h	Hour
H_{awf}	Ash and water free calorific value
H_{inf}	Lower (inferior) calorific value
$H_{inf, overall}$	Overall lower calorific value
HRD	Human resource development
H_{sup}	Upper (superior) calorific value
$H_{sup,DS}$	Superior calorific value of dry sample
kcal	Kilocalories
K	Kelvin
KF	Key figure
kJ	Kilojoule
kPa	Kilopascal
LCV	Lower calorific value
LOI	Loss of ignition
LP	Low pressure
m	Meter
M_{CW}	Weight of condensed water per kg of dry sample
mg	Milligrams
Mg	Megagrams
MJ	Megajoule
mm	Millimeter
MSW	Municipal solid waste
MW	Megawatt
MWh	Megawatt hour
n.a.	Not applicable
ng	nanograms
NGO	Non-government organization
NIMBY	Not-in-my-back-yard
Nm^3	Standard or normal cubic meters
OD	Operational directive
OECD	Organization for Economic Co-operation and Development
OSH	Occupational safety and health
PIU	Project implementation unit
PP	Present population
SCR	Selective catalytic reduction
sec	Second
SNCR	Selective non-catalytic reduction
SWOT	Strengths, weaknesses, opportunities, threats
t	Metric ton (1,000 kg)
t/d	Metric tons per day
t/h	Metric tons per hour
TOC	Total organic carbon
TS	Total solids
US$	US dollars. Price level of 1998 unless otherwise specified.
W	Moisture of raw waste
WB	World Bank

Chemical abbreviations

As	Arsenic
$Ca(OH)_2$	Hydrated lime
$CaCl_2$	Calcium chloride
$CaCO_3$	Calcium carbonate
CaF_2	Calcium fluoride
$CaSO_3$	Calcium sulfite
$CaSO_4$	Calcium sulfate
$CaSO_4$-$2H_2O$	Gypsum
Cd	Cadmium
$CdCl_2$	Cadmium chloride
CO	Carbon monoxide
Co	Cobalt
CO_2	Carbon dioxide
Cr	Chromium
Cu	Copper
H_2O	Water
H_2SO_4	Sulfuric acid
HCl	Hydrogen chloride
HF	Hydrogen fluoride
Hg	Mercury
Mn	Manganese
Mo	Molybdenum
Na_2SO_4	Sodium sulfate
NaOH	Sodium hydroxide
NH_3	Ammonia
NH_4Cl	Ammonium chloride
Ni	Nickel
NO_x	Nitrogen oxide
O_2	Oxygen
Pb	Lead
PVC	Polyvinyl chloride
Sb	Antimony
Se	Selenium
SO_2	Sulfate
Tl	Thallium
V	Vanadium
Zn	Zinc

PART 1
ASSESSMENT

1 Introduction

The *Technical Guidance Report* provides background information for the *Decision Makers' Guide to Municipal Solid Waste (MSW) Incineration.* The *Report* focuses on large-scale incineration plants for large urban areas or intermunicipal cooperatives. It does not address hazardous and infectious wastes.

The *Decision Makers' Guide* is a practical tool for a preliminary assessment of whether the key criteria for a solid waste incineration scheme are present.

The *Technical Guidance Report* provides decision makers and their advisers with more elaborate information on how to investigate and assess the degree to which the key criteria are fulfilled. Hence, the *Report* comprises a comprehensive account of many aspects of waste incineration. Part 1 of the *Report* provides information needed to assess the feasibility of MSW incineration. Part 2 covers technical aspects and the available technologies related to an MSW incineration plant.

The *Decision Makers' Guide* primarily addresses an audience at the political level, whereas the *Technical Guidance Report* presumes some degree of general technical knowledge. However, no expertise within the field of waste incineration is required to understand the *Technical Guidance Report*.

Finally, note that the *Technical Guidance Report* is far from being a design manual for an MSW incineration plant. The responsibility, the final feasibility assessment and the consecutive design of such a plant must be entrusted to experienced consultants and suppliers with an extensive track record in this complex subject.

Methodology

The *Technical Guidance Report* is organized as follows:

Part 1 — Assessment

- Introduction
- Waste as Fuel
- Institutional Framework
- Incineration Plant Economics and Finance
- The Project Cycle

Part 2 — Technical

- Plant Location
- Incineration Technology
- Energy Recovery
- Air Pollution Control
- Incineration Residues
- Operation and Maintenance
- Environmental Impact and Occupational Health

Each chapter is standardized to make information easy to access, as follows:

- Key issues—Main points, critical issues, and decisions to be made.
- Key criteria—listed in order of importance, using the following symbols to emphasize priority:

✓ ✓ ✓	Mandatory
✓ ✓	Strongly Advisable
✓	Preferable

If any mandatory key criterion is not expected to be fulfilled, it is advisable to stop planning the solid waste incineration plant.

- General principles—Elaboration of the general considerations.

The *Technical Guidance Report* is supplemented by an evaluation checklist for decision makers who are considering MSW incineration as part of their waste management strategy.

Furthermore, as an introduction, the following two sections provide a brief overview of the flow and management of municipal solid waste, objectives and applicability of waste incineration, and the necessary institutional framework.

The Flow and Management of Municipal Solid Waste

Solid waste arises from human activities—domestic, commercial, industrial, agricultural, wastewater treatment, and so on. If the waste is not properly handled and treated, it will have a negative impact on the hygienic conditions in urban areas and pollute the air and surface water and groundwater, as well as the soil and crops.

A hygienic and efficient system for collection and disposal of solid waste is therefore fundamental for any community. Generally, the demands on the solid waste management system increase with the size of the community and its per capita income. Figure 1.1 shows that the final destination of waste is always a disposal site. Residues from waste treatment processes are returned to the waste mainstream and end up in the landfill with untreated waste. Hence, the backbone of any waste management system is an efficient collection system and an environmentally sound sanitary landfill.

The system's resource recovery and recycling reflect that solid wastes are materials and by-products with potentially negative value for the possessor. Understanding what may be considered waste will thus change with the circumstances of the possessor as well as in time and place. Waste may be transformed into a resource simply by transportation to a new place or through treatment. Such a transformation depends on the costs involved and whether the economy is looked upon as a private business, a national priority, or even globally.

Waste treatment involving mechanical plants requires large investments and operating costs. Hence, it should be only introduced after gaining profound knowledge of the existing system and waste generation—which is quite a challenge, except in a highly organized waste management system. The most important factor in obtaining such information is that the waste is already disposed of in fully monitored and controlled landfills only.

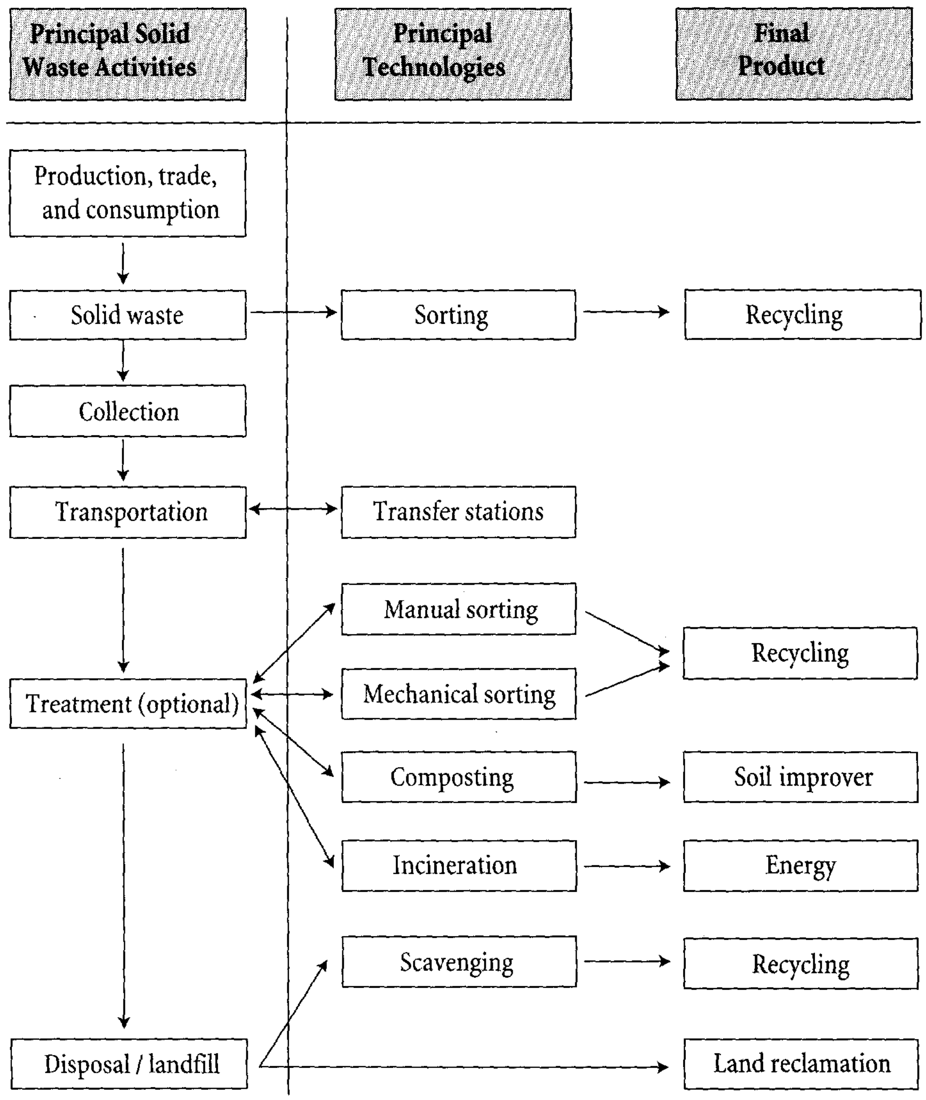
Incineration Project Summary

MSW incineration is found at the most advanced level of the waste disposal/treatment hierarchy: indiscriminate dumping, controlled dumping, landfilling, sanitary landfilling, and mechanical treatment (for example, composting and incineration). Additional environmental control is introduced at each level and the disposal costs increase substantially. Introducing mechanical treatment of MSW entails a significant jump in technology and costs and is generally only feasible when all waste is already being disposed of in a sanitary landfill established and operated according to *Decision Makers' Guide to Solid Waste Landfills, WB.* Even so, many things can cause the project to fail and leave society with a huge bill to pay.

Deciding to incinerate waste instead of, for instance, dumping it, takes careful consideration of the criteria for success. In the mid 1980s, a number of Eastern European and Asian cities jumped directly from simple dumping to MSW incineration. Any success was, however, questionable in many of these cities. In the former Soviet Union, several plants were commissioned in the late 1970s and early 1980s. Unfortunately, some of these plants were never completed, others were discontinued, and the rest are operating at reduced capacity because of financial, managerial, and operational shortcomings.

In Asia, there is limited experience with waste incineration outside the industrialized countries of Japan, Singapore, and Taiwan. A few plants in other places

Figure 1.1 Solid Waste Handling and Treatment System Components



have experienced managerial, financial, or operational problems, including low calorific value of the waste due to scavenging, precipitation, or the basic composition of the generated waste.

The failure of MSW incineration plants is usually caused by one or more of the following:

- Inability or unwillingness to pay the full treatment fee, which results in insufficient revenue to cover loan installments and operation and maintenance costs
- Lack of convertible currency for purchase of spare parts
- Operation and maintenance failures (including lack of skilled workers)
- Problems with the waste characteristics and/or quantity
- Poor plant management
- Inadequate institutional arrangements
- Overly optimistic projections by vendors.

Objectives and Applicability of MSW Incineration

In highly industrialized European countries, waste incineration plants have been used increasingly over the last 50 years, mainly because it has been more difficult to find new sites for landfills in densely populated areas. The public concern for the environmental impact of MSW incineration has, however, increased significantly over the last 20 years—forcing the manufacturers to develop, and the plants to install and operate, high-cost advanced technology for pollution control (especially air pollution).

Incineration of MSW does not completely eliminate, but does significantly reduce, the volume of waste to be landfilled. The reductions are approximately 75 percent by weight and 90 percent by volume. The residues arising from air pollution control (APC) are, however, environmentally problematic, as they present a severe threat to ground and surface waters. Current technology is supposed to dispose of such residues in highly controlled sanitary landfills equipped with advanced leachate collection and treatment measures, or in former underground mines to prevent leaching of heavy metals and, for some APC residues, chlorides. Fear of pollution often brings MSW incineration plants to the center of emotional public debate.

Incinerating solid waste fulfills two purposes in the advanced waste management system. Primarily, it reduces the amount of waste for sanitary landfilling; and it uses waste for energy production (power or district heating). Hence, waste incineration plants are generally introduced in areas where the siting of sanitary landfills is in conflict with other interests such as city development, agriculture, and tourism.

Solid waste incineration is a highly complex technology, which involves large investments and high operating costs. Income from sale of energy makes an important (and necessary) contribution to the total plant economy, and, consequently, the energy market plays an important role in deciding whether to establish a plant.

Several types of incineration technologies are available today, and the most widely used is mass burning incineration—with a movable grate or, to a lesser extent, rotary kilns. Fluidized bed incineration is still at the experimental stage and should therefore not yet be applied. The mass burning technology with a movable grate has been successfully applied for decades and was developed to comply with the latest technical and environmental standards. Mass burning incineration can generally handle municipal waste without pretreatment on an as-received basis.

Mass burning technologies are generally applied for large-scale incineration of mixed or source-separated municipal and industrial waste. Compared to movable grates, the rotary kiln incineration plants have a smaller capacity and are mostly used for special types of waste unsuitable for burning on a grate, such as various types of hazardous, liquid, and infectious waste.

Institutional Framework—Overview

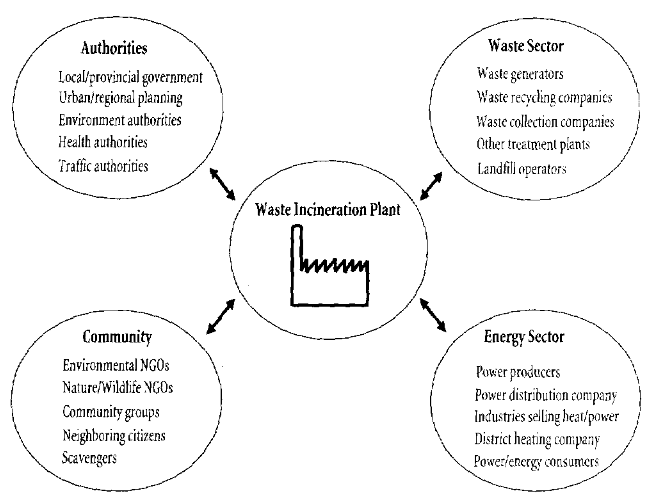
When considering the construction of an incineration plant, it is necessary to consult with many project stakeholders. The relevant stakeholders are usually authorities, the waste sector, community groups, and the energy sector. A further subdivision of these stakeholders appears in figure 1.2 below.

It is important to review possible local stakeholders based on the actual local conditions, political and financial situation, and other current and planned waste treatment and disposal facilities.

The most important issue, financially, could be generation of revenue from the sale of heat or power (or both), as well as the possibility of collecting fees from commercial, domestic, and public waste generators.

Environmentally, important issues may be to define suitable standards for flue gas emissions, quality and disposal of solid outputs (slag, ash, and flue gas cleaning residuals), as well as waste water in case a wet flue gas cleaning system is applied.

Figure 1.2 Typical MSW Incineration Project Stakeholders



The most important question, institutionally, could be how to control the waste flow for optimum treatment and utilization of the available waste treatment and disposal facilities; and how to ensure that the institutional and managerial capacity required to operate a multiple stringed waste management system.

Depending on local traditions and the level of environmental awareness, a special and transparent information campaign could be carried out for community groups and neighboring citizens.

The goals, strength, resources, and awareness of the stakeholders often differ among each other and with those of the proposed incineration plant owner/operator. Reaching a solution that is acceptable to all may be difficult.

2 Waste as Fuel

Key Issues

The successful outcome of a waste incineration project first depends on fairly accurate data on the future waste quantities and characteristics that form the basis for the design of the incineration plant.

Waste for incineration must meet certain basic requirements. In particular, the energy content of the waste, the so-called lower calorific value (LCV), must be above a minimum level. The specific composition of the waste is also important. An extreme waste composition of only sand and plastics is not suitable for incineration, even though the average lower calorific value is relatively high. Furthermore, in order to operate the incineration plant continuously, waste generation must be fairly stable during the year.

Hence, the amount and composition of solid waste generated in the collection area for a potential incineration plant, and possible seasonal variations, must be well established before the project is launched. Waste composition depends on variables such as cultural differences, climate, and socio-economic conditions. Therefore, data usually cannot be transferred from one place to another.

All waste studies and forecasts must focus on the waste ultimately supplied to the waste incineration plant. Consequently, the effect of recycling activities (for example, scavengers) that change the composition of the waste must always be considered.

In many developing countries, the domestic waste has a high moisture or ash content (or both). Therefore, a comprehensive survey must be taken to establish whether it is feasible to incinerate year-round, as seasonal variations may significantly affect the combustibility of the waste.

Waste from industries and the commercial sector (except for market waste) generally has a much higher calorific value than domestic waste. However, collection of such wastes is often less organized or controlled, and delivery to an incineration plant can be difficult. Some types of waste, such as demolition waste and waste containing certain hazardous or explosive compounds, are not suitable for incineration.

The waste composition may change in time because of either additional recycling or economic growth in the collection area. Both changes can significantly alter the amount of waste and its calorific value.

Key criteria

✓ ✓ ✓ The average lower calorific value of the waste must be at least 6 MJ/kg throughout all seasons. The annual average lower calorific value must not be less than 7 MJ/kg.

✓ ✓ Forecasts of waste generation and composition are established on the basis of waste surveys in the collection area for the planned incineration plant. This task must be carried out by an experienced (and independent) institution.

✓ ✓ Assumptions on the delivery of combustible industrial and commercial waste to an incineration plant should be founded on an assessment of positive and negative incentives for the various stakeholders to use the incineration facility.

✓ ✓ The annual amount of waste for incineration should not be less than 50,000 metric tons and the weekly variations in the waste supply to the plant should not exceed 20 percent.

Waste Generation and Composition

The quantity and composition of solid waste depend on how developed the community is and the state of its economy. Industrial growth is an important tool for raising the per capita income and welfare of the population. In return, industrial growth and higher per capita income generate more waste, which, if not properly controlled, causes environmental degradation.

Key figures for generation of municipal solid waste (MSW) appear in table 2.1. MSW is collected by, or on the order of, the authorities and commonly comprises waste disposed of at municipal collection facilities from households, commercial activities, office buildings, public institutions, and small businesses. The actual definition of "municipal solid waste" may, however, vary from place to place.

Urbanization and rapid growth of cities increase the amounts of waste generated in limited and densely populated areas. This, in turn, may eliminate the possibility of inexpensive disposal methods.

In more rural areas, crops and animal wastes are increasing as pesticides and fertilizers are applied more often. However, many of these biodegradable materials may be burned as fuel or easily converted into a soil conditioner and should not be regarded as true waste.

Table 2.1 Key Figures—Municipal Solid Waste (kg/capita/ year)

Area	*Waste generation [kg/cap./year]* *Range*	*Mean*	*Annual growth rate*
OECD—total	263–864	513	1.9%
North America		826	2.0%
Japan		394	1.1%
OECD—Europe		336	1.5%
Europe (32 countries)	150–624	345	n.a.
8 Asian capitals	185–1000	n.a.	n.a.
South and West Asia (cities)	185–290	n.a.	n.a.
Latin America and the Caribbean	110–365	n.a.	n.a.

Types of Waste

Domestic Waste Waste from household activities, including food preparation, cleaning, fuel burning, old clothes and furniture, obsolete utensils and equipment, packaging, newsprint, and garden wastes.

In lower-income countries, domestic waste is dominated by food waste and ash. Middle- and higher-income countries have a larger proportion of paper, plastic, metal, glass, discarded items, and hazardous matter.

Commercial Waste Waste from shops, offices, restaurants, hotels, and similar commercial establishments; typically consisting of packaging materials, office supplies, and food waste and bearing a close resemblance to domestic waste.

In lower-income countries, food markets may contribute a large proportion of the commercial waste. Commercial waste may include hazardous components such as contaminated packaging materials.

Institutional Waste Waste from schools, hospitals, clinics, government offices, military bases, and so on. It is similar to both domestic and commercial waste, although there is generally more packaging materials than food waste. Hospital and clinical waste include potentially infectious and hazardous materials. It is important to separate the hazardous and non-hazardous components to reduce health risks.

Industrial Waste The composition of industrial waste depends on the kind of industries involved. Basically, industrial waste includes components similar to domestic and commercial source waste, including food wastes from kitchens and canteens, packaging materials, plastics, paper, and metal items. Some production processes, however, utilize or generate hazardous (chemical or infectious) substances. Disposal routes for hazardous wastes are usually different from those for non-hazardous waste and depend on the composition of the actual waste type.

Street Sweepings This waste is dominated by dust and soil together with varying amounts of paper, metal, and other litter from the streets. In lower-income countries, street sweepings may also include drain cleanings and domestic waste dumped along the roads, plant remains, and animal manure.

Construction and Demolition Waste The composition of this waste depends on the type of building materials, but typically includes soil, stone, brick, concrete and ceramic materials, wood, packaging materials, and the like.

Generally, construction, demolition, and street sweeping wastes are not suited for incineration.

The composition of the various types of MSW varies greatly by climate and seasonal variations and the socio-economy of the waste collection area.

In general, high-income areas generate more waste than low- or middle-income areas. Thus, waste generation and composition may differ greatly even within the same metropolis.

Waste collected in affluent areas is typically less dense, as it contains more packaging and other lighter materials and less ash and food waste. This is because more ready-made products are consumed and the food processing takes place in the commercial/industrial sector.

The moisture is greater in lower-income areas due to the water content of the food waste and smaller amounts of paper and other dry materials. Annual variations in moisture content depend on climatic conditions such as precipitation and harvest seasons for vegetables and fruit.

Examples of the composition of waste from China, the Philippines, and European countries are presented in table 2.2.

Heating Value

Once ignited, the ability of waste to sustain a combustion process without supplementary fuel depends on a number of physical and chemical parameters, of which the lower (inferior) calorific value (H_{inf}) is the most important. The minimum required lower calorific value for a controlled incineration also depends on the furnace design. Low-grade fuels require a design that minimizes heat loss and allows the waste to dry before ignition.

During incineration, water vapors from the combustion process and the moisture content of the fuel disperse with the flue gasses. The energy content of the water vapors accounts for the difference between a fuel's upper and the lower calorific values.

The upper (superior) calorific value (H_{sup}) of a fuel may, according to DIN 51900, be defined as the energy content released per unit weight through total combustion of the fuel. The temperature of the fuel before combustion and of the residues (including condensed water vapors) after combustion must be 25° C, and the air pressure 1 atmosphere. The combustion must result in complete oxidation of all carbon and sulfur to carbon dioxide and sulfur dioxide, respectively, whereas no oxidation of nitrogen must take place.

The lower calorific value differs from the upper calorific value by the heat of condensation of the combined water vapors, which comes from the fuel's moisture content and the hydrogen released through combustion.

The ash- and water-free calorific value (H_{awf}) expresses the lower calorific value of the combustible fraction (ignition loss of dry sample) as stated on page 12.

Table 2.2 Composition of Municipal Wastes (percentage of wet weight)

% of waste		*Guangzhou, China, 8 districts*		*Manila*	*22 European Countries*	
	Year	*1993*		*1997*	*1990*	
	Ref.	*/7/*		*/9/*	*/3/*	
Fraction		*Range*	*Mean*	*Mean*	*Range*	*Mean*
Food and organic waste		40.1 – 71.2	46.9	45.0	7.2 – 51.9	32.4
Plastics		0.9 – 9.5	4.9	23.1	2 – 15	7.5
Textiles		0.9 – 3.0	2.1	3.5	n.a.	n.a.
Paper & cardboard		1.0 – 4.7	3.1	12.0	8.6 – 44	25.2
Leather & rubber		..	..	1.4	n.a.	n.a.
Wood		..	..	8.0	n.a.	n.a.
Metals		0.2 – 1.7	0.7	4.1	2 – 8	4.7
Glass		0.8 – 3.4	2.2	1.3	2.3 – 12	6.2
Inerts (slag, ash, soil, etc.)		14.0 – 59.2	40.2	0.8	..	..
Others		..	..	0.7	6.6 – 63.4	24.0

Notes: n.a. = Not applicable
.. = Negligible

Determination of H_{awf}

1. In a laboratory, the upper calorific value of the dry sample $H_{sup,DS}$ is determined according to DIN 51900.
2. H_{awf} is then determined according to the following formula:

$$H_{awf} = H_{inf,DS} / (1-A) * M_{CW} * 2445 \text{ in kJ/kg},$$

where A is the ash content per kg dry sample and M_{CW} is the weight of the condensed water per kg dry sample.

As a rule of thumb, H_{awf} may be estimated at 20,000 kJ/kg for ordinary MSW, except when the waste contains extreme amounts of a single material—such as polyethylene—which has about double the energy content.

Municipal waste is an nonhomogeneous fuel that differs greatly from conventional fossil fuels. Calculating the calorific value of MSW is, therefore, complex and may lead to gross errors if done incorrectly. The representativeness of the samples analyzed is most critical, and variations must be accounted for.

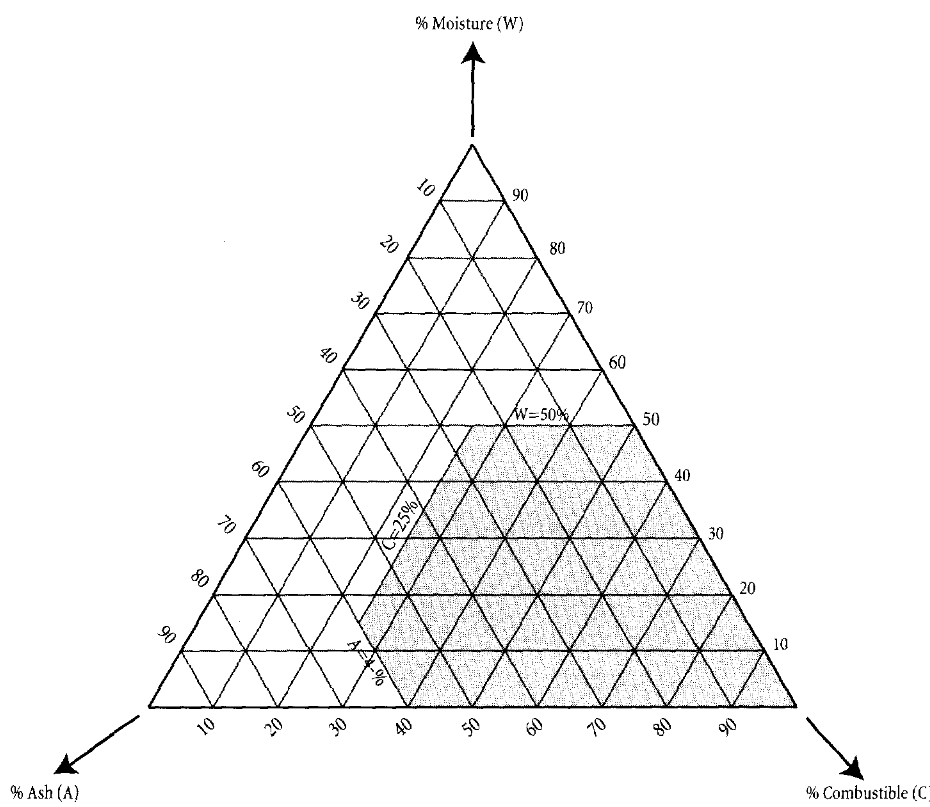
Assuming that it is not possible to assess the fuel characteristics of a particular waste from test runs at an existing waste incineration plant, more or less sophisticated evaluation methods may be applied.

A first indication may be obtained simply by establishing the following three parameters (in percentage by weight):

A: Ash content (ignition residuals)
C: Combustible fraction (ignition loss of dry sample)
W: Moisture of raw waste

The lower calorific value of a fuel may then be calculated from the following:

Figure 2.1 Tanner Triangle for Assessment of Combustibility of MSW



$$H_{inf} = H_{awf} * C - 2445 * W \text{ in kJ/kg}$$

Assuming that the waste has no dominant fraction with an extremely low or high calorific value, the lower calorific value may be obtained by applying an approximate value of 20,000 kJ/kg for H_{awf}:

$$H_{inf} \cong 20{,}000 * B - 2445 * W \text{ in kJ/kg}$$

The result may also be plotted in a Tanner triangle diagram to see where it falls within the shaded area indicating a combustible fuel (figure 2.1). The waste is theoretically feasible for combustion without auxiliary fuel when: $W < 50$ percent, $A < 60$ percent, and $C > 25$ percent.

A more accurate way to assess the fuel quality of a waste is to divide it into characteristic components (organic waste, plastics, cardboard, inert materials, and the like), determine the water content (%W), the ash content (%A) and the combustible matter (%C). The lower calorific value for each component can be found in laboratory or literature values for H_{awf} for that component. Finally, the overall lower calorific value and ash content are calculated as the weighted average for all components.

Table 2.3 provides examples of the results of this simple waste analysis, as well as the lower calorific value determined as the weighted average of the heat value for characteristic components of the waste. The waste from Manila has the highest combustible content and calorific value.

The method of calculating the calorific value as the weighted average of characteristic fractions of the waste is further illustrated in table 2.4.

See table 2.9, page 17, for more accurate literature values on H_{awf}.

Waste Surveys/Forecasts

Estimating the amount and composition of solid waste requires in-depth knowledge of the waste collection area's demographic and commercial/industri-

Table 2.3 Fuel Characteristics of Municipal Wastes

		Guangzhou China			
			8 districts-93	5 districts-94	Philippines
Parameter	*Units*	*Range*	*Mean*	*Mean*	*Manila - 97*
Combustible	%	14.6 – 25.5	22.3	31.4	37.6
Ash	%	13.8 – 43.1	28.8	22.0	15.6
Moisture	%	39.2 – 63.5	48.9	46.6	46.7
Lower calorific value	kJ/kg	2555 – 3662	3359	5750	6800

Table 2.4 Example of Calculation of Lower Calorific Value from Analysis of Waste Fractions and H_{awf} Values from Literature

Mass basis		*Fraction basis*				*Calorific values*	
Fraction	*% of Waste*	*Moisture W %*	*Solids TS%*	*Ash A%*	*Combustible C%*	*H_{awf} kJ/kg*	*H_{inf} kJ/kg*
Food and organic waste	45.0	66	34	13.3	20.7	17,000	1,912
Plastics	23.1	29	71	7.8	63.2	33,000	20,144
Textiles	3.5	33	67	4.0	63.0	20,000	11,789
Paper & cardboard	12.0	47	53	5.6	47.4	16,000	6,440
Leather and rubber	1.4	11	89	25.8	63.2	23,000	14,265
Wood	8.0	35	65	5.2	59.8	17,000	9,310
Metals	4.1	6	94	94.0	0.0	0	–147
Glass	1.3	3	97	97.0	0.0	0	–73
Inerts	1.0	10	90	90.0	0.0	0	–245
Fines	0.6	32	68	45.6	22.4	15,000	2,584
Weighted average	100.0	46.7	53.3	10.2	43.1		7,650

al structure. Reliable waste generation data and forecasts are scarce in most countries. Data and key figures are often related to the overall waste generation/disposal of large cities and municipalities. Significant differences will, however, exist between waste generation and composition in a city's various zones such as its high- or low-income residential, commercial and industrial areas.

Literature is available on key figures for waste generation and composition. When properly selected and applied, such data may be used for a preliminary assessment of the feasibility of various waste treatment methods. For design purposes, however, it is best to establish and apply specific data for the area. It is recommended that waste quantity and quality be surveyed year-round to monitor the seasonal variation both in amounts and in waste characteristics. This may be particularly important in regions with distinct tourist seasons, high monsoon rains, and the like.

Waste Forecasts

To be economically feasible, waste incineration plants must have a life span of at least 15 to 20 years. Waste quantity and composition should be forecast over the lifetime of the incineration plant. A waste generation forecast requires a combination of data normally used for town planning purposes along with specific waste generation data (see table 2.5).

Changes in waste composition will be influenced by government regulations of issues such as recycling and the overall economic development of society. However, possible development trends maybe obtained by studying the waste composition in different parts of the same metropolis—for instance, in high-, medium-, and low-income areas. Literature on investigations from similar societies may also be useful. Annual variations are likely to continue according to the present pattern.

As an example, the forecast for the domestic waste for the year (n) may be calculated according to the formula below. Variables include the present population, the expected long-term annual growth, the most recent waste generation key figure, and the foreseen increase in this figure.

$$\text{Domestic waste} = PP \times (1 + GR_{PP})^n \times w_c \times (1 + GR_{KF})^n$$

PP is the present population, GR the growth rate and w_c is the actual key figure, waste generation per capita.

If available, the per capita generation key figure (wc) should be determined by assessing reliable existing waste data. If reliable data is not available, an accurate waste survey should be carried out. An example of per capita generation key figures are shown in table 2.6.

Waste Survey

If reliable waste data and record keeping systems are not available, a waste survey should be used to generate statistically significant results. The survey must consider a large number of parameters selected according to the objective of the study—for example, waste quantity or composition. Also, to detect seasonal variations, the survey should be performed all through the year. Generally, continuous reliable waste data recording and record keeping are important for developing

Table 2.5 Waste Generation Forecast Parameters

Parameter	*Development trend*
Population	Growth/year (overall and by district)
Industrial employment/industrial area build up	Growth/year
Commercial sector employment	Growth/year
Gross domestic product (GDP)	Annual general prosperity growth
Waste generation key figures	Growth/year
Waste composition	Function of socio-economic development

Table 2.6 Per Capita Generation Data for Selected Countries

		Estimated Domestic Waste Generation	
Country		*Year*	*kg/capita/day*
China	general	1990–96	0.5
	cities	1990–96	0.8–1.2
USA		1990	2.0
		1985	1.8
Japan		1990	1.1
		1985	1.0
France		1990	1.0
		1985	0.8
Denmark		1996	1.5
		1990	1.0

realistic waste management plans, monitoring the effects of waste management strategies, and publicly controlling waste flows and the performance of waste management organizations.

The degrees of freedom are statistically reduced when the sampling point moves away from the origin of the waste and towards the disposal site—that is, fewer samples are required to obtain the desired precision of the data. In return, a number of systematic errors may be introduced. For example, scavenging and other recycling activities will reduce weight and change the composition of the waste. In developing countries, where there is much scavenging, the calorific value of the waste may be reduced considerably due to recovery of wood, plastic, textiles, leather, cardboard, and paper. Plus, the weight of the waste may be influenced by climatic conditions on its way from the point of origin to ultimate disposal. During dry seasons, weight is lost through evaporation, and precipitation during the wet season may increase the weight.

Waste Quantity—Key Figures and Annual Variation

For well-organized waste management systems where most of the waste ends up in controlled landfills, long-term systematic weighing of the incoming waste will allow a good estimate of the key figures for waste generation and the annual variation. Thus, landfills and other facilities receiving waste must have weighing bridges to produce reliable waste data.

To establish waste generation key figures, waste quantity should be registered systematically and fairly accurately. For every load, the collection vehicles must submit information about the type of waste and its origin. Further information about the district where the waste was collected can be obtained from town planning sources and the socio-economic aspects can consequently be included in the key figure calculations. Table 2.7 indicates how a waste collection area may be divided into collection districts to reflect characteristics of waste generation.

In places with no waste registration records, typical districts may be outlined according to Table 2.7. Then, the collected waste should be systematically weighed. The registration should continue for at least a full year to detect any seasonal variations. Great care must be taken to ensure that no changes are introduced in the collection districts, which could make the results ambiguous.

Introducing a waste incineration plant will reduce the livelihood of landfill scavengers. They may move to a new place in front of the treatment plant, thus changing the composition and calorific value of the waste. It is important to assess the impact of such a change, according to the amount the scavengers remove at the existing landfill.

Waste Composition

Waste composition varies with the waste type, the socio-economic conditions of the collection area, and seasonal variations. Planning a comprehensive survey of the composition of waste types therefore requires input from a town planner, a waste management expert, and a statistician.

The survey planners should do at least the following:

- Divide the waste collection area into zones according to land use.
- Subdivide land-use zones according to types of waste generated (see table 2.7).
- Identify well-defined and representative waste collection districts for the types of waste.
- Choose one or more representative districts to survey for each type of waste.
- Select the point of waste interception in such a way that the waste will reflect what will reach a future treatment facility or incineration plant.

Table 2.7 Waste Types and Collection Districts

Waste type	*Collection District*		
Domestic	High income	Medium income	Low income
Commercial	Shopping/office complexes	Department stores	Markets
Industrial	Large enterprises	Medium industries	Small industries

- Establish baseline data for the district (population, industry, trade, and such).
- Monitor the amount of waste generated in the district and the daily number of truckloads.
- Statistically assess the number of samples required to obtain a 95 percent confidence level on the waste composition. The distribution of the individual waste component can be assumed to be Gaussian. However, there should never be less than 25 of each type of waste.
- Assess whether the seasonal variation necessitates more than one round of sampling (for example, summer/winter or wet/dry).

Executing the practical part of the waste composition survey requires additional careful planning. The physical facilities must be prepared to protect the staff performing the sorting and ensure that samples and results remain representative. Sorting is best carried out in well-vented buildings with concrete floors to ensure that no waste is lost. The sorting station must be furnished with sorting tables, a screen, easy-to-clean buckets or containers, and at least one scale. The logistics are summarized in table 2.8.

Sorting waste to a reasonable degree of accuracy requires that staff have advanced training. The pickers must learn to recognize the different waste categories—especially different types of plastics. They must empty cans, jars and bags before placing them in containers. To ensure consistency, the sampling and sorting process must be controlled and supervised by the same person throughout the waste survey. Furthermore, all procedures, including laboratory analyses and methods of calculation, must be described in detail in a waste characterization manual.

Sorting categories should be based on the amount of the characteristic categories and their influence on the calorific value. Table 2.9 presents some of the typical characteristic categories. The recommended minimum number of categories are presented together with optional subdivisions. Typical lower calorific values for the ash and water free samples (H_{awf}) are given for each type of material. These values are approximate, and laboratory measurements of H_{awf} should to a certain extent be applied to supplement and confirm or substitute literature values when calculating the overall heat value of the waste.

Table 2.8 Logistics and Principles of Sampling and Analysis of Waste Data

Sampling	The collection vehicle from the representative collection district is intercepted according to the plan.
Weighing	The vehicle is weighed full and later empty resulting in the total waste weight. The waste volume is determined/ estimated and the average density calculated.
Subsampling	Sometimes sorting of full truckloads is too time consuming. Preparing a representative subsample (perhaps 100 kg) often makes it possible to sort waste from more trucks and thereby makes the result more significant. However, preparing a representative subsample is not simple, and a detailed procedure for this routine must be prepared – for example, accounting for drained-off water.
Sorting	The waste is unloaded on the floor of the sorting building. It is then spread in layers about 0.1 meter thick on sorting tables covered by plastic sheets. The waste is manually sorted according to the predetermined material categories. The leftover on the table is screened (with a mesh size of about 12 mm). The screen residues are again sorted manually, and the rest is categorized as "fines." This procedure is followed until the entire load or subsample – including floor sweepings – has been divided into the appropriate fractions.
Physical Analysis	All fractions are weighed and the moisture content determined through drying after shredding at 105° C until a constant weight is obtained (about 2 hours). The moisture content is determined on representative samples of all fractions on the day of collection.
Chemical Analysis	The chemical analysis should be performed at a certified laboratory. The key parameters are ash content and combustible matter (loss of ignition at 550° C for the dried samples) and net calorific value for at least the food and the fines fractions. Samples must be homogenized through proper repetitive mixing and grinding, and at least three analyses should be performed on each fraction to minimize analytical errors.
Data Processing	The wet and dry weight waste composition are calculated together with the interval of confidence.

Table 2.9 Ash and Water Free Calorific Value (Hawf) for Selected Types of Waste

Component		
Main category (mandatory)	*Subcategories (optional)*	H_{awf} *(MJ/kg)*
Food scraps and vegetables (to be analyzed in each case)		15–20
Plastics	Polyethylene (bottles, foil, etc.)	45
	PVC (bottles, etc.)	15–25
	Polystyrene (wrapping)	40
	Polypropylene	45
Textiles		19
Rubber and leather		20–25
Paper	Dry	16–19
	Wet	16–19
Cardboard	Dry	16–19
	Wet	16–19
Wood and straw		19
Other combustibles		*
Metals		0
Glass		0
Bones		0
Other noncombustible		0
Hazardous wastes		*
Fines (<12 mm mesh)		15 (to be analyzed in each case)

Note: * = Depends on chemical makeup of material.

Ultimately, the waste survey allows a calculation of the average lower calorific value for each type of waste.

The formula for determining the lower calorific value (H_{inf}) for each type of waste is:

$$H_{inf} = H_{awf} * C/100 - 2445 * C \text{ (kJ/kg)}$$

By weighting these individual H_{inf} for each type of waste with the percentage wet weight (M), the overall lower calorific value can be found by applying the following formula.

$$H_{inf,\,overall} = M1/100 * H_{inf,1} + M2/100 * H_{inf,2} + \cdots + M_n/100 * H_{inf,n}$$

Waste Load Design Calculation

The waste survey and forecast will establish the expected amount and composition of waste generated during the lifetime of the facility (for example, a 20-year period). The actual volume of waste arriving at the incineration plant will depend on the efficiency of the collection system, together with negative and positive incentives for supplying the waste to the plant. The most negative incentive may be an increased gate fee compared to fee of landfilling.

Before deciding on the plant's design capacity, it is recommended to apply a factor for collection efficiency to the theoretical amounts. This is especially important for commercial and industrial waste, which may include a larger proportion of materials suitable for recovery and recycling.

The waste load on the incineration facility will consist of a combination of domestic, commercial, and industrial waste.

The basic load will, however, be domestic waste, which can be assumed to be supplied almost entirely to the incineration plant.

Separate collection of waste with a high energy content can theoretically increase the calorific value of the waste fuel. However, this method is likely to fail in the practical world due to a lack of efficient waste separation at the source and the additional cost involved in the collection system. Incineration of waste from certain areas (typically the more affluent ones) may, however, be feasible.

Mechanical sorting is another way to raise the average calorific value before incineration. This is typically a step in the production of waste-derived fuel, and suitable technology is available, but it usually isn't used before mass burning because of additional costs.

3 Institutional Framework

Key Issues

The success of an MSW incineration plant depends as much on the institutional framework as on the waste and technology. Four main institutional framework areas must be considered: the waste sector, the organization and management of the incineration plant itself, the energy sector, and the authorities responsible for control and enforcement.

The institutional framework for the waste sector and the waste management system must be sufficiently developed to ensure supply of the design waste flow and quality of waste for the life span of the incineration plant. The waste sector must further design and operate a controlled landfill for environmentally safe disposal of the incineration residues.

An organizational setup that can administer the plant and support the waste incineration project so that it becomes an integral part of the waste management system is crucial. There should be a high degree of interaction between the different parts of the waste management system and the waste incineration plant either through ownership or long-term agreements.

Incineration is significantly more costly than using landfills. The waste generators—that is, the population and the commercial sector—must therefore be willing to pay the additional cost, or else there must be a subsidy scheme. Insofar as the operator/owner of the MSW incineration plant is supposed to collect treatment charges, there must be ways to enforce this.

When ownership is private, there may be institutional borderline problems in the delivery of a sufficient quantity and quality of waste, the pattern and price of sale of energy, or both. Waste flow must be controlled, thus ensuring that it is delivered to the most appropriate plant and, in particular, that indiscriminate dumping is avoided. Waste flow can be controlled by a combination of tariff policy (including cross-subsidization via the tipping fee at the licensed facilities), enacting and enforcing waste management legislation, and a waste data and record keeping system.

Traditionally, the waste management sector is viewed as an undesirable place to work. In some regions, this has resulted in poorly managed waste services. Plus, it has been difficult to recruit and maintain qualified staff—for instance, in rapidly growing economies where the public sector cannot match the salaries of private companies.

In particular, operating and maintaining waste incineration requires highly skilled and effective management—which means that new and skilled managers may have to be attracted. Existing staff will have to be trained and capacity will have to be expanded. Also, it should be decided whether to involve the private sector in operation and maintenance. The necessary skills and education resemble the human resource demands in the energy sector, for example, management of power plants.

To ensure proper and environmentally safe operation, authorities responsible for control and enforcement must be on hand. These authorities must be independent of the owner and operator of the waste incineration plant.

In general, incineration plants are influenced by and depend on numerous legal, institutional, and socioeconomic factors in the environment. To assess fully the appropriateness of a proposed institutional framework, a comprehensive stakeholder analysis must be performed for both the existing and any projected situations.

Key Criteria

✓ ✓ ✓ A well-functioning solid waste management system, including a properly engineered and controlled landfill, has been present for a number of years.

✓ ✓ ✓ Solid waste collection and transportation (domestic, commercial, and industrial) are managed by a limited number of well-regulated and controlled organizations.

✓ ✓ ✓ There are signed and approved letters of intent or agreements for waste supply and energy sale.

✓ ✓ ✓ Consumers and public authorities are able and willing to pay for the increased cost of waste incineration.

✓ ✓ ✓ Authorities responsible for control, monitoring, and enforcing operation are present.

✓ ✓ The authorities responsible for control, monitoring, and enforcement are independent of the ownership and operation of the plant.

✓ ✓ Skilled staff for plant operation are available at affordable salaries. Otherwise, reliable operation and/or maintenance contracts are in place either in the form of operation and service contracts or via BO/DBO/BOOT/BOO schemes.

✓ The waste management authority owns the incineration plant.

✓ Municipal guarantees cover any shortfalls in the plant economy due to insufficient supply or quality of waste.

Waste Sector

The waste sector includes public institutions and organizations as well as private companies involved in collection, transportation, and final disposal of all types of solid waste. Generally, collection of waste from households and shops in residential areas is based on a public initiative. Large commercial centers, office complexes, and industries are, however, often required to arrange their own waste collection and disposal. Thus, there may be many operators involved in solid waste collection and transportation.

A fully developed and controlled solid waste management system is a precondition for establishing an MSW incineration plant. A functional management system should have been in placefor at least a few years before implementing the incineration plant.

A well-functioning solid waste management system ensures that all domestic, commercial, and industrial wastes are collected, transported, and disposed of in a hygienic and environmentally safe manner at sanitary landfills. Where such systems do not exist, the collection is much less efficient, and a significant part of the waste is likely to be disposed of through uncontrolled dumping.

If the waste management system is not fully controlled, increased incineration costs are likely to instigate more illegal waste disposal activities. The ultimate effect may be that the supply to the plant becomes insufficient in quantity or quality.

From waste generation to disposal, various kinds of more or less organized recycling activities take place. The commercial sector and the industries employ their own staff to salvage materials to sell and recycle. Scavengers may be found at any stage of the handling system. They search dust bins and containers close to the point of origin of the waste dump sites. Disturbing the waste flow by introducing solid waste treatment facilities may "force" the scavengers to shift their operation from the end of the waste chain toward the beginning—thus changing the waste composition believed to be available.

The complexity of the waste management system has occasionally caused legal problems regarding the ownership of the waste. The crucial question is: When does waste change from private property to a public nuisance or asset? If this is not clear from a legal point of view, it is difficult to commit or ensure the supply of waste to the treatment facility. Thus, regulatory changes may be necessary.

Payment for services rendered is generally crucial in waste management. Public health protection requires waste to be collected and disposed of away from inhabited areas, but not all areas or sectors may be willing or able to pay for such services. The only secure way of recovering the costs is through mandatory service charges collected from the waste generators—possibly together with property taxes or service charges for water and electricity.

Private waste operators serving trade and industry are likely to dispose of waste in the cheapest possible way, even using an illegal method such as indiscriminate dumping. Strict control and enforcement are required to prevent such activities.

Energy Sector

Incineration plants consume and generate large amounts of energy and are therefore important players in the local energy market—especially in relatively small communities. It is thus important to establish whether an incineration plant for solid waste can be integrated into the legal and institutional framework of the energy sector.

The energy sector is often heavily regulated. Concession to produce and sell electricity is generally granted only to a limited number of public or private operators. An incineration plant established by another organization may therefore face opposition in obtaining necessary approval. Cooperation with existing energy producers or consumers can therefore be useful.

Prices of energy paid by consumers may be subsidized or taxed rather than based solely on production costs. The prices of energy from waste incineration may therefore have to be fixed by the government—which brings up important political and socio-economic considerations. A high price resulting in a reduced gate fee will subsidize the waste sector, whereas a low price will favor the energy consumers.

It is most feasible when the energy can be sold to a single consumer for its own use or resale. The consumer may be a utility company with an existing distribution network for district heating or power or a large steam-consuming industrial complex.

The purpose of solid waste incineration plants is to treat waste and hence reduce the waste volume for disposal. The design and layout of an incineration plant are based on continuous operation at 100 percent load. In principle, the energy output will be almost constant 24 hours a day. The waste energy can therefore be regarded as a supplement to other fossil fuel-based energy sources that are operated at a load corresponding to the actual energy demand. Normally, the energy produced from incineration plants is regarded as base load. Depending on the price pattern, the price of the waste generated energy will reflect this base load status.

To use all the energy produced, incineration plants should mainly be established in large energy networks where they can function as base load units with both diurnal and seasonal variation.

Incineration Plant Organization and Management

Ownership and Operation

MSW incineration plant ownership and allocation of operational responsibility is of great importance. Different kinds of borderline problems may arise depending on the model. These problems are related to supply and quality of waste, as well as sale and distribution of heat, or both—depending on whether the plant belongs within the waste sector, the energy sector, or to a private operator.

Incineration plants belonging to the solid waste management organization responsible for waste collection, transportation, treatment, and ultimate disposal generally experience few problems regarding the supply of "fuel" or disposal of residuals. The main institutional problems are related to the selling and distributing energy.

Alternatively, the incineration plant may be located within the energy sector and belong to the power supply companies. Here, there are no problems with selling and distributing energy. However, there may be problematic cultural differences between the energy sector and the waste sector.

The energy sector is accustomed to a highly standardized fuel quality and is not used to variations in quantity and quality of waste. Normally, energy producers modulate the operational pattern according to the energy demand. MSW incineration plants, however, have to follow the pattern of supply rather than demand. They must therefore accept variations in quantity and quality of the fuel and energy output. An energy sector–based incineration plant owner will therefore try to exercise control over maximum and minimum waste supply and quality.

Privatization of incineration plants can include combined ownership and operation or operation only. Fully privatized facilities may experience borderline problems towards both the waste management and energy sectors. Establishing the necessary agreements is complicated, and problems monitoring and controlling the waste supply and energy sale will develop.

The borderline problems between the sectors must be solved through firm and irrevocable agreements before plans are made to build the plant. Otherwise, the feasibility of the plant is jeopardized.

Staff recruitment and maintenance may be crucial when deciding on the plant's ownership. In booming economies, the government often pays significantly smaller salaries than the private sector. In return, the government and other authorities often provide pension schemes and greater job security than the private sector.

This may make it difficult for the public sector to attract enough qualified staff. Staff trained at the plant's expense may leave for better paying jobs. The privately owned and operated facilities can better retain staff, since they can pay competitive salaries and incentives. Both private and publicly operated plants must, however, expect to have a continuous human resource development (HRD) program to maintain staff for plant operation and maintenance.

The organizational setup and financial management system for the incineration plant can influence plant upkeep and maintenance. Several special equipment spares and components may be available only from abroad. Because spending foreign currency can be restricted or may require an extended approval process, procuring emergency replacement parts may cause the plant to shut down for long periods of time.

It is preferable for the incineration plant to be an economic entity of its own, whether publicly or privately owned and operated. This gives the plant manager the freedom to acquire local spares and maintenance contracts quickly.

Waste incineration is significantly more costly than waste disposal in sanitary landfills, even after incorporating the revenues from sale of energy. The additional costs can seldom be collected as a gate fee alone, because the waste might be taken and disposed of in an uncontrolled manner. The budget deficiency must be covered by general waste service charges, otherwise collected or compensated for through subsidies.

Waste management charges should generally be collected by an authority which holds sufficient legal power to apply reprisals when payments are not made. Establishing new entities solely to collect incineration fees is costly and must be accompanied by an allocation of enforcement power to collect overdue payments.

Tender Models for Waste Incineration Plants

Table 3.1 outlines the principal tender models and ownership and management models for waste incineration plants.

The traditional tender model is the multiple contract or single turnkey contract model. After commissioning the plant, the client—typically the municipality, a group of municipalities, or a public waste management institution—begins operating the plant.

These models ensure the most public control of service level, plant performance, plant finance, and tariff setting. However, the client must bear the financial burden of the investment and acquire the management and technical skills for implementing and operating the plant. A time-limited management and training (HRD) contract (about 1 or 2 years) must be included in the scope of supply.

If the multiple contract model is applied, the division into lots must be limited and respect the natural entities. The furnace and boiler, for instance, must be in one lot. However, unless the client has experienced personnel with firm knowledge of procurement and waste incineration skills, it is strongly advisable to divide the lots into no more than two main supplies: complete machinery and structural.

The operation contract has been applied where municipalities wish to free resources from operational duties or where it has been more economical to let an experienced private contractor operate and

Table 3.1 Applicable Tender and Contracting Models for Waste Incineration Plants

Tender Model	*Client's Obligations*	*Contractor's Obligations*	*Advantages*	*Constraints*
Multiple contracts	Financing. Function specifications, tendering, project coordination, and construction supervision. Ownership and operation.	Supply and detailed design of individual parts for the plant.	Full client control of specifications. Possible to create the optimum plant based on most feasible plant components.	Absolute requirement for project management and waste incineration skills in the client's organization.
Single turnkey contract	Financing. Function specifications, tendering, and client's supervision. Ownership and operation.	Responsible for all project design, coordination, and procurement activities.	One contractor has the full responsibility for design, erection, and performance.	Limited client control of choice of plant components.
Operation contract	Multiple or single turnkey contract. Ownership. Supply of waste.	Operation of the completed and functional plant in a certain period.	Limited strain on the client's organization.	Difficult for client to secure affordable tariffs, (put or pay contract), control finances, and monitor the contractor's performance and service level.
Build Operate	Financing, function specifications, tendering, and client's supervision. Ownership. Supply of waste.	Detailed design, project management, contractor's supervision, operation, and maintenance.	Contractor committed to well-functioning and effective solutions. Limited strain on client's resources.	Difficult for client to secure affordable tariffs (put or pay contract), control finances, and monitor the contractor's performance and service level.
Design Build Operate	Financing. Overall function specifications and tendering. Ownership. Supply of waste.	Detailed design, project management, supervision, operation, and maintenance. Ownership.	Contractor committed to well-functioning and effective solutions. Limited strain on client's resources.	Difficult for client to secure affordable tariffs (put or pay contract), control finances, and monitor the contractor's performance and service level. Limited client control of choice of plant components.
Build Own Operate Transfer	Overall function specifications and tendering. Ownership after transfer. Supply of waste.	Financing, design, project management, supervision, operation, and maintenance. Ownership until transfer.	Contractor finances, constructs, and operates the plant for a period after which the plant is transferred to the client. Very limited strain on client's resources.	Difficult for client to secure affordable tariffs (put or pay contract), control finances, and monitor the contractor's performance and service level. Limited client control of choice of plant components.
Build Own Operate	Overall function specifications and tendering. Supply of waste.	Financing, ownership, design, project management, supervision, performance guarantees, operation, and maintenance.	Client does not need to finance the project. Contractor committed to well-functioning and effective solutions. Very limited strain on client's resources.	Difficult for client to secure affordable tariffs (put or pay contract), control finances, and monitor the contractor's performance and service level. Limited client control of choice of plant components.

maintain the plant. It is also applicable where the client has established a plant according to one of the aforementioned models but wants a different contractor—for example, a local company—to operate the plant.

There are several variants for using private contractors in designing, financing, and operating incineration plants. In one common variant of privatization, supervision and control of private contractors is performed by highly skilled clients (municipalities/authorities). In particular, the client must have highly skilled legal, contractual, and financial specialists to set up contracts for implementing, operating, owning, and financing incineration plants with private contractors. Detailed and professional contracts must be established to protect the client's obligation to provide efficient, affordable, and environmentally sustainable waste management services to the community.

In general, the client loses financial and technical maneuverability when entering into long-term service contracts with private contractors, but on the other hand, financial resources and staff are liberated for other purposes. The client must also offer guarantees on the supply of waste, sale of energy, and payments to the contractor (put or pay contracts). The put or pay contracts are the contractor's insurance against increased net treatment cost if major preconditions fail—for example, minimum waste supply or calorific value of the waste. (For information on the consequences when preconditions fail, see chapter 4—particularly figure 4.4.)

The client will also be asked to issue guarantees for the servicing of the loans used by the contractor to finance building the plant.

Deciding whether to contract out the establishment, operation, financing, or ownership of incineration plants to private contractors should not be taken lightly. It is important to weigh consciously the advantages and constraints of all options against the local conditions—in particular, the client's creditworthiness and resources in terms of capital and staff skills, as well as the actual legal framework for publicly monitoring and controlling a private contractor.

Authorities

Authorities responsible for control, monitoring, and enforcement must be present to ensure proper plant operation and compliance with the environmental standards against which the incineration plant was approved and intended. These authorities must be independent of the ownership and operation of the plant.

About once a month, the plant management must submit reports on the average flue gas emission values, amounts and composition of residues, flue gas retention times, and other operational parameters (for more information, see part 2). The report must clearly state all exceeded limits and explain them.

Based on these reports, correspondence with the plant management, and inspections, the authorities must take proper action if the plant is not operated in an environmentally safe way.

4 Incineration Plant Economics and Finance

Key Issues

Waste incineration involves high investment costs with a large share of foreign currency and high operating and maintenance costs. Hence, the resulting net treatment cost per metric ton of waste incinerated is rather high compared to the alternative (usually, landfilling).

Depending on the actual costs (which are sensitive to the size of the plant) and revenues from the sale of energy, the net treatment cost per metric ton of waste incinerated will normally range from US$25-$100 (in 1998) with an average of about US$50. Depending on the quality (for example, number of membrane layers and leachate treatment) of the actual landfill site, the net cost of landfilling ranges from US$10-$40.

Thus, higher net treatment cost is a critical issue when considering implementing a waste incineration plant. Financing can be done in terms of tipping fees, a general levy, public subsidies, and combinations thereof. However, the ability and willingness to pay should be considered thoroughly to avoid the risk of uncontrolled dumping or burning is latent.

Key Criteria

✓ ✓ ✓ There is a stable planning environment (15 to 20 years) with relatively constant or predictable prices for consumables, spare parts, disposal of residues, and sale of energy. Furthermore, the capital costs (large share of foreign currency) can be predicted.

✓ ✓ ✓ Financing the net treatment cost must ensure a waste stream as intended in the overall waste management system. Consequently, the waste incineration tipping fee must be lower than (or at least, no greater than) the fee at the landfill. Willingness and ability to pay must be addressed.

✓ ✓ ✓ Foreign currency is available for purchasing critical spare parts.

✓ ✓ To be economically feasible, the capacity of the individual incineration lines should be at least 240 t/d (10 t/h). A plant should have at least two individual lines.

✓ ✓ When surplus energy is to be used for district heating, the incineration plant must be located near an existing grid to avoid costly new transmission systems.

✓ If a regular market for the sale of hot water (district heating or similar) or steam is present, the plant should be based on the sale of heat only—both in terms of technical complexity and economic feasibility. A certain extent of cooling to the environment during the warm season may be preferable to costlier solutions.

Economics

The mass burning principle with a moving grate is applied in the following economic analysis and estimate of the investment costs for the machinery. This is the most widespread and well-tested technology for incinerating MSW. Furthermore, other technologies cannot be recommended for incineration of normal MSW (see part 2 of this guide).

Investment Costs

The actual investment cost for a waste incineration plant depends on a wide range of factors, especially the size (capacity) of the plant—the number of metric tons per year or day and the corresponding lower calorific value of the waste. Low-capacity plants are relatively more expensive than high-capacity plants in terms of investment cost per metric ton of capacity.

The machinery (and hence, the investment costs) depends on the type of energy production, ranging from simple cooling of all excess heat (no energy sale) to combined heat and power production. Furthermore, the equipment necessary for flue gas cleaning is to a great extent determined by the desired or required emission quality level, which consequently influences the investment costs.

The investment costs as a function of the annual (and daily) capacity for a typical new waste incineration plant are estimated in figure 4.1. A lower calorific value of the waste of 9 MJ/kg (2150 kcal/kg) is assumed as the design basis. A higher calorific value will increase the actual investment costs and vice versa.

Furthermore, the following preconditions corresponding to a typical plant configuration in South and Southeast Asia apply.

- *Number of incineration lines.* The minimum capacity of each incineration line is 240 t/d (10 t/h) and the maximum is 720 t/d (30 t/h). There should be at least two incineration lines—so plants should be at least approximately 500 t/d. When calculating the necessary daily capacity based on the annual dimensioning waste volume, an availability rate (number of operating hours a year) of 7500 is presumed. Furthermore, 5 percent excess capacity is presumed to cover conditions such as seasonal variations.

- *Energy production.* The plant produces steam primarily for electricity production but if it also is involved in combined heat and power production or sale of electricity and steam, excess heat is cooled away. Hence, the plant is equipped with steam boilers, turbine units, and condensing/cooling units.

- The total investment cost can be reduced by approximately 30 percent if the plant is equipped for hot water production only.

- *Flue gas cleaning.* The plant is equipped with dry or semidry scrubbers and a subsequent electrostatic precipitator or bag-house filter to exercise medium level emission control.

The total investment cost can be reduced by approximately 10 percent if the plant is equipped for compliance with basic-level emission control. However, if the plant has to comply with advanced-level emission control, the total investment cost must increase approximately 15 percent.

In figure 4.1, the average investment cost per daily capacity in metric tons is calculated according to the aforementioned preconditions.

Normally, at least 50 percent of the investment costs for the machinery part of the plant has to be covered by foreign currency.

Operating and Maintenance Costs

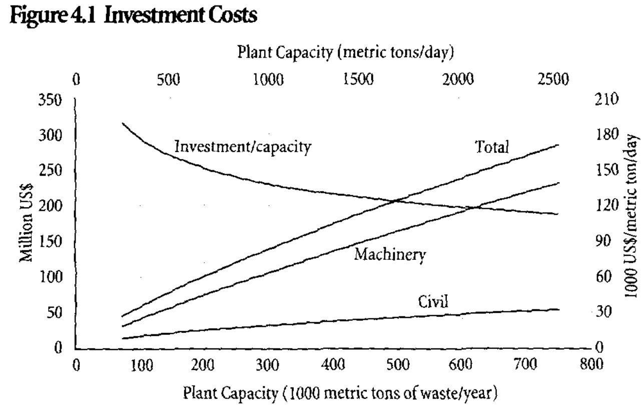
The operating and maintenance costs comprise:

- *Fixed operating costs*
  Cost of administration and salaries

- *Variable operating costs*
  Cost of chemicals for the flue gas cleaning system
  Cost of electricity (if the plant is equipped with a steam turbine and a turbine/generator set, there will be a net production of electricity)
  Cost of water and handling of waste water
  Cost of residue disposal

- Maintenance costs
  Cost to maintain the machinery (such as spare parts)
  Cost to maintain the buildings

Figure 4.1 Investment Costs



The fixed operating costs depend heavily on the number of employees, the percentage of skilled and unskilled workers and engineers, and the local salary level. The annual fixed operating costs for plants in South and Southeast Asia are estimated at 2 percent of the total investment.

The variable operating costs will to a certain extent depend on the specific flue gas cleaning system. But more important, the actual cost of disposal of the residues from the flue gas cleaning has a strong influence on the variable operating costs. Based on a disposal cost of approximately US$100 per metric ton of APC (Air Pollution Control) residue and US$5 per metric ton of bottom ash reused or disposed of, the overall variable operating costs are estimated at US$12 per metric ton of waste incinerated.

According to customary practice, the annual maintenance costs are estimated at 1 percent of the investment for the civil works plus 2.5 percent of the investment for the machinery.

Figure 4.2 presents the resulting annual operating and maintenance costs. The figures are based on the actual amount of waste treated and the investment cost discussed earlier. In addition, the annual capital costs and the total costs of incineration are indicated. The figure uses a real rate of interest of 6 percent and a planning period of 15 years.

Sale of Energy

The sale of energy is a significant element in the economy of waste incineration. In extreme cases, the income from energy sale can cover up to 80 percent to 90 percent of the total costs. A figure around 40 percent is average in Europe and North America, with waste having a lower calorific value in the range of 9 to 13 MJ/kg.

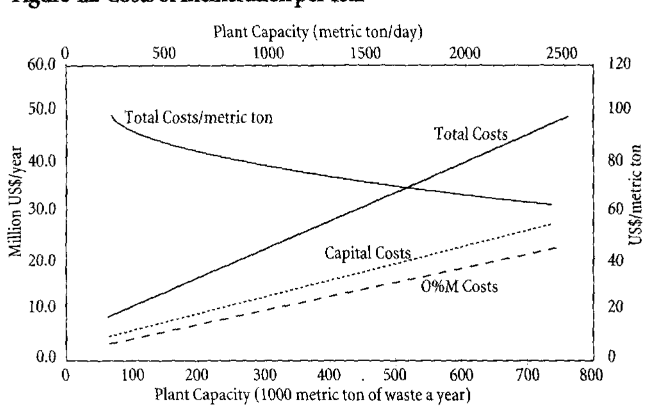
However, it is important to remember that the main purpose of an incineration plant is treatment resulting in a volume reduction and in rendering the waste harmless.

The potential energy production—and income from energy sale—depends heavily on the energy content (net calorific value) of the waste. In table 4.1, representative energy production per metric ton of waste incinerated is listed for heat production, electricity production, and combined heat and power production (see part 2 of this guide for further information). Furthermore, the potential income from sale of energy is stated—based on a heat price of US$15/MWh and an electricity price of US$35/MWh.

The specific energy demand must be taken into consideration—especially for heat production only. Unless the district heating network is relatively large, it is normally necessary to cool off some of the produced heat in the summer period, thus reducing the annual income from sale of heat.

If production and sale of process steam are part of the overall concept, this income must be evaluated according to a specific sales agreement. The income in terms of U.S. dollars per metric ton of steam supplied depends especially on the pressure and temperature of the steam.

Figure 4.2 Costs of Incineration per Year



Calculation of Net Treatment Cost

The net treatment cost (balanced tipping fee) can be calculated based on the estimates of costs and potential income from sale of energy. Using the preconditions stated in the previous sections, the following figure can be applied for a rough estimate of the net costs of waste incineration.

The income from sale of energy is based on the lower calorific value (LCV) of the waste of 9 MJ/kg. In case the LCV is lower than 9 MJ/kg, the income from sale of energy is reduced, resulting in a higher net treatment cost.

By assuming an annual amount of waste suitable for incineration per capita of 0.25 metric tons (0.7 kg/capita/day), the resulting annual cost per capita can be estimated. Depending on the size of the plant, this cost will

Table 4.1 Energy Yield and Income from Energy

Heat value	*CHP*			*Heat Only*		*Power Only*	
H_{inf} *MJ/kg*	*Power MWh/t*	*Heat MWh/t*	*Income US$/t*	*Heat MWh/t*	*Income US$/t*	*Power MWh/t*	*Income US$/t*
6	0.33	1.08	28	1.33	20	0.58	20
7	0.39	1.26	33	1.56	23.	0.68	24
8	0.44	1.44	37	1.78	27	0.78	27
9	0.50	1.63	42	2.00	30	0.88	31
10	0.56	1.81	47	2.22	33	0.97	34

Note: CHP 76 percent of yield as heat.

Figure 4.3 Estimated Income from Energy Sales and Recovery of Energy

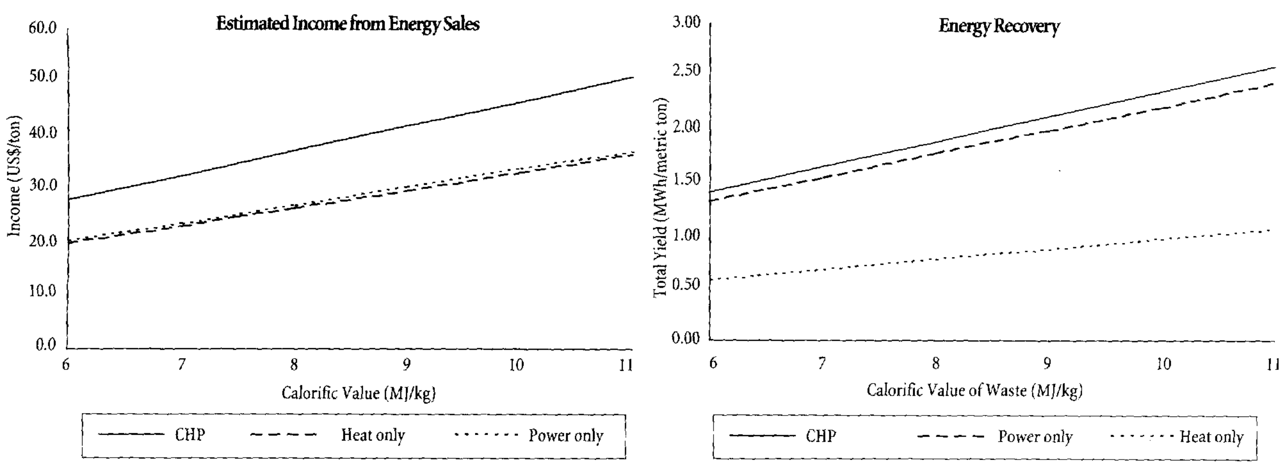
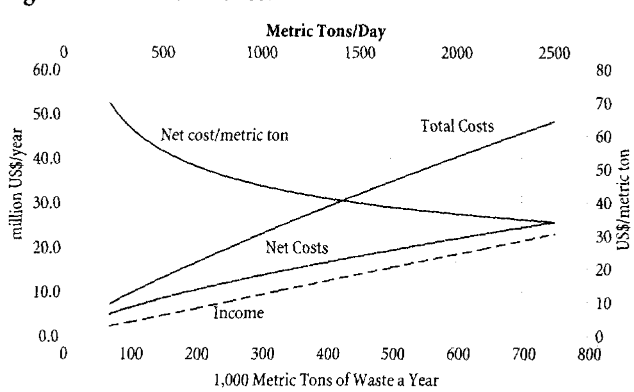


Figure 4.4 Net Treatment Cost



normally be within the range of US$10-$20/capita/year. This is the treatment cost only and does not include the collection of waste, recycling systems, and other waste services.

As an example, the economy for an MSW incineration plant with an annual capacity of 300,000 metric tons of waste (approximately 1,000 metric tons/day) is outlined in Example 4.1. Furthermore, the economic consequences of failing preconditions (waste supply and LCV) are analyzed.

The calculation of the net treatment cost in this example is based on a lower calorific value of the waste of 9 MJ/kg. Furthermore, the incineration plant is dimensioned for an annual waste supply of 300,000 metric tons. These preconditions together with the assumptions stated in the example result in an estimated net treatment cost of US$43/metric ton.

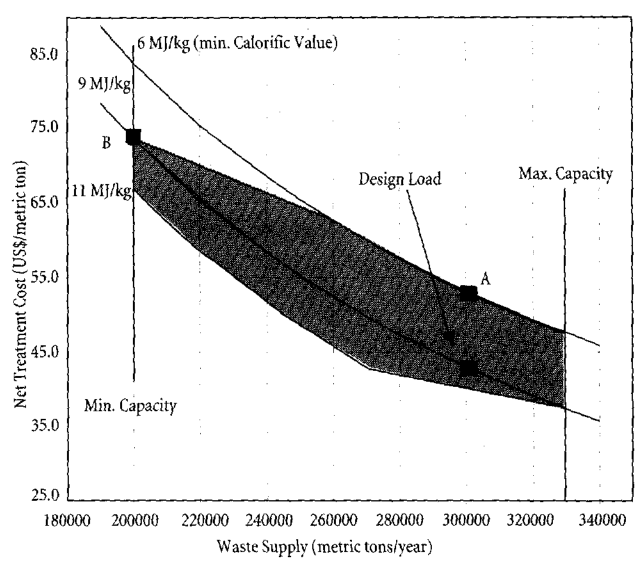
However, in case one or more of the critical preconditions fail (especially waste supply and/or calorific value of the waste), the incineration plant will be operated "off design." If the waste supply or the calorific value is lower than forecasted, the actual net treatment cost may be severely influenced. Figure 4.5 graphically depicts the sensitivity of the calculated net treatment cost.

The bold line in the figure shows the effect of a varying waste supply on the net treatment cost. The graph

Example 4.1 Calculation of Net Treatment Cost

Preconditions:			
Capacity	300,000 t/y	960 t/d	40 t/h
Output			
– Bottom ash	75,000 t/year		
– APC residues	10,500 t/year		
– Electricity for sale	265 GWh		
Investment		145.0 mill.	
Annual capital costs (6% p.a., 15 years)		13.0 mill.	43 US$/metric ton
Annual operating cost			
– Administration and salaries	3.0 mill.		
– Electricity, lime, water, chemicals	2.0 mill.		
– Disposal of residues (100 US$/metric ton)	1.0 mill.		
– Disp/re-use of bottom ash (5 US$/metric ton)	0.4 mill.		
– Maintenance (machinery & civil)	3.0 mill.	9.4 mill.	31 US$/metric ton
Total annual costs		22.4 mill.	74 US$/ metric ton
Annual revenue energy sale (35 US$/MWh)		9.3 mill.	31 US$/ metric ton
Net cost		14.3 Mill.	43 US$/ metric ton

Figure 4.5 Sensitivity of the Net Treatment Cost



shows that if the actual waste supply is only 200,000 metric tons/year (point B), the net treatment cost will increase from US$43 to US$75/metric ton. If the waste supply is lower than 200,000 metric tons/year, the plant cannot be operated continuously.

The high sensitivity of the net treatment cost is a consequence of the different nature of the costs. All fixed costs must be financed independently of the amount of waste treated. Only the variable part of the operating and maintenance cost will be reduced when the waste supply decreases, but at the same time, the income from energy sale will decrease.

In case the calorific value of the actual waste supplied is only 6 MJ/kg (point A), the net treatment cost will increase from US$43 to US$53/metric ton.

This sensitivity analysis stresses the importance of a thorough, reliable waste survey and forecast.

Financing

The primary sources of financing for incineration plant facilities are free income from the user population, income from sale of energy and heat, and public subsidies. These financing forms are not mutually exclusive and are often used in combination.

Fee income from user population: Ideally, the annual net capital and operating costs of the plant are financed largely through user fees from households and industry. Public commitments are necessary to allow the incineration facility autonomy in defining fee schedules, which again will allow the facility to be self-financing—that is, revenues must cover all operating and maintenance costs, including depreciation and financing expenses.

Household service fees are generally collected together with taxes for other municipal services and are based on average waste amounts generated by various categories of household (apartments, single-family homes, and so on). These service fees represent a reasonably secure income stream, depending on the local government's success in collecting local taxes.

Gate or tipping fees are commonly used for large industrial customers, who pay a fee for waste delivered directly to the incineration facility. There is a greater risk that this waste will not be collected, which causes plant income to vary. "Stray" customers may seek alternative, less expensive, waste treatment through landfilling, or they illegally dump or burn waste. Controls must be in place to ensure that sufficient volumes are delivered to the facility to cover capital and operating costs. It is often necessary for local authorities to commit to delivering acceptable minimum levels of waste to the incineration facility before bank loans are financed.

Public controls or incentives are necessary to compel the customers to use the incineration facility. Measures may include directly billing industrial customers based on estimated waste generation as an alternative to gate fees; capping competing landfills; equalizing costs through increased landfilling tipping fees or subsidized incineration fees; and fines for using landfill facilities, illegal dumping, and burning. The agreement of local government to set up and enforce controls is critical in evaluating project risk.

Income from sale of energy or heat: While the sale of energy or heat is not a necessary component of an incineration plant, it can significantly reduce net annual facility expenditures. A stable demand for plant-generated energy can in some cases be critical to securing plant financing, and agreements for selling energy to distributors may be a financing prerequisite.

Obviously, low-cost alternative energy sources in the region decrease the value of energy sales by offsetting annual costs. Additionally, an unstable energy market makes forecasting of operating costs difficult and increases the risk of facility financing.

Public subsidies: Public subsidies in various forms from local government or donor organizations can decrease the user's tariff burden. Subsidies may include grant financing, favorable term loans for plant facilities, or general tax levies. Subsidies can be financed from the budget or linked to environmental taxes.

While fee subsidies generated by general tax levies take the fiscal burden from the user population, the burden is placed on local government and may lead to inefficient plant operations. Fee subsidies may reduce the management's incentives to reduce costs and can erode professional management practices.

The financing structure must allow the facility to provide a service that the consumer can and will pay for—the investment program is viable only to the extent that it is also affordable. Generally, 3 percent to 4 percent of the household income is the maximum acceptable level for the waste fee by international development banks. To help "sell" any increase in waste fees, they should coincide with a service improvement or reduced environmental impact.

In developing countries, it is recommended to survey the population's willingness and ability to pay as part of the financial and economic project evaluation. Such a survey must be carefully designed to determine the actual and real incomes and expenditures of the waste generators. There may be a considerable difference between official and actual incomes, as well as differences among household incomes. It may be necessary—and in some countries also a tradition—to provide specific concessions to pensioners, soldiers, war veterans, the unemployed, students, and so on.

Average tariffs must be fixed at such a level that cash needs are covered, including—where possible—an adequate self-financing margin, but the average tariff should not exceed accepted affordability standards. Investments are not sustainable if the user population finds them unaffordable and seeks undesirable alternatives to waste handling and treatment.

The service population's ability to pay for incineration services is a key factor in determining plant size and treatment capacity. Long-term forecasts of household income and the financial situation of local industries are necessary to determine affordability.

Cost-Benefit Assessment

The estimate and calculations in this chapter draw the conclusion that the net treatment cost per metric ton of waste incinerated is normally at least twice the net cost of the alternative controlled landfilling. At the same time, when applying waste incineration, the economic risk in case of project failure is high because of:

- The high investment cost and the need for foreign currency
- The complexity of the technical installations, which requires qualified and skilled staff, availability of spare parts, and so on
- Special requirements in terms of quantity and composition (for example, minimum net calorific value)
- The need for a comprehensive and mature waste management system and institutional setup in general
- Stable energy demand and prices.

By carrying out a cost-benefit assessment (CBA), the higher net treatment cost (and higher risk) must be justified for the specific waste incineration project before proceeding. The CBA should be performed in the feasibility phase (see chapter 5).

The outcome and content of the CBA strongly depend on the local socio-economic environment. Some of the elements to be considered are:

- Waste transport distance
- Land use and land reclamation
- City development and tourism
- Environmental impact of waste disposal (short and long term)
- Technology transfer and raise in the level of workers' education and skills
- Local jobs
- Sustainability of energy generation.

Sometimes political issues also play a major role in deciding whether to implement waste incineration—as many countries would like to be identified with this technology.

If the CBA is negative, disposal of waste at well-engineered and well-operated landfills is an economically and environmentally sound and sustainable solution. Indeed, upgrading existing landfill capacity and quality is often the better alternative.

5 The Project Cycle

Key Issues

The project cycle for implementing a waste incineration plant involves three main phases: feasibility, project preparation, and project implementation. After finishing one phase, major political decisions have to be made regarding whether to continue to the next phase. The phases themselves contain a number of minor steps also involving the decision makers. Figure 5.1 outlines the steps. The cumulative time from the project start is indicated after the duration of the individual steps. From the launch of the project idea, it takes approximately six years before the plant opens, assuming there are no delays.

Key Criteria

✓ ✓ ✓ A skilled, independent consultant with experience in similar projects should be employed at the onset of the planning.

✓ ✓ ✓ The public perception of waste incineration should be taken into consideration. The public should be involved in and informed about all phases—but particularly the feasibility and project preparation phases.

Feasibility Phase

The feasibility phase comprises a prefeasibility and a feasibility study. A political decision needs to be made between them to determine whether it is worth progressing to the more detailed investigations.

The main considerations of the feasibility phase are presented in figure 5.2. The content for the two components is about the same. However, the prefeasibility study will often be based mainly on existing data and literature references. Hence, the prefeasibility study may be regarded as only a preliminary assessment of the applicability of waste incineration for the waste from the area in question and of the existing institutional framework. The feasibility study requires an in-depth investigation of all the local preconditions and a sufficiently detailed conceptual design of the entire plant, transmission systems, and necessary infrastructure for a reliable economic assessment of the entire project.

Developing an MSW incineration project requires the combined skills of a variety of experts, most of whom are not available locally. The project initiator should therefore consider hiring an independent consultant to work closely together with local organizations and staff. This consultant will offer experience gained from similar projects and also act as a mediator in case of conflicting local interests.

The feasibility report is a valuable tool for the decision makers, not only when deciding whether to proceed with the project but also in assessing the entire institutional framework. The ideas and proposals outlined in the feasibility phase will be transformed into concrete project agreements and documents in the following phase.

Project Preparation Phase

Project preparation is a highly political phase during which many fundamental decisions are made. The objectives are to ensure that the accepted ideas from the feasibility study materialize.

Figure 5.1 Generic Implementation Plan for Constructing a Waste Incineration Plant

Phase	Step	Purpose and Issues to Consider	Duration
Feasibility Phase	Prefeasibility Study	Waste quantities, calorific values, capacity, siting, energy sale, organization, costs, and financing	6 months
	Political Decision	Decide whether to investigate further or to abort the project	3 months
	Feasibility Study	Waste quantities, calorific values, capacity, siting, energy sale, organization, costs, and financing in detail	6 months
	Political Decision	Decide on willingness, priority, and financing of incineration plant and necessary organizations	6 months
Project Preparation Phase	Establishment of an Organization	Establishment of an official organization and an institutional support and framework	6 months
	Tender and Financial Engineering	Detailed financial engineering, negotiation of loans or other means of financing, and selection of consultants	3 months
	Preparation of Tender Documents	Reassessment of project, specifications, prequalification of contractors and tendering of documents	6 months
	Political Decision	Decision on financial package, tendering of documents and procedures in detail and final go-ahead	3 months
Project Implementation Phase	Award of Contract and Negotiations	Prequalification of contractors. Tendering of documents. Selection of most competitive bid. Contract negotiations.	6 months
	Construction and Supervision	Construction by selected contractor and supervision by independent consultant	2 1/2 years
	Commissioning and Startup	Testing of all performance specifications, settlements, commissioning, training of staff, and startup by constructor	6 months
	Operation and Maintenance	Continuous operation and maintenance of plant. Continuous procurement of spare parts and supplies.	10–20 years

Project Implementation Unit

The amount of work the institution or agency developing and implementing the project faces is so great that a dedicated organization/unit must be established for the project. This Project Implementation Unit (PIU) and its attached independent consultants will manage the project overall—including supervision and commissioning.

The PIU may be dissolved when the plant is taken over by the plant management organization, or it may become integrated therein, or—on a smaller scale—continue to supervise the performance of an independent plant operator.

Figure 5.2 Key Activities to be part of the Prefeasibility and the Feasibility Studies

	Prefeasibility Study	*Feasibility Study*
Waste collection area	Land use and demographic information	Land use and demographic information
Waste sector	Stakeholder identification Existing waste management system and facilities (collection through disposal) Preliminary SWOT assessment	Stakeholder analysis Detailed system description and analysis SWOT analysis
Energy sector	Stakeholder identification and assessment Institutional setup Market evaluation	Stakeholder analysis Institutional setup Market analysis Detailed information about energy generation and consumption pattern
Waste generation	Waste generation forecast based on current data and literature values Calorific value of waste Incineration plant design load	Waste survey Revised waste generation forecast Annual variation of surveyed waste calorific value Plant design load and calorific value
Plant siting	Identification of siting alternatives	Selection of plant location
Plant design	Tentative plant design • Furnace • Energy recovery • Flue gas cleaning • Building facilities • Mass balance • Staffing	Conceptual plant design • Furnace • Energy recovery • Flue gas cleaning • Building facilities • Mass balance • Staffing
Cost estimates	Investments Operating costs Energy sale Cost recovery	Investments Operating costs Energy sale Cost recovery
Environmental assessment	Preliminary EA	Full EA according to OD4.01
Institutional framework	Project organization Waste supply Energy sale Plant organization and management Training needs assessment	Project organization Draft waste supply and energy sale agreements Plant organization and management Tender model HRD plan

The PIU and its consultants will be responsible for developing:

- Waste supply agreement(s)
- An energy sales agreement
- An environmental assessment
- An arrangement on the ultimate disposal of incineration residues
- Financing and loan agreements
- Project tender documents
- Contracts
- A plan to monitor construction activities
- A plan to monitor plant acceptance tests and commissioning.

The degree of details of these individual documents depends on the selected tender model. If the plant is to be established on the basis of multiple contracts, everything must be elaborated on in full detail and all the agreements must be signed.

If, on the other hand, the selected tender model is based on BOT or BOO, it is necessary only to establish functional demands and outline the responsibilities of the various stakeholders. Establishing stakeholder responsibilities is crucial in avoiding or helping settle future claims. Claims may arise—for example, regarding insufficient waste supply, energy consumption, environmental performance, or loan servicing. Because of the size of the project, the financing institution is likely to ask the city or even the government to cosign the loan financing the establishment of the plant.

The PIU will supervise the contractors, regardless of the tender model. It will check that projects are designed according to the proper specifications and that the quality of work and materials is of the prescribed standard.

The PIU must thus possess managerial, technical, and financial expertise or engage independent consultants.

If the city responsible for the project development decides to manage it on its own, the PIU will also become involved in staff recruitment and training before startup.

Draft Agreements/ Letters of Intent

The project preparation phase eliminates any "killer assumptions"—which could cause the project to fail—before proceeding to the implementation phase.

To eliminate killer assumptions, the project must be redesigned technically, financially, and institutionally. Borderline issues must be settled through irrevocable letters of intent or even finalized agreements.

Outstanding issues regarding the plant economy must be settled during the project preparation phase. The project financing must be decided, loans have to be negotiated, and it must be clarified whether and on what conditions the client (city or government) is prepared to guarantee or cosign loans taken out by a contractor. Alternative systems for collecting the costs of incineration must be investigated. A feasible distribution between gate fees and city budget payment must be established based on an assessment of the waste generators' ability and willingness to pay (as discussed in chapter 4).

Political Decision

When all consequences of the project have been clarified to the extent possible, the PIU prepares a report for political decisionmaking before entering the implementation phase.

Project Implementation Phase

Tendering

Independently of the selected tender method, the tender process should always be carried out in two stages: prequalification of eligible contractors and tendering among those selected.

The PIU performs a tender evaluation, negotiates amendments, and submits a tender report with recommendations to the political decision makers before any contracts are closed.

Most countries have detailed procurement rules ensuring a fair and unbiased award of contract as well as the best combination of cost and quality when purchasing services and equipment for the public. International development banks have established similar rules.

It is important to review the procurement rules carefully, including the optimum tendering form (see table 3.1). To ensure the most cost-effective and operational implementation procedure, it is useful to review the availability, competitiveness, and skills of local suppliers of equipment and services as well.

Construction, Erection, and Commissioning

The PIU tasks during construction, erection, and commissioning will depend on the tender model. The tasks may range from a simple financial control function to a detailed supervisory function.

For process plants, the commissioning will comprise not only the scope of supply and quality of work, but also a control that the functional demands are fulfilled. Seasonal variations in waste composition may require functional controls during both periods with high and low calorific values of the waste.

Final acceptance testing is essential. Other important issues include timely and adequate staff training and provision of operational support. However, the most important factor in establishing a cost-effective and efficiently operating plant is having skilled and internationally experienced consultants to support the client in specifying and supervising performance criteria and plant layout.

Staffing and Training

Engaging staff must start from 6 to 12 months before plant commissioning. Key management, operational. and maintenance staff should be trained at similar plants for at least three to six months.

It is advantageous if the plant operation and maintenance crews participate in the last part of the erection and the commissioning so they can gain intimate knowledge of how the plant is built and functions.

Staff training programs must be initiated well before startup. This is often included in the services to be delivered by the vendor or equipment supplier, under supervision of an international waste incineration consultant or a corporate partner with long-term experience in operating incineration plants.

Socio-Economic Aspects and Stakeholder Participation

Stakeholders

Any changes made to the waste management system will have a socio-economic impact—for example, on those individuals, companies, and groups making a living from waste management; citizens of neighboring areas; and nongovernmental organizations (NGOs). Possible stakeholders and interest groups are shown in figure 5.3.

Scavenging and Unofficial Economic Activities

In developing countries, scavengers and unofficial recycling companies are often important in the actual collection, disposal, and recycling of waste. They may involve low-income citizens, the city's waste collection crews, and a number of small-scale waste recyclers located at or near the city dump, at waste transfer stations, or along major roads leading to waste management facilities.

Figure 5.3 Typical Stakeholders for Construction of an Incineration Plant

Stakeholders	*Stakeholder Interests*	*Possible Stakeholder Influence*
Scavengers	Changed waste management may affect or eliminate their source of income.	Scavengers' activities may affect the properties and amounts of waste.
Community groups and nearby citizens	Project may lead to adverse community impact – for example, traffic, noise, visual impact, etc. Positive impacts could include work opportunities.	Termination, delay, or change of projects due to community protests.
Nature NGOs	Reduced impact of waste management on nature.	Termination, delay, or change of projects due to NGO protests.
Environmental NGOs	Reduced impact of waste management on the environment.	Termination, delay, or change of projects due to NGO protests.
Neighbors	Reduction of noise, dust, traffic loading, and visual impact. Impact on real estate prices.	Termination, delay, or change of projects due to neighbor protests.
Collection and transportation companies	Wish to maintain or expand the business.	New requirements for sorting, containers, and vehicles.
Energy producers	Opposition to purchase of energy from smaller external producers.	Barriers to sale of energy at local market prices.
Waste generators	Wish to maintain low waste management service charges.	Opposition to large investments and increased service charges.

In some developing countries, income from sale of reusable materials such as aluminum or steel cans, plastic, cardboard, paper, metals, and bottles is the primary income for a whole community of scavengers and waste recyclers. Hence, any changes made to the waste management system may seriously affect their livelihood. Likewise, the interests and activities of such unofficial scavenging may seriously reduce the calorific value or the amounts of waste received at the waste incineration plant.

Hence, it is important to pay attention to scavenging and other unofficial waste management activities. This helps address possible constraints in planned service improvements and mitigates the socio-economic problems that a waste incineration plant can bring—which in turn, influences the waste flow.

Combatting the NIMBY Syndrome

In areas with no public experience with state-of-the-art waste incineration plants, there is normally resentment and distrust towards the environmental and technical performance of such a facility.

Typically, incineration and stacks are associated with emission of black smoke and particles, and waste is associated with odor problems. Citizens are often well acquainted with occasional open burning of accumulated solid waste, for example. Also, contrary to dumps, waste incineration plants are normally constructed in or near residential areas. Hence, "not in my backyard" (NIMBY) can become a common protest. To combat this, it is important to make sure that citizens have a correct picture of the pros and cons of waste incineration through a public participatory consultation process.

It is important to communicate information on waste incineration technology, as well as the global and local environmental impacts, in a trustworthy and detailed manner. The community should be encouraged to express its concerns at an early stage—for example, during public information meetings and hearings. Here, the client can present the potential risks and impacts as well as the environmental protection measures that will be introduced. If necessary, additional environmental protection measures or community nuisance control measures can be planned and announced after the public meetings.

Many countries have implemented Environmental Impact Assessment (EIA) requirements. Likewise, all major development banks and lending institutions have their own EIA requirements. Typically, such requirements include public participation or hearing procedures for relevant NGOs and community groups. An EIA and hearing procedures could provide a way to communicate actual environmental and neighborhood impacts. Generally, a waste incineration plant equipped with energy recovery and international air pollution control measures will be environmentally more desirable than dumping, even if the dumping takes place in state-of-the-art sanitary landfills equipped with engineered lining, leachate treatment, and landfill gas management systems. Hence, it is key to identify the optimum site and to mitigate potential neighborhood nuisances.

Socio-Economic Impact of Advanced Waste Treatment Facilities

Typically, introducing more advanced waste treatment facilities requires investments and, hence, public or private capital and higher incomes to cover increased operation and maintenance costs. Also, typical advanced waste treatment facilities, other than engineered sanitary landfills, produce a salable output, such as steam or heat, electricity, and recovered materials (for example, metals).

When salable outputs are generated, it is necessary to decide on a cost recovery system that balances the income from salable output and from treatment fees to be paid by the waste generators. The income from sale of steam or heat and power from waste incineration plants varies between 0 and 40 percent of the total annual costs, depending on the national legislation and the regional energy market.

National or regional traditional power and district heating companies may be reluctant to purchase energy produced at waste incineration plants because:

- Energy can be produced with higher profit margins by using the supplier's own plants and other fuels
- Capacity of the supplier's own plants will be redundant and, hence, return on investments already made will be less

- The supplier is unwilling to rely on external energy suppliers
- Supply is not sufficiently stable or guaranteed
- The incineration plant is not suitably located within the current energy infrastructure system.

Therefore, national or regional legislation favoring energy produced from solid waste (renewable energy source) is important for securing high income from sale of energy from waste incineration plants. Such regulating procedures have been introduced in practically all developed countries with waste incineration plants, thus forcing electricity and district heating companies to purchase energy from waste incineration plants at a specific price.

Affordability is particularly important in developing countries. Citizens with low incomes may find it difficult to pay the full cost of an advanced waste management system. Surveys can be used to determine the actual level of affordability. For example, differentiated service fees can be charged—for example, households with incomes below a certain threshold; households with incomes above a certain threshold; private production companies; private service companies; and public institutions.

A political decision should be made on how to deal with waste generators who are unable to pay the full service fees. Service fees for less affluent waste generators can be cross-subsidized by the public budget or the more affluent waste generators; or each low-income waste generator can be subsidized directly.

In any case, a suitable policy for collection of service fees should correspond with an overall fee policy for other public services, such as water, sewage, heating, and power.

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PART 2
TECHNICAL

Technical Plant Overview

A typical incineration plant comprises the unit functions and processes shown in Figure 0.1 on the following page.

The components of the unit functions and processes are briefly described as follows:

- **Waste registration and control.** For billing, monitoring, and control purposes, the waste is declared, weighed, and registered after it enters the plant.

- **Size reduction, sorting, and inspection of waste (optional).** Depending on the type of waste and its origin, it may be necessary to reduce the size (for example, of bulky waste), sort, and inspect all or part of the waste received.

- **Unloading and hopper for waste.** Waste is unloaded into a bunker or hopper system. The storage capacity should allow for both daily and weekly variations in the waste quantities and for mixing (homogenization) of the waste to be fed into the furnace.

- **Feeding system.** The homogenized waste is fed from the hopper into the furnace, normally by overhead cranes.

- **Furnace.** The waste is first dried, then ignited, followed by complete burning in a series of combustion zones on the movable grate. Flue gases are completely burned out in the after-burning chamber.

- **Energy recovery system.** Energy is recovered as power, heat, or steam (or a combination thereof), depending on the local energy market.

- **Ash and clinker removal system.** The burned-out ash and clinkers are collected and transported in a conveyor or pusher system. The ash and clinkers can be sieved, sorted, and used for filling purposes, road construction, or the like. Rejected ash and clinkers are disposed of in a sanitary landfill.

- **Air pollution control (APC) system.** The principal APC systems are—depending on the desired level of cleaning—electrostatic precipitators or baghouse filters for physical removal of dust and some heavy metals; additional chemical flue gas cleaning in dry/semidry scrubbers followed by fabric filters or wet scrubbers for washing/spraying the flue gas; and additional NO_x, or dioxin removal in special filters.

- **Stack.** The treated flue gas is finally emitted via the stack. The stack height depends on the local topography and prevailing meteorological conditions.

Figure 0.1 Exploded View of Typical MSW Incineration Facility (mass burning)

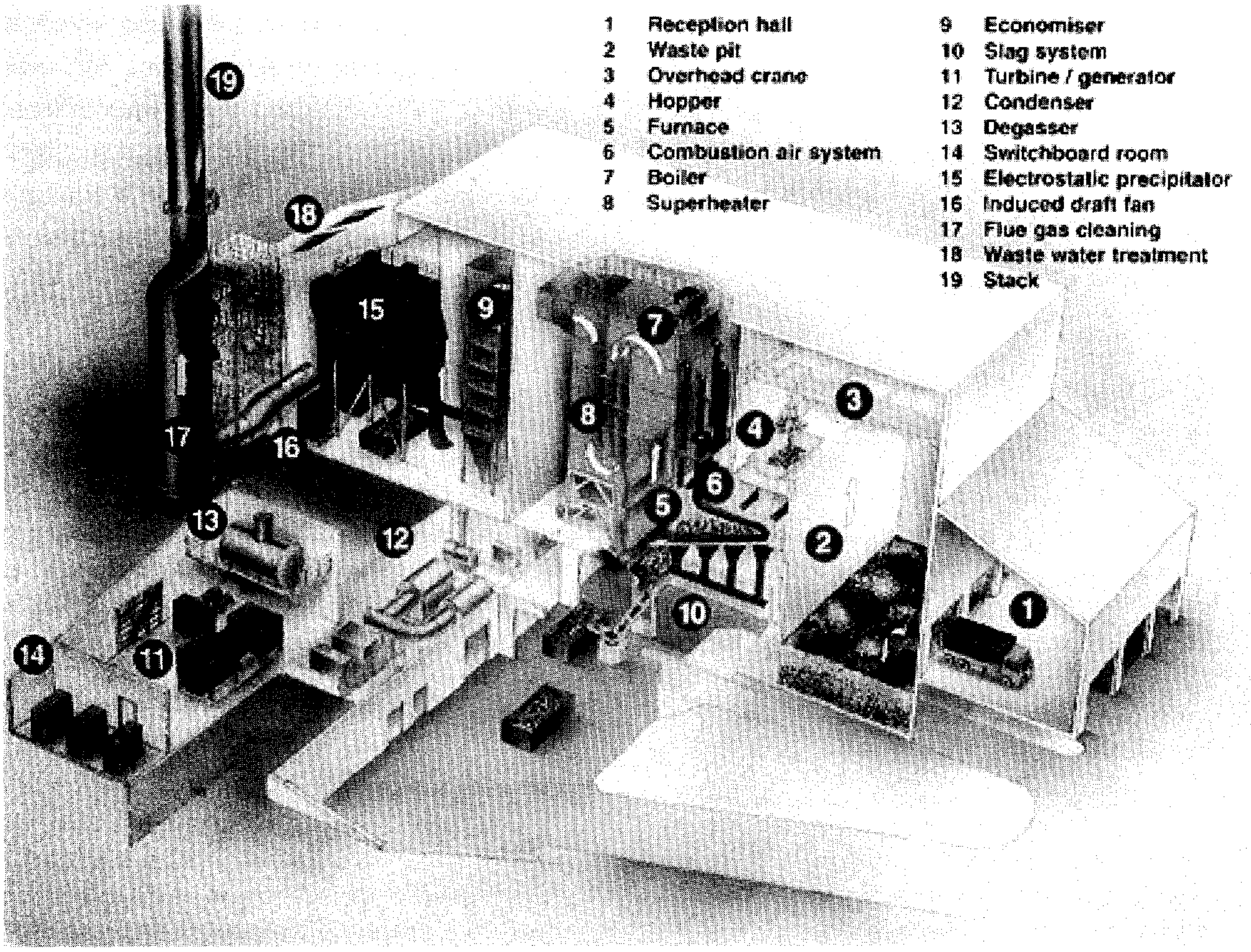


Figure 0.2 Unit Functions and Processes of an MSW Incineration Plant

Unit Function/ Processes	Typical Technology	Alternative Technology	
Waste Reception and Control	Weighbridge and personnel for control and billing	Automatic weighing and billing based on self-reporting	Manual measuring and reporting
Size Reduction, Sorting and Inspection (Optional)	If needed, inspection on floor and revolving knives/shredder	Manual sorting conveyer for certain types of waste	Smaller cranes for removal of oversized waste
Unloading Area and Hopper for Waste	Deep hopper for direct unloading of waste from vehicles	Same level hopper/ floor for unloading and inspection	
Feeding System	Manual overhead cranes	Semi-automatic overhead cranes	
Furnace	Movable grade furnace	Rotary kiln furnace	Fluidized bed furnace
Energy Recovery System	Heat recovery for district heating or power only	Combined heat and power production	
Ash and Clinker Removal System	Mechanical or hydraulic pushers	Conveyer systems	Additional sorting and sieving of slag and ashes for reuse
Flue Gas Cleaning System (Air Pollution Control)	Electrostatic precipitators	Additional dry, semi-dry or wet ACP	Additional dioxin or NO_x removal
Stack	Stack 70+ meters		

1 Plant Location

Key issues

A municipal solid waste (MSW) incineration plant is a public service facility. The location should always be determined with respect to both economic and environmental issues. The environmental impact must always be assessed (see the chapter on Environmental Impact and Occupational Health).

Properly constructed and operated, a waste incineration plant will be comparable to a medium to heavy industry in its environmental impact, potential public nuisances, transport network requirements, and other infrastructure needs.

An MSW incineration plant will generate surplus energy, which may be made available in the form of heat or power depending on the demand of the local energy market. In that respect, an MSW plant is comparable to a fossil fuel power plant. It is further comparable to a coal-fueled power plant in respect to flue gas emissions and solid residues from the combustion process and flue gas cleaning.

Therefore, a waste incineration plant should be close to an existing fossil fuel power plant for the two plants to enjoy mutual benefits from the service facilities needed—or it could be adjacent to or part of a new power plant.

Key Criteria

✓ ✓ ✓ A controlled and well-operated landfill must be available for disposing residues.

✓ ✓ In relation to the air quality in the site area, frequent and prolonged inversion and smog situations are not acceptable.

✓ ✓ MSW incineration plants should be located in land-use zones dedicated to medium or heavy industry.

✓ MSW incineration plants should be located in industrial areas close to power plants.

✓ It should take no longer than one hour to drive a truck from the waste generation area to the plant.

✓ MSW incineration plants should be at least 300 to 500 meters from residential zones.

✓ MSW incineration plants should be located near suitable energy consumers.

Site Feasibility Assessment

Siting the MSW incineration plant will generally take place when the demand for such a facility has been established through waste surveys. The surveys will identify the amount of waste, how it is collected or transported, and provide information about the area to be serviced—including the approximate location of the waste generation's center of gravity.

The considerations when evaluating locations for a waste incineration plant are similar to the environmental impact assessments. The main difference is that the siting process considers a multitude of locations, then ranks them by applying existing information to the variables. However, the environmental impact assessment looks at a plant's impact on the environment in more detail—and often only after providing additional and more dextailed information on both the site and the plant.

The siting phase should deal with a number of topics—including proximity to the waste generation center, traffic and transport, air quality, noise impact, proximity to energy distribution networks, utilities, and landfill. If any such topic is irrelevant for a specific location, this should nevertheless be noted.

Proximity to Waste Generation Center

Long-distance waste hauling is both costly and environmentally unsustainable (because of CO_2 and NO_x emissions). Therefore, waste incineration plants should be as close as possible to the center of gravity of the area delivering waste to the plant. This is even more imperative if the plant also produces heat and will be connected to a district heating network servicing the same area.

Proximity to the waste center of gravity is important for using the collection vehicles and crews as efficiently as possible—that is, to minimize idle time on the road. Extended transport time due to long distances or traffic jams requires more vehicles and staff for collection and transportation, or transfer of the waste to larger vehicles at transfer stations. Both solutions increase costs.

Traffic and Transport

Incineration plants attract heavy traffic, with waste and consumables coming in and treatment residues going out. The plant should therefore be near major roads or railway lines (or, in special circumstances, rivers) that allow heavy traffic.

A location close to the center of gravity of waste generation minimizes collection vehicles' idle time on the road. Depending on the size of the plant and the collection vehicles, 100 to 400 trucks can arrive at the plant daily. A traffic study may be required to minimize traffic jams and avoid wasting time.

Besides contributing to traffic congestion, the trucks will vibrate, emit dust, and generate noise. Waste transportation vehicles should therefore not pass through residential streets or other sensitive areas.

Air Quality

Waste incineration plants equipped with a modern standard flue gas cleaning system create little air pollution or odor (see the chapter on Air Pollution Control). Therefore, siting seldom poses a problem with regard to air quality. The plants should, however, be located with due respect to meteorological conditions—that is, in open areas where emissions will not normally be trapped. For example, plants should not be sited in narrow valleys or areas prone to smog.

Waste emits odor during transportation and handling in the plant. However, using the bunker area ventilation air in the incineration process normally eliminates most odor.

Noise

Most noise will come from flue gas fans and the ventilators used in cooling, which operate 24 hours a day. Ventilators are usually on the roof of the plant, which makes them particularly noisy. Handling the waste and residues inside the plant may also emit noise. Transportation to and from the plant will create noise, particularly during the day.

Therefore, waste incineration plants should be at least 300 to 500 meters away from residential areas to minimize the noise impact and to protect against odor nuisances.

Proximity to Energy Distribution Networks

A waste incineration plant will generate surplus energy. The recoverable energy is an important asset, as it can be sold to bolster the plant's income considerably.

The recovered energy can be used for heating, power generation, and process steam. It is normally most economical when the energy is used for heating and similar purposes, as this is technically simpler in respect to the plant's construction and operation. The demand for heating may, however, be limited in terms of either the size of the distribution network or seasonal variations, thus creating an excess which could be used for power production.

Regardless of the how the energy is used, it is important that the incineration plant be near the distribution network so the plant's delivery system can be connected to an existing distribution network (thus avoiding high construction or operating costs).

Utilities

An incineration plant demands the same kind of utilities as medium to heavy industries.

The heat generated in the combustion process is generally assumed to be used wisely in district heating or power production. There will, however, be times when cooling is needed, either as direct water cooling or via air coolers or cooling towers.

An incineration plant will also discharge waste water, which will be polluted to a certain degree depending on the slag cooling and the flue gas cleaning system (see the chapter on Air Pollution Control). Waste water generation is most significant with a wet flue gas cleaning system. Storm water will be discharged from the paved areas (although it may, to some extent, be collected and used for cooling purposes before discharge). If the plant has a wet flue gas cleaning system, it must be located at a watercourse or near public sewers with sufficient capacity to receive the waste water discharge.

Landfill

Although waste incineration significantly minimizes the volume of waste for disposal, residues that have to be disposed of in landfills will remain. These residues consist of bottom ash (slag) from the burned waste and fly ash and other residues from flue gas cleaning. Depending on the environmental and geotechnical demands, the bottom ash can be recycled for construction purposes or disposed of with no special measures. In all circumstances, the plant must have access to a properly designed and operated landfill for ultimate residue disposal.

The residues from the flue gas cleaning techniques with acid gas removal are highly soluble and may cause ground water pollution. Proper lining and coverage of the landfill can control this, together with treating the leachate to remove heavy metals before discharge. Even after treatment, the leachate will have a concentration of salts and should be discharged somewhere with sufficient flow for a high degree of dilution.

Although the incineration plant should be relatively close to a landfill, the distance is not crucial, as the weight of the residues to be disposed of will equal about 25 percent of the amount of the waste incinerated at the plant (depending on the ash content and the flue gas cleansing technique), and the volume will reduce to about 10 percent of the original waste.

2 Incineration Technology

Key Issues

The heart of an incineration plant is the combustion system—this can be divided into two broad categories: mass burning of "as-received" and nonhomogeneous waste, and burning of pretreated and homogenized waste.

Mass burning of "as-received" and nonhomogeneous waste requires little or no pretreatment. Mass burning systems are typically based on a moving grate.

Mass burn incineration with a movable grate incinerator is a widely used and thoroughly tested technology. It meets the demands for technical performance and can accommodate large variations in waste composition and calorific value. A less-common mass burning alternative is the rotary kiln.

Burning pretreated and homogenized waste requires size reduction, shredding, and manual sorting—or even production of "refuse-derived fuel," which is a demanding complication. Therefore, the incineration technologies for burning pretreated and homogenized waste are limited.

An alternative for burning pretreated and homogenized MSW may theoretically be a fluidized bed. However, the fluidized bed is a fairly new technology and hence still limited in its use for waste incineration. It has a number of appealing characteristics in relation to combustion technique, but these have not been thoroughly proven on MSW. The fluidized bed may be a good alternative and widely applied for special types of industrial waste (for example, in Japan).

When implementing an MSW incineration plant, the technology must be feasible and proven. At present, only the mass burning incinerator with a moveable grate fulfills these criteria. Furthermore, suppliers with numerous reference plants in successful operation for a number of years also in low- and middle-income countries (preferably) must be chosen.

The combustion system must be designed to hinder the formation of pollutants, especially NO_x, and organic compositions such as dioxins. Appropriate measures to ensure an efficient combustion process (complete burnout of the bottom ashes and the flue gases, low dust content in the raw flue gas, and such) comprise a long flue gas retention time at high temperature with an appropriate oxygen content, intensive mixing and recirculation of flue gases, optimal supply of combustion air below the grate and before inlet to the after-combustion chamber, and proper mixing and agitation of the waste on the grate.

The content of CO and TOC (total organic carbon excluding CO) in the raw flue gas (before inlet to the APC system) is a good indicator of the efficiency of the combustion process.

Key Criteria

✓ ✓ ✓ The lower calorific value (LCV) of the waste must be at least 6 MJ/kg throughout all seasons. The annual average LCV must not be less than 7 MJ/kg.

✓ ✓ ✓ The technology must be based on mass burn technology with a movable grate. Furthermore, the chosen (or proposed) supplier must have numerous reference plants in successful operation for a number of years.

✓ ✓ ✓ The furnace must be designed for stable and continuous operation and complete burnout of the waste and flue gases (CO<50 mg/Nm^3, TOC<10 mg/Nm^3).

✓ ✓ The annual amount of waste for incineration should be no less than 50,000 metric tons, and the weekly variations in the waste supply to the plant should not exceed 20 percent.

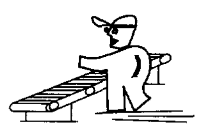
Pretreatment of Waste

Depending on the quality of the waste and the incineration system, sorting and homogenizing the waste before incineration may be necessary.

Sorting

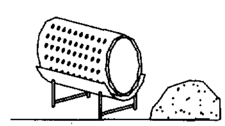
The waste may be sorted manually, automatically, or mechanically—or as a combination thereof.

Manual and advanced automatic sorting allows the waste to be divided into recyclable materials, waste for treatment, and waste which is suitable only for direct landfilling.



Fine Manual Sorting

Advanced sorting processes, however, are time consuming and costly, take up a lot of space, and require special precautions to ensure that the sorters do not suffer any health problems as the result of their work.

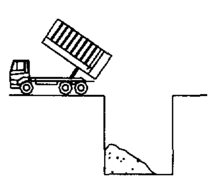


Automatic Sorting

Coarse mechanical sorting may not be sufficient for fluidized bed incineration, but can be used for mass burning incineration. It may be performed on the reception hall floor.

Coarse Mechanical Sorting

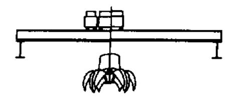
With a movable grate, the waste may be burned without sorting, shredding, or drying. However, an overhead crane typically removes inappropriate bulky waste from the pit through a coarse and simple sorting.



No Sorting

Homogenization

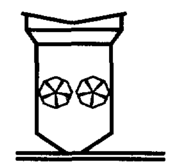
Some degree of waste homogenization is always necessary.



Mixing

To control the energy input and the combustion process, proper mixing of the waste is necessary before incineration. For mass burn incineration, the mixing is typically done by the overhead crane in the pit.

A shredder may be used when there are large quantities of bulky waste. For fluidized bed incineration, shredding is a minimum requirement and further pretreatment is necessary.

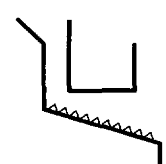


Shredding

Moving Grate Incineration

The conventional mass burn incinerator based on a moving grate consists of a layered burning on the grate transporting material through the furnace.

An overhead crane feeds waste into the hopper, where it is transported via the chute to the grate in the furnace. On the grate, the waste is dried and then burned at high temperature with a supply of air.



Moving Grate

The ash (including noncombustible fractions of waste) leaves the grate as slag/bottom ash through the ash chute.

Main Advantages and Disadvantages of the Moving Grate

Advantages

- No need for prior sorting or shredding.
- The technology is widely used and thoroughly tested for waste incineration and meets the demands for technical performance.
- It can accommodate large variations in waste composition and calorific value.
- Allows for an overall thermal efficiency of up to 85 percent.
- Each furnace can be built with a capacity of up to 1,200 t/day (50 metric tons/hour)

Disadvantages

- Capital and maintenance costs are relatively high.

The Grate

The grate forms the bottom of the furnace. The moving grate, if properly designed, efficiently transports and agitates the waste and evenly distributes combustion air. The grate may be sectioned into individually adjustable zones, and the combustion air can usually be preheated to accommodate variations in the lower calorific value of the waste.

There are several different grate designs—including forward movement, backward movement, double movement, rocking, and roller. Other alternatives may be suitable as well.

The detailed design of the grate depends on the manufacturer, and its applicability should therefore be carefully evaluated for the actual waste composition. Moreover, the design of the grate must be well proven by the manufacturer by thorough experience and several relevant references.

The Furnace

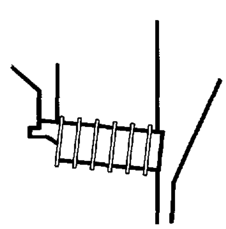
The walls in the furnace of the incinerator can be refractory lined or water-wall designed. Most water-wall furnaces operate with less excess air, which reduces the volume of the furnace and size of the air pollution control equipment.

See page 56 for selected design criteria and layout data for mass burning incineration based on a moving grate.

Rotary Kiln Incineration

The mass burning incinerator based on a rotary kiln consists of a layered burning of the waste in a rotating cylinder. The material is transported through the furnace by the rotations of the inclined cylinder.

The rotary kiln is usually refractory lined but can also be equipped with water walls.



Rotary Kiln

The cylinder may be 1 to 5 meters in diameter and 8 to 20 meters long. The capacity may be as low as 2.4 t/day (0.1 t/hour) and up to approximately 480 t/day (20 t/hour).

The excess air ratio is well above that of the moving grate incinerator and even the fluidized bed. Consequently, the energy efficiency is slightly lower but still may be up to 80 percent.

As the retention time of the flue gases is usually too short for complete reaction in the rotary kiln itself, the cylinder is followed by, and connected to, an afterburning chamber which may be incorporated in the first part of the boiler.

The rotary kiln may also be used in combination with a movable grate—where the grate forms the ignition part and the kiln forms the burning-out section. This allows for a very low level of unburned material in the slag. The slag leaves the rotary kiln through the ash chute.

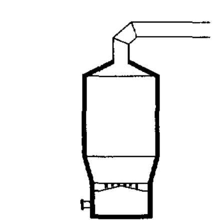
Main Advantages and Disadvantages for the Rotary Kiln

Advantages	**Disadvantages**
• No need for prior sorting or shredding.	• A less common technology for waste incineration.
• Allows an overall thermal efficiency of up to 80 percent.	• Capital cost and maintenance costs are relatively high.
• Able to accommodate large variations in waste composition and calorific value.	• The maximum capacity of each furnace is limited to approximately 480 t/day (20 t/hour).

Fluidized Bed Incineration

Fluidized bed incineration is based on a principle whereby solid particles mixed with the fuel are fluidized by air. The reactor (scrubber) usually consists of a vertical refractory lined steel vessel containing a bed of granular material such as silica sand, limestone, or a ceramic material.

The fluidized bed technology has a number of appealing characteristics in relation to combustion technique: reduction of dangerous substances in the fluidized bed reactor itself, high thermal efficiency, flexibility regarding multifuel input, and cost.



Fluidized Bed

A main disadvantage of the fluidized bed for waste incineration is the usually demanding process of pretreating the waste before the fluidized bed so that it meets the rather stringent requirements for size, calorific value, ash content, and so forth. Because of the heterogeneous composition of MSW, it can be difficult to produce a fuel that meets the requirements at any given point.

Main Advantages and Disadvantages of the Fluidized Bed

Advantages	Disadvantages
• Relatively low capital and maintenance costs due to a simple design concept.	• At present, not a common nor thoroughly tested techology for MSW incineration.
• Allows a overall thermal efficiency of up to 90 percent.	• Relatively strict demands to size and composition of the waste,which usually requires thorough pretreatment.
• Suitable for a wide range of fuel and mixtures of fuel and can handle liquid or solid waste either in combination or separately.	

Design and Layout of the Mass Burning Incineration System

This section covers selected main design criteria and layout data, particularly related to the mass burning incineration technology.

Grate

The grate has two principal purposes: to transport, mix, and level the "fuel" (waste), and to supply and distribute primary combustion air to the layer of waste.

Various grate designs are available, usually characterized by the way they transport the "fuel": slanting or horizontal forward- and backward-pushing grates, roller grates, or rocking grates.

As the grate performance is important to the entire plant, the grate and grate design should be chosen carefully. As a basic principle, the grate should in every respect be suitable for the specific waste the plant will treat. The grate should be able to accommodate a great variation in calorific value and waste composition.

Moreover, in connection with selecting and dimensioning the grate, special attention should be given to possible changes in the calorific value and waste composition.

Regardless of the specific properties and varying "quality" of the waste, the grate should meet the requirements for waste capacity, operational reliability, combustion efficiency, and operation at partial load.

The grate should be designed for mass burning—that is, the waste, except for particularly bulky waste, should be fed into the furnace and combusted without any special preseparation or crushing.

The grate system should also be designed so that waste can be transported automatically from feeding to slag extraction without obstacles or clogging and without any manual intervention.

Division into Grate Sections

The grate should be divided into individually adjustable sections. This division may be longitudinal and, in cases where the grate is very wide, it should be divided into separate tracks. The number of grate sections depend on several factors, including the grate type, the waste composition, the required capacity, and the requirements made for operation at partial load and maximum load at varying calorific values.

Depending on the type of grate, the longitudinal division may vary from one to six sections—where the lowest number represents the backward-pushing grate and the highest number represents the roller grate. It should be noted, however, that each roller is, in principle, individually adjustable.

Some types of grates, including the different forward-pushing grates and the double-motion overthrust grates, typically require three or four individually adjustable grate sections to ensure optimal treatment and combustion.

Grate Length, Grate Width

The approximate dimensions of each type of grate can be estimated based on the grate suppliers' own recommendations or guidelines for thermal grate load (MW/m^2), mechanical grate load (metric tons/m^2/h), mechanical grate width load (metric ton m/h), thermal grate width load (MW/m), permissible length/width ratio, and so on.

One requirement should be a dimensioning which ensures an appropriate grate width in relation to the thermal grate width load, and a grate length which—focusing on a good slag quality—allows for satisfactory final thermal treatment of the slag in the furnace.

Moreover, a maximum of 65 to 70 percent of the length of the grate must be applied as a drying and combustion zone when operating in the design point at nominal load.

The remaining part of the grate should always be available to ensure final combustion and complete burnout of the slag and the ash.

Air Supply Ensuring Optimum Grate Performance
The grate should be able to intensively agitate, mix, and level the waste layer to create the largest possible "fuel" surface and, thus, efficient drying, ignition, combustion, and final burnout of the slag/ash.

The variations in load and calorific values require a flexible primary air supply system in respect to both the amounts supplied and the supply spots—it should be possible to change the extent and location of the drying and primary combustion zones in relation to the waste composition and the waste load.

Consequently, a number of adjustable air zones should be established under the grate—about four to six, depending on the type of grate.

The primary combustion air should be supplied to the waste layer through small slots in the front side of the grate bars or through 1- to 2-mm slots between the grate bars.

Experience shows that, to ensure satisfactory air distribution, the air supply area should be no more than 1.5 to 2.0 percent of the total grate area. The air supply will typically go through the slots at a rate of 10 to 15 m/sec.

Furnace
In principle, the furnace and the secondary combustion chamber, the after-burning zone, should be designed to ensure a long retention and reaction time of the flue gases at high temperatures. Most important is the secondary combustion chamber, the first radiation pass of the boiler, which should be designed with a large volume and height so that all processes and reactions in the flue gas end before they reach the unprotected boiler walls.

Moreover, the size, volume, and geometry of the furnace should minimize the risk of slag deposits and ash fouling on the furnace walls, which requires an adequately low thermal furnace load and as well as a low relative flue gas velocity in the furnace.

The flue gas velocity in the furnace should be maintained at a level lower than 3.5 to 4.0 m/sec. It should be possible to control the furnace temperature in such a way to avoid undesired peaks. The furnace sections depend to a great extent on the chosen flue gas flow, which may be the so-called mid-flow, co-flow, or counter-flow principle.

The choice of flue gas flow in the primary combustion chamber depends to a great extent on the prevailing type of waste, the calorific value, and the specific grate concept.

Another precondition for optimal furnace performance is the design of the secondary air supply system, which ensures effective mixing of the flue gases both above the waste layer and at the inlet to the secondary combustion chamber or the first pass of the boiler.

The secondary air should be supplied through rows of nozzles in the zones at the inlet to the secondary combustion chamber, and possibly through rows of nozzles in the furnace—depending on the furnace's flue gas flow.

The furnace and the combustion control concept should be designed to recirculate flue gas to partially replace secondary air to the furnace.

The furnace should be prepared for establishing startup and auxiliary burners.

Flue Gas Recirculation
Establishing flue gas recirculation is part of the furnace design. After passing through the dust filter, part of the flue gas (20 to 30 percent) is limited and retained through an insulated duct to the furnace. The recirculated flue gas is injected through separate nozzles in the furnace and in the turbulence zone at the inlet to the secondary combustion chamber, the first pass of the boiler.

Among its primary advantages, flue gas:

- Recirculates flue gas, which leads to a higher thermal efficiency, as the excess air and the oxygen content can be significantly reduced (efficiency can increase about 1 to 3 percent)
- Reduces NO_x (20 to 40 percent when recirculating 20 to 30 percent of the flue gas)
- Reduces the dioxin generation (connected with a low amount of excess air and a low oxygen content)
- Stabilizes or improves the flow and turbulence conditions—particularly at partial load
- Minimizes the risk of "bursts" in the secondary combustion chamber, the first pass of the boiler
- Decreases the amount of flue gas entering the flue gas cleaning system.

Consequently, establishing flue gas recirculation has operational, economic, and environmental advantages.

If flue gas is recirculated, all duct connections must be welded and a minimum of flex connections should be used. Otherwise, there may be leaks, and any escaping flue gas is likely to cause corrosion.

Secondary Combustion Zone (After-Burning Chamber)

The secondary combustion zone, which consists of the first part of the first radiation pass of the boiler, starts after the last injection of secondary air or recirculated flue gas.

Efficient turbulence of the flue gas at the inlet to the secondary combustion zone should be ensured at any load except at startup and shutdown.

According to standard legislation, including the draft EU directive of 1997.04.24, the flue gas temperature should be increased to a minimum of 850°C for at least two seconds under the presence of at least 6 percent oxygen in the actual secondary combustion zone, even under the most adverse conditions.

Combustion Air Systems and Fans

Special attention should be given to the design and regulation of the combustion air systems, which provide excess air in the flue gas—to ensure a high combustion efficiency and avoid a reducing (corrosive) atmosphere, incomplete burnout of the flue gases, and related problems.

The primary air should be drawn from above the crane slab in the waste pit and injected through the pressure side of the primary fan below the grate in at least four to six air zones regulated automatically by motorized dampers.

Intakes for the secondary air are situated at the top of the furnace or boiler—possibly in the waste pit—and should be supplied to the furnace and at the inlet to the first pass of the boiler (after-burning chamber) through three to five rows of nozzles (depending on the design).

The amount of secondary air supplied to each of the rows of nozzles is regulated automatically by motorized dampers.

An air preheater manufactured in a bare tube structure should preheat the primary air at low calorific values and with moist waste.

It should be possible to heat the primary air from 10° C to approximately 145° C, depending on the waste composition and moisture content.

3 Energy Recovery

Key Issues

A main benefit of solid waste incineration is the possibility of reusing the waste as fuel for energy production. Waste incineration may thus both reduce methane gases at the landfill and replace fossil fuel, reducing the emission of greenhouse gases overall.

The flue gases carrying the energy released in a waste incineration furnace have to be cooled in a boiler before entering the air pollution control system. The boiler is also a necessary technical installation for energy recovery. The feasible type of boiler, however, depends whether the energy is used for hot water for district heating, process steam for various types of industries, or electricity.

The end use possibilities depend on the local energy market conditions, including:

- Infrastructure for energy distribution—for example, the availability of a power grid and district heating network
- Annual energy consumption pattern (the energy output from MSW incineration plants is fairly constant)
- Prices of the various types of energy and possible agreements with the consumer(s).

The overall thermal efficiency of an MSW incineration plant equipped for energy recovery depends on the end use of the energy recovered. Production of electricity has a low thermal efficiency, but results in high-priced energy, whereas hot water for district heating is considered inexpensive energy, but the overall thermal efficiency is high, and the complexity and the costs of the necessary technical installations are relatively low.

Key Criteria

✓ ✓ ✓ The flue gases from the furnace must be cooled to 200°C or lower in a boiler in order to apply available flue gas treatment technology.

✓ ✓ The plant economy should be optimized through energy recovery and sale.

✓ ✓ Irrevocable agreements for energy sale (type and quantity) should be in place before any final decision is made on the design of the energy recovery section of an MSW incineration plant.

✓ ✓ When surplus energy is to be used for district heating, the incineration plant must be located near an existing grid to avoid costly new transmission systems.

✓ If there is a regular market for the sale of hot water (district heating or similar), or if steam is present, the plant should be based on production of hot water or steam only. These configurations are normally preferable both in terms of technical complexity and economic feasibility. During the warm season, a certain extent of cooling to the environment may be preferable to solutions demanding greater investments.

Table 3.1 summarizes the efficiency of energy recovery for each use of energy with respect to the heat input. Assuming that the heat input is known, the efficiency numbers can be used to compute the absolute amount of energy recovered and the revenues from the energy sale.

Part 1 of this Technical Guidance Report discusses the importance of the revenues from energy sale to the overall economy of the plant .

Energy is released from the incineration and leaves the furnace as flue gases at a temperature of approximately 1,000°-1,200° C. The hot flue gases from the incineration must be cooled before they can be passed on to a flue gas cleaning system. The flue gases are cooled through a boiler, where the energy released from incineration is initially recovered as hot water or steam.

The end use possibilities of power, district heating, or steam depend on the type of boiler. The boilers are divided into three broad categories, as follows:

- The hot water–producing boiler produces heat only (hot water). This boiler is also used if heat recovery is not possible (cooling of the surplus heat).
- The low pressure (LP)–producing boiler produces LP steam only.
- The steam-producing boiler generates power and combines power and process steam or heat.

The Hot Water Boiler

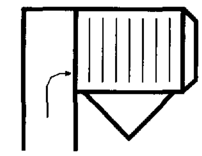
The hot water boiler is fairly simple to design, accommodate in building arrangements, finance, operate,

Table 3.1 Summary of Efficiencies in Different Energy Recovery Systems

Energy utilization	*Recovery*		*Overall efficiency*[a]
Heat only	Heat	80%	80%
Steam only	Steam	80%	80%
Power only	Power	35%	35%
Combined steam	Steam	0-75%	
and power	Power	0-35%	35-75%
Combined heat	Heat	60-65%	
and power	Power	20-25%	85%

a. Efficiencies defined as usably energy related to energy content (lower calorific value) of the waste

and maintain. Technically, special attention must be paid to the corrosive nature of the flue gases from waste incineration.



Hot Water Boiler

Hot water (approximately 110°-160° C) may be produced. It can be heated to higher temperatures depending on the operating pressure level of the boiler.

A boiler efficiency of up to approximately 80 percent can be achieved. The recovery is limited by the temperature of the returning cooling water.

The Hot Water Boiler Circuit

The energy from the hot flue gases is via a hot water boiler transferred to an internal circuit of water which again passes the energy to the end user circuit (district heating system). The end user circuit is separated from the boiler circuit by heat exchangers.

The internal circuit for the transfer of energy via the hot water is illustrated in figure 3.1.

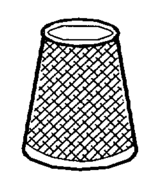
Hot Water Application

The relatively low energy content of hot water limits its uses. In temperate climates, it is commonly used in district heating systems to heat homes and public buildings.

Heat Only

When there is no beneficial use for the waste generated energy, a hot water boiler connected to a cooling facility is the most economical way to cool the flue gases before cleaning.

Cooling may take place through a number of well-known methods—including cooling towers, a fan-mounted air cooler (radiator), and heat exchangers using river or seawater.

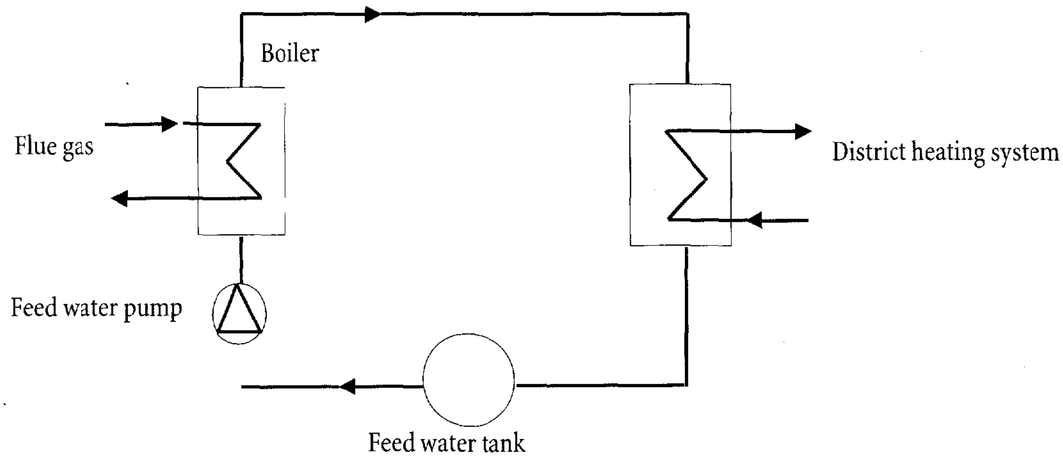


Cooling Tower

A cooling tower uses water as the cooling medium and emits steam. A heat exchanger requires river water or seawater, and hot water is led back to the recipient.

If cooling water is not available, a fan-mounted air cooler can serve the purpose, although it is less energy efficient. Moreover, an air

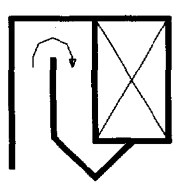
Figure 3.1 Hot Water Boiler Circuit



cooler is less appropriate in hot environments, as the cooler dimensions increase with the ambient air temperature.

The Low-Pressure Steam Boiler

If a district heating network is not available and there is a demand for process steam, a low-pressure boiler may be an alternative to the hot water boiler.



LP Steam Boiler

The low-pressure boiler is similar to the hot water boiler in terms of complexity, accommodation in building arrangements, financing, operation, and maintenance—although the design requires more attention because the flue gases are so corrosive.

Depending on the operating pressure level of the boiler and the extent of superheating, the steam may be approximately 120° to 250° C.

A steam pressure of up to approximately 20 bar may be relatively low. This allows for saturated steam at approximately 210° C. A certain amount of superheating may be necessary, depending on the vicinity of the end users—as uses for low-pressure steam depend on its energy content. See table 3.2 for relevant parameters for steam demand in various industries.

Cooling capacity must remain available, as the demand for process steam may not be continuous. Moreover, the industries with demands for process steam should be located near the plant to prevent extensive heat loss and eliminate the need for expensive pipelines. The risks related to supplying the steam to a single or a few industrial facilities must be thoroughly assessed.

A boiler efficiency of up to approximately 80 percent can be achieved. The recovery is limited by the temperature of the water returned to the boiler.

The High-Pressure Steam Boiler

A steam boiler requires more attention to design than the hot water–producing or LP steam boiler because of the highly corrosive nature of the flue gas. It also requires more attention to its operation and more space.

Special attention must be paid to several characteristic of the steam boiler—including design and arrangement and steam parameters.

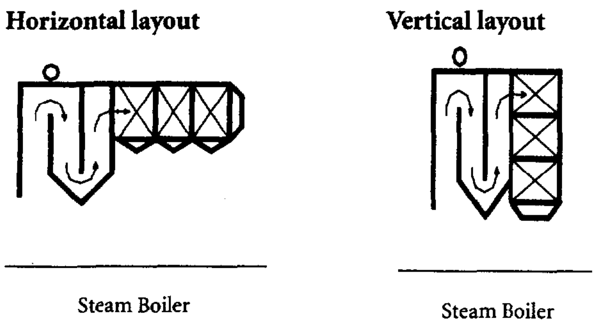
Design and Arrangement

The steam boiler is divided into one to three open radiation passes and a convection part.

After passing the radiation part, the flue gases enter the convection heating surfaces. Here, they first pass heat to the steam in the superheaters. Then, in the economizers, the flue gases are finally cooled to approximately 160° to 220° C before being passed on to the flue gas cleaning system.

The radiation part of the boiler requires a room up to 30 to 40 meters in height.

The convection part of the boiler can be arranged either horizontally or vertically. The horizontal arrangement takes up approximately 20 meters more space than the vertical arrangement in the longitudinal direction. The arrangement of the convection section can significantly affect building costs and should be determined as early as possible.



Steam Parameters

The energy recovery from the steam boiler may be more significant than that of the hot water or LP boiler. However, there is a tradeoff between high recovery and reliability of the boiler because of the highly corrosive nature of the flue gases.

The steam boiler must be designed to operate with a waste furnace to avoid potential serious operational problems such as erosion, corrosion, fouling, short continuous operation periods, insufficient availability, and extensive repair and maintenance.

The risk of corrosion and erosion can be reduced by observing a number of specific design criteria and by designing the boiler for moderate steam parameters (pressure and temperature). The waste-fired plant cannot be designed with steam parameters similar to those of traditional power plants fired with coal, gas, or oil. This is because waste differs from fossil fuel, particularly in terms of the content of chlorine, which—combined with sulfur—may lead to high-temperature corrosion, even at relatively low temperatures.

Some combustion processes may, furthermore, have a risk of CO corrosion.

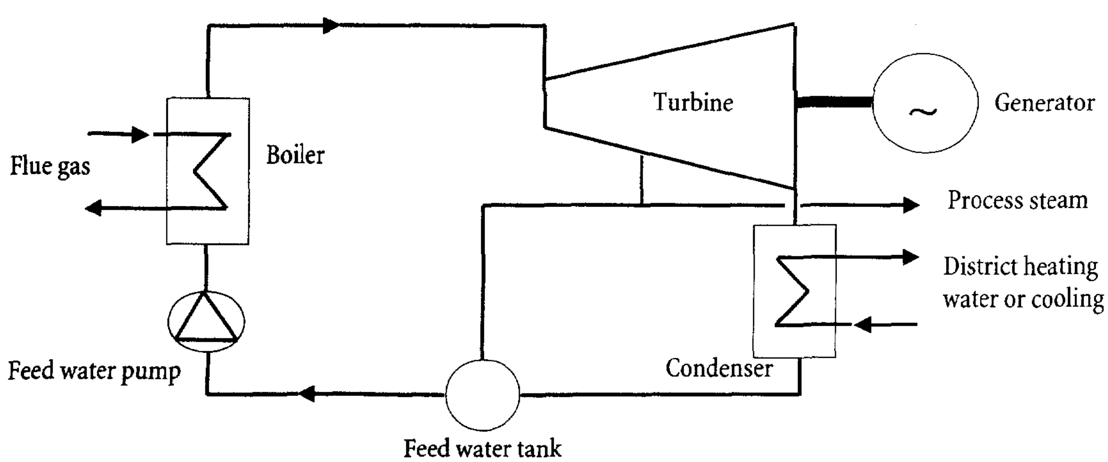
The corrosive nature of the flue gas from waste incineration usually limits the steam parameters to a maximum temperature of approximately 400° C and a pressure of approximately 40 bar.

The temperature of the water returning to the boiler (feed water) is maintained at a minimum of 125 to 130° C to limit the risk of low-temperature corrosion in the coldest part of the boiler.

The Steam Circuit

The energy recovery from a steam-producing boiler is conventionally known as the Rankine process. The Rankine process allows energy outputs in the form of power, steam, and combinations of power, steam, and hot water (see figure 3.2).

Figure 3.2 The Rankine Process



The energy from the hot flue gases is recovered through the boiler and passed to the internal circuit of steam.

The steam energy may be converted to power by a turbine and generator set. The superheated and high-pressurized steam from the boiler expands in the steam turbine, which transforms the energy content of the steam to kinematic energy, which is further transformed to electrical energy by the generator.

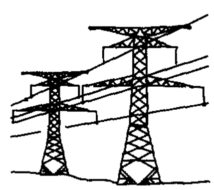
The excess heat of the low-pressure steam is converted to hot water within the heat exchanger (condenser) and either passed to a district heating network or cooled away.

Steam Application

Electrical Power Generation Only

When producing electrical power only, it is possible to recover up to 35 percent of the available energy in the waste as power. The surplus heat has to be cooled in a condenser or a cooling tower.

This option is attractive if the plant is situated far from consumers who demand or industries that require process steam.

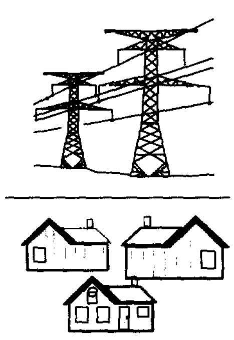


Power Only

When only power is produced, a fully condensing turbine is used. The excess heat is produced at such a low temperature in this condenser that it is not attractive for recovery. The cooling medium is usually seawater or air.

Combined Heat and Power Generation

When producing a combination of heat and power, it is possible to use up to 85 percent of the energy of the waste. With a boiler designed for waste incineration (moderate steam parameters), an output of electricity of 20 to 25 percent and an output of heat of 65 to 60 percent can be achieved.

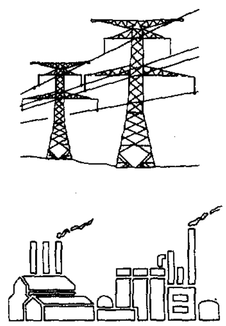


Combined Heat and Power

When a combination of power and district heating is produced, a so-called back pressure turbine is used. The back pressure is determined by the temperature and the flow of the coolant, which is usually water from a district heating network.

Combined Process Steam and Power Generation

When producing both process steam and power, the electrical output may be found somewhere between the values for power production only and combined heat and power production—that is, between 35 and 20 percent, depending on the amount of process steam extracted from the turbine.



Combined Steam and Power

During this process, a minimum amount of the steam has to pass all the way through the turbine. This means that at least 10 percent of the low pressure steam has to be cooled away.

When power and process steam are produced, an extraction turbine is used, which combines the two aforementioned concepts. It may be operated as a fully condensing turbine cooled by seawater or air and then, when needed, steam can be extracted from a bleed in the turbine at relevant parameters (pressure and temperature).

To prevent extensive heat loss and avoid expensive pipelines, the industries that need process steam should be located near the plant.

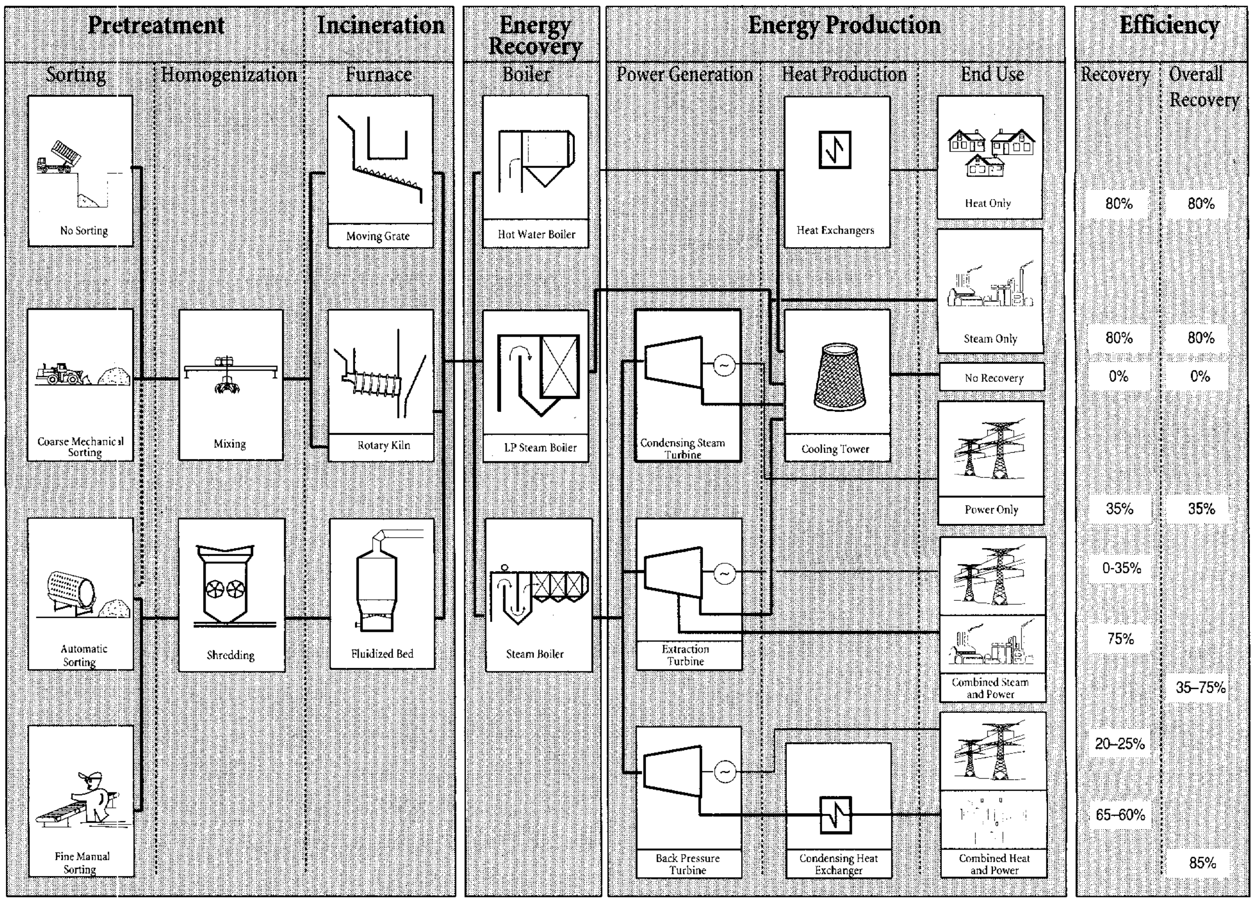
Table 3.2 Steam Parameters for Process Steam in Various Industries

Industry	*Steam temperature*
Breweries	150° to 250° C
Chemical industries	200° to 500° C
Sugar production	100° to 200° C
Paper industries	100° to 300° C
Wood industries	100° to 200° C
Concrete elements, cement production	120° to 150° C
Absorption cooling	150° to 200° C
Food industries	150° to 200° C
Drying purposes (e.g., sludge drying)	150° to 200° C

Energy Recovery Systems Overview

Diagram 3.1 gives an overview of equipment and processes for feasible energy recovery systems of MSW incineration facilities. It presents applicable combinations of waste pretreatment, furnace type, boiler, and energy recovery equipment. The diagram further compares the efficiency of energy recovery depending on end usage.

Diagram 3.1 Technological Overview



4 Air Pollution Control

Key Issues

Incinerating MSW generates large volumes of flue gases. The flue gases carry residues from incomplete combustion and a wide range of harmful pollutants. The pollutants and their concentration depend on the composition of the waste incinerated and the combustion conditions. However, these gases always carry ash, heavy metals, and a variety of organic and inorganic compounds.

The pollutants are present as particles (dust) and gases such as HCl, HF, and SO_2. Some harmful compounds such as mercury, dioxins, and NO_x can be fully removed only through advanced and costly chemical treatment technologies.

Primary and secondary measures can help reduce emission of pollutants.

Primary measures—which are initiatives that actually hinder the formation of pollutants, especially NO_x and organic compositions such as dioxins—must be applied as much as possible. Primary measures comprise an efficient combustion process (long flue gas retention time at high temperature with an appropriate oxygen content, intensive mixing and recirculation of flue gases, and so forth—as discussed in the Incineration Technology chapter), preprecipitation of ashes in the boiler, and short flue gas retention time at intermediate temperatures. The content of CO and TOC (total organic carbon excluding CO) in the raw flue gas before inlet to the cleaning system is a good indicator of the efficiency of the combustion process.

The air pollution control (APC) system comprises electrostatic precipitators; bag-house filters; dry, semi-dry, and wet acid gas removal systems; catalysts; and the like. Some characteristics of the secondary measures are that they precipitate, adsorb, absorb, or transform the pollutants.

The selection of the APC system depends primarily on the actual emission limits or standards, if any, and the desired emission level. In this context, the different APC systems can be grouped as basic, medium, or advanced emission control.

Basic emission control, which involves only reducing the particulate matter, is simple to operate and maintain, and the investment is minimal. At the same time, a significant part of the most harmful substances is also retained because dust particles (fly ash) and pollutants adsorbed on the surface of the particles can be removed in efficient dust removal equipment like electrostatic precipitators. Basic emission control is a minimum requirement.

When moving from basic to medium or advanced emission control, the increased efficiency must be evaluated in the light of factors such as the increased complexity, the amount and types of residues, the investment, and operating cost. The state-of-the-art flue gas cleaning systems (advanced emission control)—applied in Europe and the United States—are quite complex, and the benefits in terms of reduced emissions should always be compared to other emission sources.

The figures in the APC Systems Overview show the most common flue gas cleaning techniques, possible combinations thereof, and the resulting emission of pollutants.

Flue gas treatment generates residues in the form of partly soluble dry products or, if a wet system is applied, of salty waste water requiring advanced treatment before being discharged to a recipient or even a municipal sewage treatment facility.

Key Criteria

✓ ✓ ✓ The furnace must be designed for stable and continuous operation and complete burnout of the waste and flue gases ($CO<50$ mg/Nm^3, $TOC<10$ mg/Nm^3).

✓ ✓ ✓ The flue gases from the furnace must be cooled to 200° C or lower in a boiler before flue gas treatment technology can be applied.

✓ ✓ ✓ The flue gas treatment installation must be capable of removing dust at least as efficiently as a two-stage electrostatic precipitator (basic emission control, dust<30 mg/Nm^3).

✓ ✓ ✓ A controlled and well-operated landfill must be available for residue disposal.

✓ Elimination of hydrogen chloride (HCl) from the flue gases should be considered.

Volume and Composition of the Flue Gas

As a rule of thumb, all fuels may be assumed to produce a dry, stoichiometric flue gas quantity of 0.25 Nm^3 per MJ. Stoichiometric means that the fuel is burned completely with just the quantity of air needed for combustion. Consequently, the oxygen content in the resulting flue gas is zero. Moreover, the volume of the water vapor formed during the combustion is deducted.

The actual flue gas flow rate may be estimated according to the formulas in box 4.1.

- **Particulate pollutants:** Fly ash, including the heavy metals of antimony (Sb), arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni), thallium (Tl), and vanadium (V).

- **Gaseous pollutants:** Hydrogen chloride (HCl), mainly from the combustion of PVC; sulfur dioxide (SO2) from combustion of sulfurous compounds; hydrogen fluoride (HF) from combustion of fluo-

Box 4.1 Flue Gas Volumes

Calorific value:	H_{inf} [MJ/kg]
Stoichiometric flue gas volume:	H_{inf} x 0.25 [Nm^3/kg] (dry, 0% O_2)
Dry flue gas at y % O_2:	H_{inf} x 0.25 x (21/(21—y)) [Nm_3/kg]
Wet flue gas at z % H_2O:	H_{inf} x 5.25 /(21—y) x (100/(100—z)) [Nm_3/kg]
Actual flue gas volume at t° C:	H_{inf} x 525 /(21—y) / (100—z) x (273 + t)/273 ≅
	$2H_{inf} \frac{(273+t)}{(21-y)(11-z)}$; [m^3/kg]
	Example: Calorific value H_{inf} =8 MJ/kg, oxygen content y =11%, water vapor content z =15%, flue gas temperature t = 100° C :
Actual flue gas volume	$2 \times 8 \frac{(273+100)}{(21-11)(100-15)} \cong 7.0$; [m3/kg]

rine compounds; and nitrogen oxides (NO_x) from part of the nitrogen in the waste and N2 in the air.

Some of the heavy metals evaporate in the combustion process, then condense to a varying degree on the surface of the fly ash particles in the boiler section. At the exit of the boiler, part of each individual metal (particularly Hg) may remain gaseous.

Table 4.1 shows international typical data on the content of pollutants in the raw flue gas from waste incineration.

Environmental Standards

Different countries adhere to different environmental standards, including standards for emissions to the atmosphere. Such standards may be based on air quality considerations only, in which case the air pollution problems are solved primarily by building tall stacks.

Other countries have emission standards that reflect either what is deemed technically and economically feasible in that country or what is considered state-of-the-art within emission control technology. But very often, countries where waste incineration is not common have no emission standards that can be used directly. In this case, the emission limits must be fixed based on an evaluation of other sources, an environmental assessment, and the complexity of the resulting APC system.

Table 4.1 Emission Control Levels

Emission control-level	*parameters controlled*
Basic	Particles only—e.g., < 30 mg/Nm^3.
Medium	Same standard for particle emission. Additional standards for HCl, HF, SO_2, and the heavy metals As, Cd, Cr, Cu, Pb, Mn, Hg, and Ni.
Advanced	State-of-the-art emission control. Stricter standards for the medium-level parameters and supplementary control of NO_x, the metals Sb, Co, Tl, and V, and dioxins.

The corresponding emission standards to be met are listed in table 4.2.

Emission standards are usually expressed in units of concentration—for example, in milligrams of the individual pollutant per cubic meter of flue gas. Since the flue gas volume varies with the composition, pressure, and temperature of the gas, the volume must relate to a reference or standard condition.

For waste incineration, the standard condition is most often 0° C (= 273 K), 101.3 kPa (= ~ 1 Atm.), 0% H_2O, 11% O_2. This standard condition is used throughout this report. Volumes corrected to 0° C and 101.3 kPa are named standard or normal cubic meters = Nm^3.

The requirements for basic air emission control may be met by a two-stage electrostatic precipitator (ESP). The ESP removes the dust physically in a dry state. The medium and advanced levels may be fulfilled by either dry or a combination of dry and wet chemical methods yielding dry solids and liquid waste streams, respectively.

The wastewater from wet flue gas cleaning must be treated at the site in accordance with the local wastewater standards before being discharged to a sewer or directly into the final recipient. The presence of small concentrations of toxic materials in the salty wastewater requires sophisticated chemical treatment technology to meet common standards. Additional solid

Table 4.2 Raw Flue Gas Concentrations and Emission Standards (mg/Nm_3, dry, 11% O_2)

	Raw	*Emission standard*		
Parameter	*flue gas*	*Basic*	*Medium*	*Advanced*
Particles	2000	30	30	10
HCl	600	n.a.	50	10
HF	5	n.a.	2	1
SO2	250	n.a.	300	50
NOx (as NO2)	350[a]	n.a.	n.a.	200
Hg	0.3	n.a.	n.a.	0.05
Hg + Cd	1.8	n.a.	0.2	n.a.
Cd + Tl	1.6	n.a.	n.a.	0.05
Ni + As	1,3	n.a.	1	n.a.
Pb +Cr +Cu +Mn	50	n.a.	5	n.a.
Sb +As +Pb +Cr +Co +Cu +Mn +Ni +V	60	n.a.	n.a.	0.5
Dioxins[b]	3	n.a.	n.a.	0.1

n.a.—Not applicable in the particular standard.

a. Without any primary measures.

b. Polychlorinated para-dibenzoe dioxins and furans, ng/Nm^3 2,3,7,8-TCDD equivalents.

residues are formed during the waste water treatment process.

The solid residues from the flue gas and water treatment processes are normally useless and must be landfilled, where they are exposed to rainwater. The residues are susceptible to a degree of leaching, depending on which flue gas treatment process was used. Therefore, the landfill must be located and designed with a view to preventing the leachate from polluting valuable groundwater reservoirs and any nearby surface water bodies. Some countries have design standards or minimum requirements for landfills.

Properly designed controlled landfills for flue gas residues include drainage systems for leachate collection and treatment. The treatment facility will be similar to what is required at the incineration plant itself.

Because advanced flue gas treatment residues are soluble, they should be disposed of where there is no risk of polluting groundwater aquifers—for example, in old mines.

Air Pollution Control Technology

Basic Emission Control

In basic emission control, only the particulate matter is reduced. The recommended emission limit value is 30 mg/Nm_3. The following types of particle or dust collectors are commonly available, but only electrostatic precipitators and fabric filters can meet the requirements when applied alone:

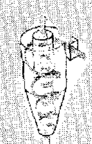
- Mechanical collectors (cyclones and multicyclones)
- Wet scrubbers (such as Venturi scrubbers)
- Fabric filters (bag house filters)
- Electrostatic precipitators (ESPs)

Mechanical collectors (such as the cyclone) do not effectively reduce the dust content of the flue gas to 150 mg/Nm_3 or below. Consequently, they are of interest only as a component of a more advanced flue gas treatment system or as a secondary dust arrestor at hoppers and similar installations (see box 4.2).

Wet scrubbers (Venturi scrubbers) and electric precipitators) can be designed to fulfill a specified emission limit value—for example, 100 mg/Nm^3. Scrubbers are not practical as the first or only air pollution control device, however, as the water applied will also remove most of the HCl present in the flue gas. Consequently, it will produce a dust laden corrosive waste water stream with a pH value around 0 (see box 4.3).

Fabric filters inherently have a high cleaning efficiency, and—whether required or not—they will remove the particles to about 10 mg/Nm^3. However, fabric filters working directly on the gases from the

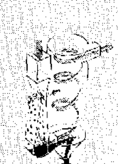
Box 4.2 Cyclone



Application	• Dust collector
Emission level	• 500 mg/Nm^3
Advantages	• Simple and robust • Inexpensive initial cost • Low operating and maintenance costs
Disadvantages	• Efficiency too low with fine particles • Prone to wear

Working principle: The dust-laden gas enters tangentially and is brought to rotate. Centrifugal forces cause the dust particles to impinge on the wall and fall into the conical bottom, where they are removed. The treated flue gas leaves through the central outlet.

Box 4.3 Venturi Scrubber



Application	• Dust collector
Emission level	• About 100 mg/Nm^3, depending on design
Advantages	• Inexpensive investment
Disadvantages	• High operating and maintenance costs • Prone to corrosion • Produces salty wastewater

Working principle: The dust-laden gas accelerates through a throat (a Venturi), atomizing the water injected. The water droplets collect the dust particles, and the droplets are subsequently precipitated in something like a cyclonic settling chamber.

boiler are vulnerable to varying temperature, humidity, and carryover of sparks from the combustion. Moreover they must be bypassed during plant startup and shutdown (see box 4.4).

Electrostatic precipitators (ESPs) are therefore the preferred fly ash collectors at waste incineration plants. They may be designed with one, two, or three independently controlled electric fields, according to the actual emission standard. A single-field ESP may reduce the particle concentration to below 150 mg/Nm^3, whereas a two-field ESP may fulfill the basic particle emission standard of this report (30 mg/Nm^3). (See box 4.5.)

A well-functioning two-field ESP will also generally reduce the concentrations of heavy metals (except Hg) to below the limit values of advanced emission control. A two-field ESP does not cost a great deal more than a single field, but yields great environmental benefits. By applying the basic standard for emission control, a significant part of the most harmful substances is also retained.

To keep the dioxin emission at the lowest possible level, the ESP must operate at a temperature below 200° C.

Medium-Level Emission Control

Medium-level emission control requires reduction of acids (HCl and HF) and heavy metals, but normally not of SO_2. Two different processes prevail:

- A simple wet system: ESP plus single-stage wet scrubbing
- Dry or semidry flue gas cleaning (dry scrubbing).

In the simple wet system (see box 4.6), the particles and most of the heavy metals, except Hg, are removed in the precipitator, whereas HCl, HF, and most of the Hg are removed in a wet scrubber by washing with water.

As the precipitator operates at 150° to 200° C, and since the scrubbing process requires the flue gas to be treated at its water vapor saturation temperature—that is, 55° to 60° C—the gas must be cooled between the ESP and the scrubber. This may be done by spraying water in a separate quencher or by a combination of a gas/gas heat exchanger and a quencher. The heat exchanger is cooled by the cold gas (55° to 60° C) leaving the scrubber, which is then reheated. The latter solution is more expensive from an investment point of view, but it saves water and reduces the density of the white stack plume resulting from the scrubbing.

The water enters the actual scrubber and absorbs the HCl and HF to concentrations below the emission limit values of the medium control level and the advanced level under formation of diluted hydrochloric acid. The low pH value (~ 0) and the high chloride concentration favor the absorption of Hg while hampering that of SO_2.

Box 4.4 Fabric Filter

Application	• Dust collector
Emission level	• 10 mg/Nm^3
Advantages	• High efficiency • Dust layer may also remove acid gases • Moderate investment and operating costs
Disadvantages	• Vulnerable to sparks and moisture

Working principle: The dust-laden gas passes into a box, then is sucked or pressed through cylindrical bags. A dust layer forms on the surface (most often, the outer surface, in which case the bags are supported by cages). This layer is removed by various shaking mechanisms.

Box 4.5 Electrostatic Precipitator

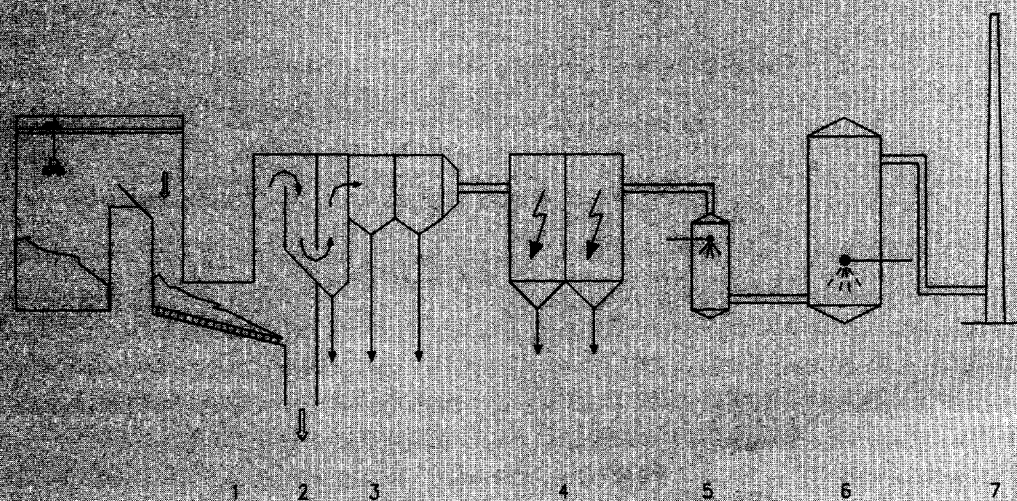
Application	• Dust collector
Emission level	• 20-150 mg/Nm^3, depending on design
Advantages	• Robust • Low operating and maintenance costs
Disadvantages	• Expensive initial cost • Dust cake does not remove acid gases

Working principle: The dust-laden gas is led into a box in which a number of grounded collecting plates are suspended. Discharge electrodes—negatively charged by rectified high-voltage DC—are located between each row of plates. This generates an electric field, charging the particles and causing them to migrate to the plates, forming a dust layer. The plates are shaken from time to time, and the dust falls into the bottom hopper.

Box 4.6 Simple Wet System

Application
- Removal of particles, HCl, HF, and heavy metals

Efficiency
- Medium control level



Legend:

1. Furnace
2. Slag removal
3. Boiler
4. ESP
5. Quencher
6. Scrubber
7. Stack

Advantages
- Low consumption of chemicals
- Most of the HCl neutralized with inexpensive $CaCO_3$
- Little formation of solid residues

Disadvantages
- Wastewater discharge
- Risk of corrosion
- Quencher and scrubber, and—if there is no reheating—ID fan and stack pipe to be made of or lined with corrosion-resistant materials (plastics and rubber)
- Dense white plume (if no reheating)

The water is recirculated until a certain chloride level is achieved, then it is passed on to the quencher. The chloride content is concentrated because of the evaporation. A constant bleed-off maintains the chloride concentration in the quencher and controls the addition of fresh water into the HCl scrubber.

The bleed-off contains the HCl, HF, and heavy metals removed in the scrubbing process. This effluent must be neutralized—for example, by calcium carbonate ($CaCO_3$) to pH 2.5 and further to pH 8 to 9 by hydrated lime ($Ca(OH)_2$) or sodium hydroxide (NaOH). At pH 8 to 9, the heavy metals precipitate—Hg, however, only by the expense of a separate chemical, TMT 15—and are removed as a thin sludge (approximately 10 percent dry substance). This may either be further dewatered in a filter press or used as it is for humidifying the fly ash from the ESP.

The treated water is discharged. It is essentially a solution of calcium chloride ($CaCl_2$). Consequently, in this process, the HCl removed leaves the incineration plant with the wastewater.

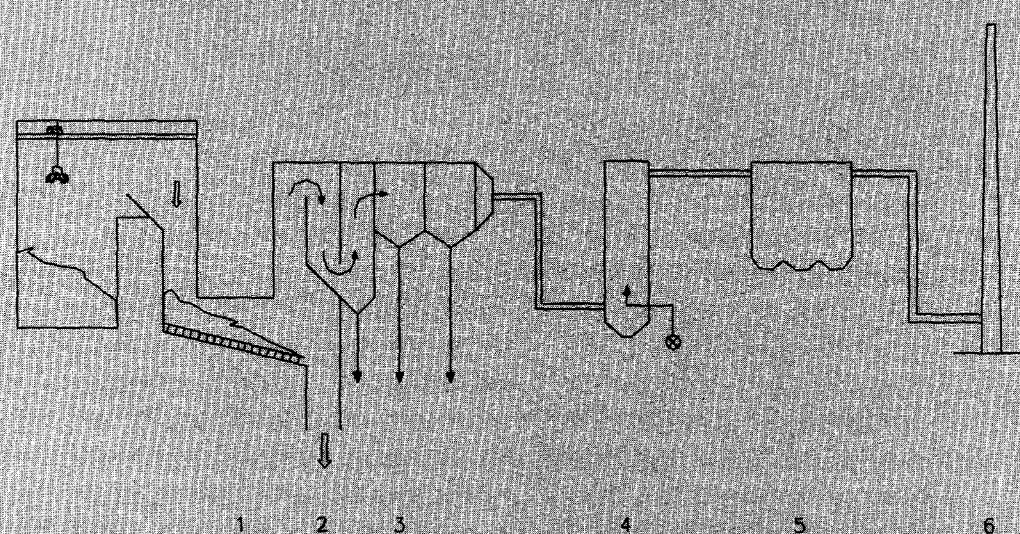
Dry and semidry flue gas cleaning systems (see boxes 4.7 and 4.8) are very similar concepts. In both systems, the acid gases react with hydrated lime ($Ca(OH)_2$). In this process, the gases are converted to solid substances: calcium chloride, calcium sulfite/sulfate ($CaSO_3/CaSO_4$), and calcium fluoride (CaF_2). The reaction products are precipitated in a subsequent bag-house filter.

The difference between the two systems is that in dry flue gas cleaning, the lime is injected in a solid form, whereas in semidry flue gas cleaning it is injected in the form of an aqueous suspension. In dry systems, water is sometimes also injected, although through separate nozzles. The water has a twofold pos-

Box 4.7 Dry System

Application
- Removal of particles, HCl, HF, and heavy metals

Efficiency
- Medium control level



Legend:

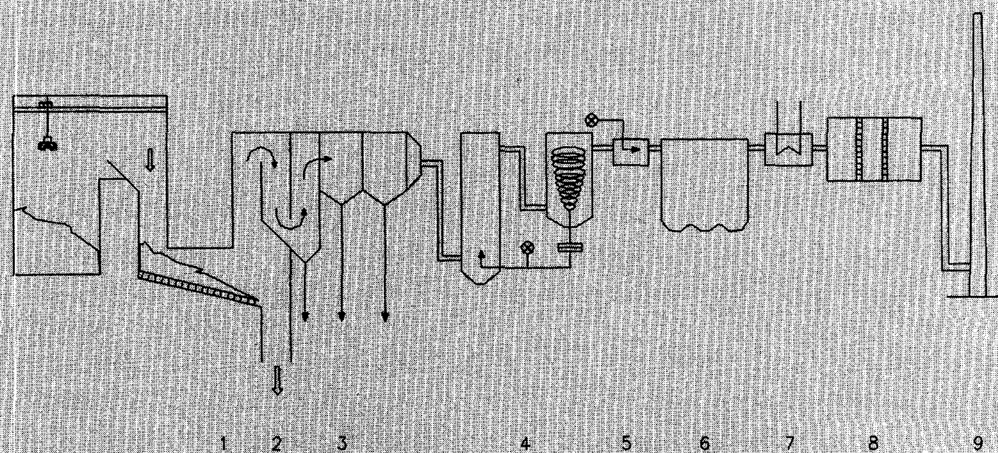
1. Furnace
2. Slag removal
3. Boiler
4. Reactor
5. Bag-house filter
6. Stack

Advantages
- No wastewater
- Less prone to corrosion
- May be fairly easily adjusted to fulfill the requirements of the advanced control level
- Only visible plume in very cold weather

Disadvantages
- Higher consumption of chemicals
- Uses the relatively expensive $Ca(OH)_2$
- More solid residues
- In medium control level, the SO_2 concentration is also reduced

Box 4.8 Semidry System with Dioxin Removal and SCR

Application	• Removal of particles, HCl, HF, SO_2, NO_x, dioxins, and metals
Efficiency	• Advanced control level



Legend:

1. Furnace	2. Slag removal	3. Boiler
4. Semidry reactor	5. Carbon injection	6. Bag-house filter
7. Heat exchanger	8. SCR	9. Stack

Advantages	• No wastewater • Less prone to corrosion • No visible plume
Disadvantages	• Expensive NO_x removal process • High consumption of chemicals and energy • More solid residues • Dioxins only adsorbed, not destroyed

itive effect. It cools the flue gas, which in itself enhances the reactions, and the increased concentration of water vapor also favors the reactions. As the resulting $CaCl_2$ is very hygroscopic (water absorbing), the flue gas temperature cannot, however, be reduced to less than 130° to 140° C, lest difficulties in the handling of the residue arise.

At this temperature, addition of lime in comparison with the stoichiometrically required consumption is necessary, primarily in connection with dry flue gas cleaning. The excess amount of lime then becomes part of the residue. It is standard to recirculate some of the residue and lock out the rest to increase the use of the lime.

$Ca(OH)_2$ is produced by slaking burned lime, CaO (which is in turn produced from limestone, $CaCO_3$). In semidry flue gas cleaning, CaO can therefore be purchased instead of $Ca(OH)_2$, and the slaking/suspension can be carried out on the site in a single process.

This solution may be economically attractive because CaO is less expensive than $Ca(OH)_2$ and because a greater amount of the active component, Ca, is produced per metric ton of lime. On the other hand, a semidry system is usually more expensive than a dry system.

The reactions between lime and the acid gases are not affected by the simultaneous presence of fly ash. Therefore, the usual practice is to precipitate the ash together with the reaction products in the bag-house filter. This also removes the heavy metals, including Cd, to the emission limits of the advanced control level—except for Hg, which is just removed to fulfill the Cd plus Hg limit value of the medium level.

The process does not result in any effluent. Consequently, dry and semidry systems are less complicated than wet systems and require smaller investments.

Advanced Emission Control

The emission limit values of the advanced control level may also be met by:

- Dry and semidry systems with increased consumption of chemicals
- Advanced wet systems combining ESP, gas/gas heat exchanger, two-stage scrubbing, and bag-house filter.

In addition, NO_x must be removed in a NO_x reduction system.

The treatment efficiencies of dry and semidry systems towards HCl, HF, and SO_2 depend on the addition of chemicals. Increasing the consumption of lime can help meet the emission limit values of the advanced control level to these three pollutants. A completely dry system will, however, need lime in excessive quantities. The Hg and dioxin limits may be fulfilled by adding activated carbon to the lime.

The increased consumption of chemicals increases the production of residues correspondingly.

The advanced wet system differs from the simple systems because it has an additional wet scrubber in which SO_2 is reduced by reaction with a NaOH solution or a $CaCO_3$ suspension. Due to the excess oxygen in the flue gas, the reaction products are a sodium sulfate (Na_2SO_4) solution and a gypsum ($CaSO_4.2H_2O$) suspension, respectively.

If NaOH is applied, the scrubber system must have an additional water treatment plant in which the sulfate ions of the Na_2SO_4 solution are precipitated as gypsum by Ca ions—for example, by mixing in the $CaCl_2$ solution from the treatment of the water from the HCl removal. If $CaCO_3$ is used, the gypsum is formed directly and may be removed as a sludge by settling or in a hydrocyclone and dewatered.

The gas from the SO_2 scrubber is reheated in the gas or gas heat exchanger and led to a bag-house filter. Before this, activated carbon or a mixture of lime and activated carbon is injected into the duct. Thus, the bags are powdered, and when the gas penetrates them, Hg and dioxins are removed to concentrations below the limit values of the advanced control level. In addition, dust, HCl, HF, SO_2, and the other heavy metals are further reduced.

None of these processes, however, has any effect on NO_x. This constituent should first be controlled by primary measures such as flue gas recirculation (see the chapter on Incineration Technology).

NO_x may be further controlled by injection of ammonia (NH_3), which selectively reduces NO_x to free nitrogen and water vapor. Both of these gases are harmless and leave the plant through the stack.

Two process variants are available: selective noncatalytic reduction (SNCR) and selective catalytic reduction (SCR). The chemical reactions are the same, but the former requires a temperature around 900° C, while the latter is effective down to some 250° C. The SNCR requires NH_3 to be added in excess of the stoichiometric consumption, whereas SCR may be run at stoichiometric conditions.

Accordingly, SNCR is applied in the after-burning chamber of the furnace simply by injecting the NH_3. The surplus NH_3 passes with the flue gas to the air pollution control system. If this is wet, the surplus is quantitatively removed as ammonium chloride (NH_4Cl), in the HCl scrubber and is discharged with the treated waste water.

Dry and semidry flue gas treatment does not have the same capacity to remove NH_3. Therefore, a SCR system tends to be the best choice.

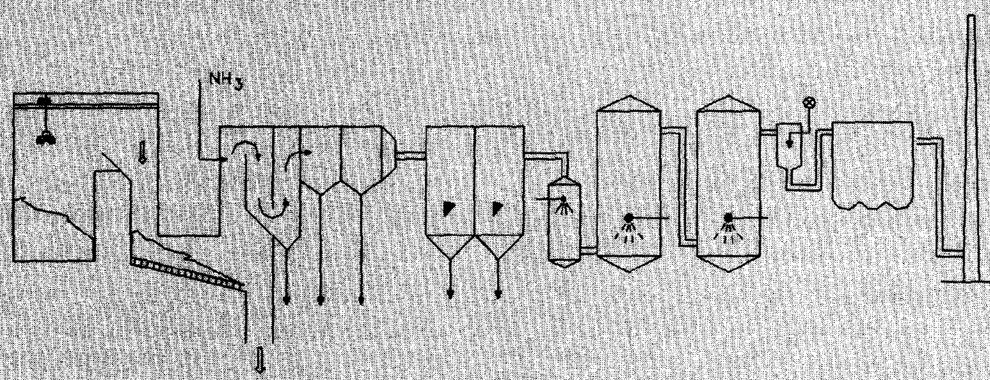
The SCR process is usually applied after the wet scrubbers, or after a dioxin filter in a wet system and after the baghouse filter in dry and semidry systems, respectively. This requires the gas to be reheated by heat exchange and a clean fossil fuel. Consequently, the SCR process is expensive, both in investment and operating costs.

Box 4.8 shows a semidry system with SCR, and box 4.9 shows an advanced wet system with SNCR. Both

Box 4.9 Advanced Wet System with SNCR, Limestone Scrubber, and Dioxin Filter

Application
- Removal of particles, HCl, HF, SO_2, NO_x, dioxins, and metals

Efficiency
- Advanced control level



Legend:

1. Furnace
2. Slag removal
3. Ammonia injection
4. Boiler
5. ESP
6. Quencher
7. Acid scrubber
8. Limestone scrubber
9. Adsorbent injection
10. Bag-house filter
11. Stack

Advantages
- Nearly stoichiometric consumption of chemicals
- Inexpensive NO_x removal process
- SO_2 removed with cheap $CaCO_3$
- Dioxins destroyed

Disadvantages
- Expensive in investment costs
- Wastewater discharge (incl. NH_4^+)
- Quencher and scrubbers to be made of plastics
- White plume in cold, humid weather

may fulfill all of the emission limit values of the advanced control level.

APC Systems Overview

Simplified diagrams for the various APC systems are presented in figures 4.1 and 4.2. They indicate the unit processes involved in obtaining basic, medium, and advance air pollution control. The emitted fraction of key pollutants is indicated in bar charts.

Induced Draft Fan and Stack

An induced draft fan is needed to overcome the pressure drop across the flue gas treatment system and maintain a certain underpressure in the furnace. This is normally placed at the rear of the flue gas treatment train and is furnished with a silencer.

The flue gas is then passed into the stack, which must be of a certain height—depending on the emission control level applied and other factors (see the chapter on Environmental Impact and Occupational Health).

Figure 4.1 Wet Air Pollution Control System with Dioxin Control

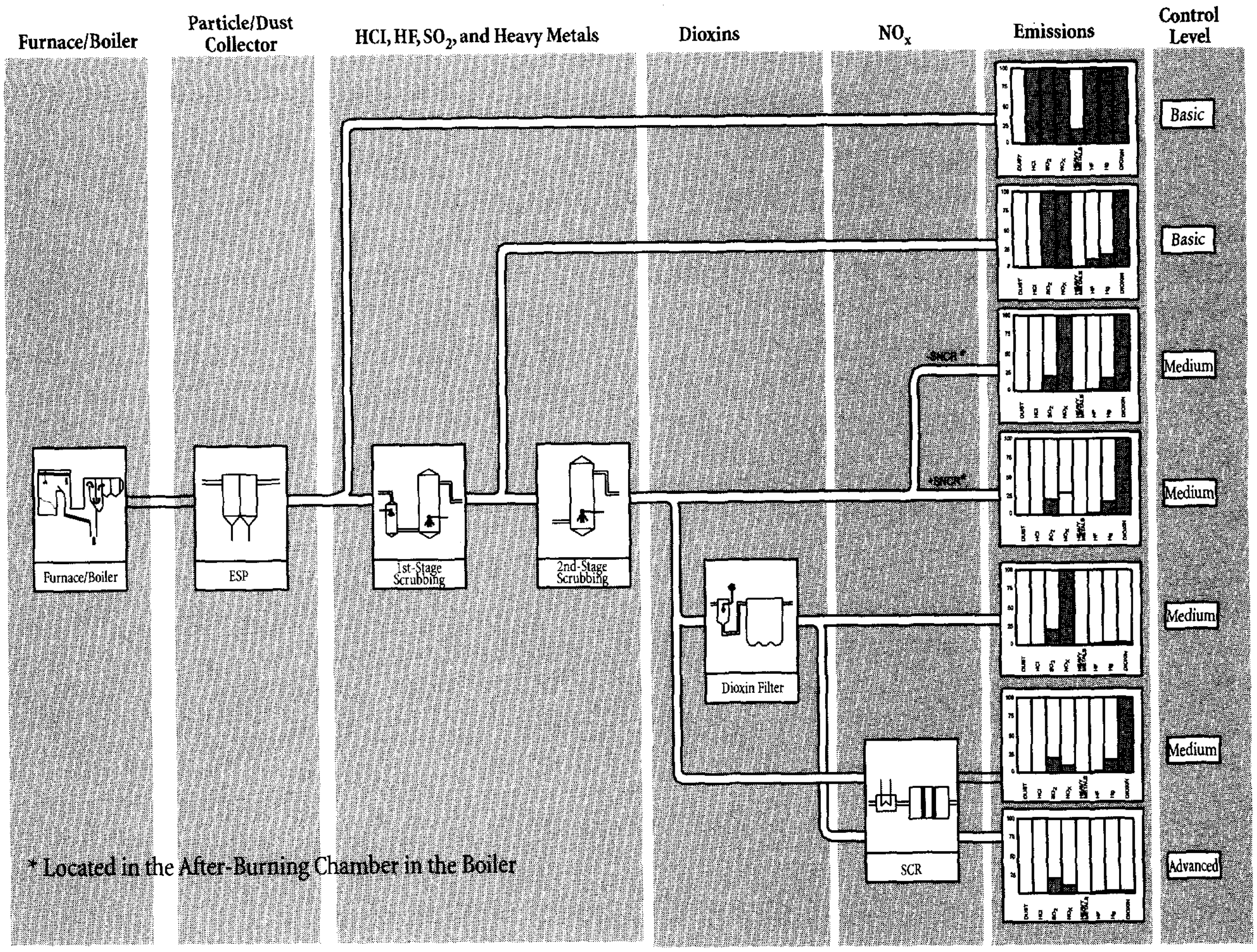
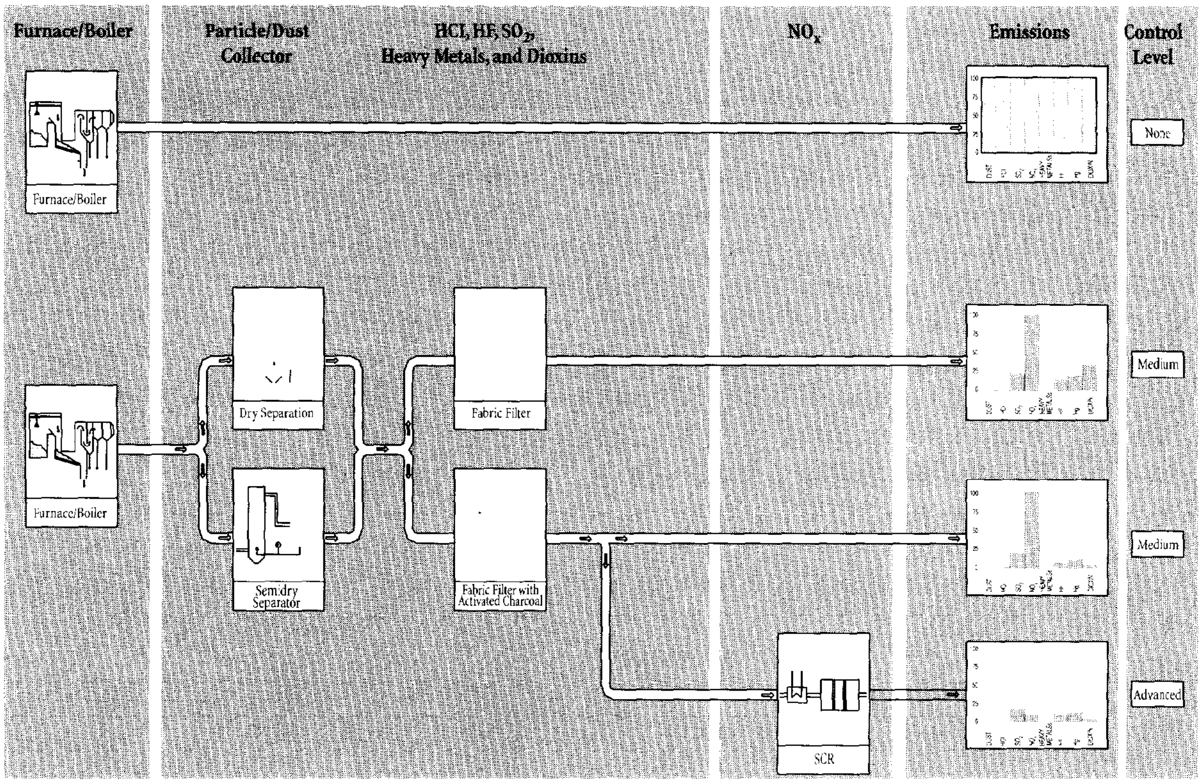


Figure 4.2 Dry Air Pollution Control System for Incinerators



5 Incineration Residues

Key Issues

During the incineration process, most of the waste is combusted and converted to harmless gases such as carbon dioxide (CO_2) and water vapor (H_2O). These gases are discharged as a flue gas into the atmosphere through the stack of the plant, together with surplus oxygen and the nitrogen of the combustion air. In addition, the flue gas contains various air polluting compounds, the concentration of which must be reduced (as explained in the chapter on Air Pollution Control).

However, part of the waste is incombustible and is removed from the incineration furnace as slag, a solid residue. The flue gas cleaning processes also produce residues, either directly or by the subsequent treatment of the spent scrubbing liquids, depending on the flue gas cleaning method applied.

Depending on the local circumstances, some of the slag may be used or recycled, but the flue gas treatment residues are normally useless and must be landfilled.

Landfilled materials are exposed to precipitation, which may dissolve the soluble components of the products. Consequently, landfills for incinerator residues must be located, designed, and operated with consideration of the leaching properties of the individual residues.

Key Criteria

✓ ✓ ✓ A controlled and well-operated landfill must be available for residue disposal. The landfill must be large enough to receive the entire quantity of solid residual products generated at the incineration plant

✓ ✓ ✓ The landfill must be located, designed, and operated in such a way as to prevent water pollution resulting from the leachate from the residues

✓ Scrap iron may be recovered for recycling by magnetic separation of the slag

✓ By sorting or sieving the slag, a "synthetic gravel" fraction may be recovered for utilization

✓ The dry residues should be prevented from generating dust at the landfill site.

Slag

Formation and Composition

The major waste product stream from incineration is the slag (sometimes called bottom ash or clinker). It amounts to 20 to 25 percent by weight of the waste combusted (or more, if there is a high amount of ash or other noncombustible material in the waste), but only to 5 to 10 percent by volume. Its main components are metals, glass, and mineral constituents of the waste, but some salts—particularly sodium chloride (NaCl)—may also be found. For additional information, see table 5.1.

Ideally, the loss of ignition (LOI) at 550° C of the slag should be 0, but—depending on the combustion conditions (for example, grate length and waste-loading factor)—LOIs of 2 to 5 percent by weight are common. The LOI is mainly incompletely burned organic material.

The grain size distribution of the slag ranges from about 1 mm to the largest waste components (such as discarded refrigerators), which can be fed into the furnace.

Table 5.1 Chemical Composition of Incinerator Residues, indicative

Element	*Unit*	*Slag*	*Fly Ash*	*Dry/semidry plus fly ash*	*Wet plus fly ash*
O	g/kg	450	—	—	—
Si	g/kg	250	150	75	80
Ca	g/kg	75	100	250	150
Fe	g/kg	75	25	15	50
Al	g/kg	50	70	25	30
C	g/kg	50	—	—	—
Na	g/kg	25	30	15	2
K	g/kg	15	35	25	5
Mg	g/kg	10	15	10	75
S	g/kg	5	25	15	5
Cu	g/kg	3	1.2	0.7	1.2
Zn	g/kg	2.5	30	15	30
Cl	g/kg	2	75	200	35
Pb	g/kg	1.5	10	10	10
F	mg/kg	500	—	—	—
Cr	mg/kg	350	650	200	250
Ni	mg/kg	250	150	100	60
As	mg/kg	15	150	175	90
Cd	mg/kg	1.5	400	300	650
Hg	mg/kg	0.05	8	15	650

Removal

The slag is removed from the rear end of the grate by gravity, and normally falls into a water bath, which cools the slag. Some of the water evaporates and must be replaced by fresh water to maintain the water level in the deslagger. Thus, it is possible to operate this removal process in such a way that there is no wastewater stream. It may, however, be advantageous to wash the slag with more water, as this may dissolve and remove some of the salt. The spent water may then be used in a medium or advanced flue gas treatment process.

Disposal

The main disposal method is landfilling. The slag may either be landfilled as it is or pretreated in one of a number of ways, depending on the requirements and the degree of environmental control measures taken at the landfill.

Pretreatment could be done through the washing process or various sorting processes. It is possible to use magnets to recover the iron content of the slag, which may be sold or delivered to a steelworks. A sieving process can recover a gravel size fraction, which may be used as a road base material. Recovery and use of these fractions reduce the amount to be landfilled and, thus, require less landfill capacity.

Normally, however, utilization possibilities develop slowly, and it is advisable to have a landfill capacity corresponding to the total slag quantity available before commissioning a new incineration plant.

When placing or using the slag in the natural environment it is, of course, important to prevent it from polluting water bodies like ground or surface water reservoirs. Thus, its leaching properties and especially the salt content must be considered.

Grate Siftings

A small part of the waste—0.1 to 2 percent, depending on the grate design—is able to penetrate the primary air openings of the grate elements and collects underneath the grate. The material normally consists of very fine particles and of molten plastics and metals with a low melting point—for example, lead (Pb).

In most cases, the material is mixed into the slag, but occasionally it is re-introduced into the incinerator furnace. Thus, the grate siftings are only seldom removed from the plant as a separate residue stream, but in this event the disposal method is landfilling.

Boiler and Fly Ash

Formation and Composition

The finest, incombustible particles of the incinerated waste pass with the flue gas out of the furnace and into the boiler. Since the flue gas velocity in the boiler is lower than in the furnace, some of the particles settle as boiler ash and are removed from the bottom hoppers of the boiler.

The finest particles, however, pass on to the flue gas treatment installation. When the flue gas cools in the boiler, various gaseous compounds—for example, evaporated heavy metals and their compounds, including zinc, lead, and cadmium chloride ($ZnCl_2$, $PbCl_2$ and $CdCl_2$), formed from hydrogen chloride (HCl) in the flue gas—condense on the particles to form fly ash.

The fly ash is either collected alone, perhaps in an ESP, or together with the reaction products of dry or semidry flue gas treatment processes (see the chapter on Air Pollution Control). In either case, it is most common to mix the boiler ash into the fly ash or the reaction product stream. This section considers the mixture of boiler ash and fly ash.

This mixture amounts to 2 to 3 percent by weight of the original waste. It consists of inert, mineral particles, variably soluble salts (for example, NaCl), and heavy metal compounds (of which $CdCl_2$ is readily soluble). The grain size is very fine; thus the ash is very dusty. For further information, see table 5.1.

Removal

The ash is removed from the bottom hoppers of the boiler and the ESP and is transported in closed conveyors to something such as a silo. When enough is collected, the ash is loaded into a tank truck and hauled to a landfill. Before this, it may be humidified by water or the fresh sludge from the treatment of spent scrubber liquid to prevent it from generating dust at the landfill. An open truck may be used with slush, if a protective tarpaulin is applied. Humidification increases the weight by around 30 percent.

Alternatively, the ash may go into big bags in a big bag station and landfilled without being humidified.

Disposal

Because of its relatively high content of salts and heavy metals, the ash cannot be used for construction purposes, and so far, no industrial use is known for it. Consequently, the only disposal method is landfilling under controlled conditions.

Residues from Dry and Semidry Flue Gas Treatment

Formation and Composition

As explained in the chapter on Air Pollution Control, dry and semidry flue gas treatment converts the acid gases of HCl, HF and SO_2 to the solid compounds $CaCl_2$, CaF_2, and $CaSO_3/CaSO_4$, respectively, through reaction with lime, $Ca(OH)_2$. The lime must be added in excess.

Consequently, the treatment residue, which is collected in a bag filter, contains these compounds; and since the fly ash is normally not collected before the lime injection, the residue also contains the ash. If activated carbon is injected, this material, of course, also ends up in the product.

The quantity depends mainly on the fly ash formation rate and on the required reduction of the HCl and SO_2 concentrations, but it is often 30 to 50 kg per metric ton of waste incinerated. (See table 5.1.)

Removal

As $CaCl_2$ is highly hygroscopic and deliquescent at temperatures below 130° C, the temperature in the bag house filter should be at least 140° C. The product should be removed at once from the bottom hoppers of the bag filter, transported in a closed conveyor to perhaps a big bag station and placed in the bags immediately. The big bag station also usually receives the boiler ash.

Disposal

The reaction product is a composite material, and no practical uses have been found for it. Consequently, it must be landfilled. The landfill exposes it to rain water which unfortunately dissolves the $CaCl_2$ and to a slight

Table 5.2 Maximum Leaching of Ions from Incinerator Residues, indicative

Concentration level	*Slag*	*Fly ash and dry plus semidry product*	*Wet product plus fly ash*
Very high[a]	Cl	Cl, Ca, Na, K, Pb	Cl, Na, K
High[b]	SO_4, Na, K, Ca	Zn, SO_4	SO_4, Ca
Medium[c]	Cu, Mo, Pb	Cu, Cd, Cr, Mo	Mo
Low[d]	Mn, Zn, As, Cd, Ni, Sc	As	As, Cr, Zn
Very low[e]	Cr, Hg, Sn	Hg	Pb, Cd, Cu, Hg

a. Initial Concentration > 10 g/l.
b. 0.1—10 g/l.
c. 1—100 mg/l.
d. 0.01—1 mg/l.
e. < 0.01 mg/l.

(but important) degree, the surplus $Ca(OH)_2$. The dissolving $Ca(OH)_2$ creates a pH of the leachate water of about 12. At this pH, Pb is readily soluble. Consequently, the leachate is alkaline and polluted by $CaCl_2$ and Pb (see table 5.2).

It is therefore immensely important that the leachate is kept from dissipating into any drinking water resource. If possible, the product should be landfilled below ground—in an old salt mine or another watertight cavity.

Sludges from Water Treatment

Formation and Composition

When the HCl and SO_2 are removed from the flue gas by wet methods, one or two wastewater streams are produced. These must be treated as explained in the chapter on Air Pollution Control.

The treatment of the acid water results in the formation of a "hydroxide/TMT" sludge, approximately 1 kg DS (dry substance) per metric ton of waste incinerated (see table 5.1). The raw, thin sludge, when removed from the settling tank, usually has a DS content of 8 to 10 percent. Accordingly, it is liquid and easy to pump.

Wet removal of SO_2 normally forms a gypsum ($CaSO_4.2H_2O$) sludge. The quantity depends on the SO_2 removal rate, but a typical figure is 3 kg DS per metric ton of waste incinerated.

Removal

The sludges may be used as they are for humidifying the boiler and fly ash and landfilled together with these ashes. However, as the water in the thin sludge contains $CaCl_2$ in solution, additional chloride is mixed into the ash. On the other hand, it is claimed that the leaching properties of the mixture are stronger than that of the two ingredients separately.

Alternatively, the two sludges may be dewatered separately or jointly in a filter press, on a vacuum filter, or in a centrifuge.

Disposal

The sludges are normally landfilled, and their leaching properties are normally far stronger than those of the dry and semidry treatment residues.

In a few cases, the gypsum is recovered and used for industrial purposes.

Spent Adsorbent from Dioxin Filters

The spent adsorbents from dioxin filters are usually fed back into the incinerator and combusted, thus destroying the dioxins adsorbed. Or, they can be used to treat the acid scrubber water, ending up in the thin sludge. Consequently, they do not normally constitute a separate waste product stream to be disposed of outside the plant.

Other Materials

While the residual products are generated and must be removed continuously, other waste products are only removed and disposed of from time to time—including:

- Spent catalysts from SCR installations
- Spent ion exchange resins from the preparation of boiler water
- Discarded refractory and other materials from maintenance operations.

These materials are mostly landfilled.

6 Operation and Maintenance

Key Issues

Efficient and competent operation and maintenance are the key to applying waste incineration technology successfully and securing the optimum benefit of the investments made.

Such operation and maintenance require:

- Well-structured and well-managed plant organization
- Trained and skilled employees, managers, and operating personnel at all levels
- A plant economy with sufficient cash flow for procuring local and imported spare parts and consumables
- Efficient housekeeping and a clean and safe working environment
- Efficient record keeping, including specifications and drawings of plant, machines, and other components; emission data; waste quantities and types; operating data (for example, temperatures, pressures, efficiencies, and consumption).

Key Criteria

✓ ✓ ✓ Foreign currency is available for purchasing critical spare parts.

✓ ✓ Skilled plant operation staff are available to the plant owner at affordable salaries. Otherwise, reliable operation and/or maintenance contracts must be in place in the form of operation and service contracts.

Typical Plant Organization and Staffing

There are several types of plant organization worldwide. The actual organization should reflect the skills and capabilities of the employees as well as the public and legal demands and constraints to be managed.

Incineration plants typically staff 50 to 200 persons depending on the size of the plant, the effectiveness and skills of its workers, whether subcontractors are used, and the division of responsibilities with other waste management organizations.

The actual number and division of departments should be balanced according to the type of assignments, the size of the plant, and the number of workers. Furthermore, some or all of the operation and maintenance tasks may be subcontracted to private contractors or the original supplier. Hence, the organizational possibilities are manifold. (See figure 6.1.)

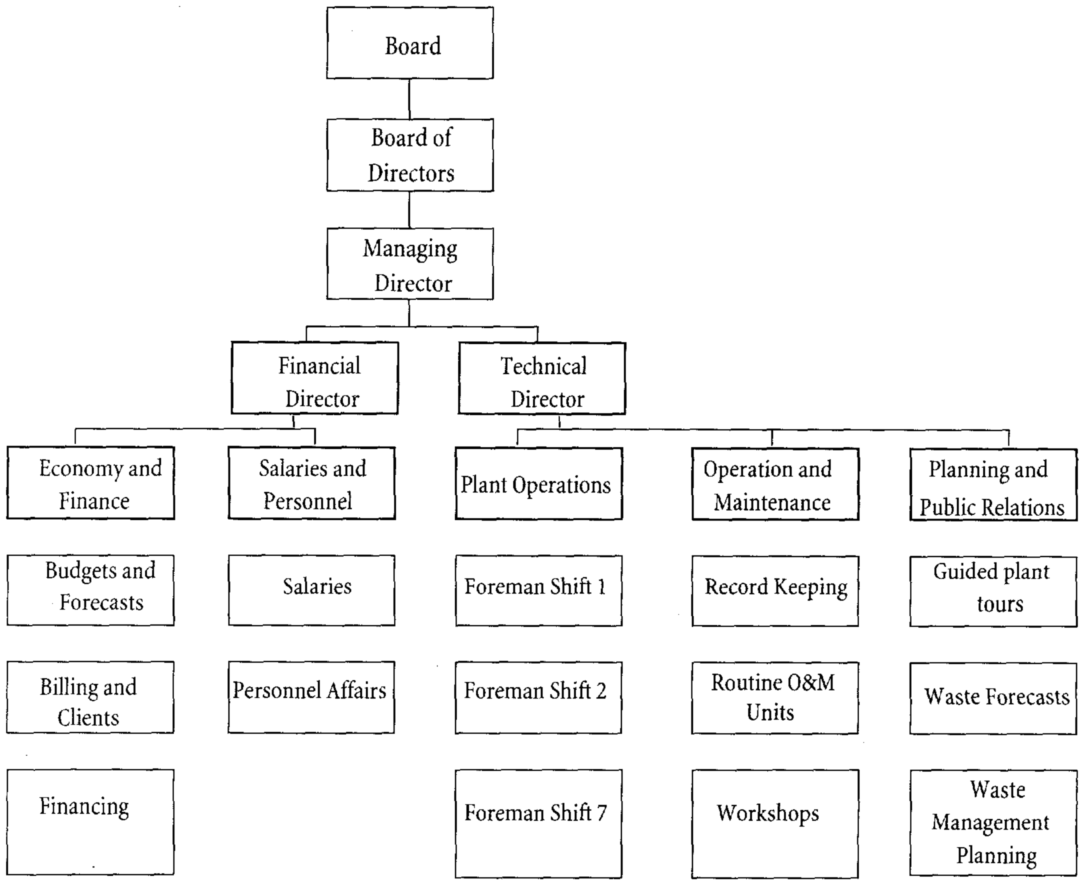
Ownership and Top Management

Waste incineration plants are typically owned by one of the following:

- The municipality/local government or a group of municipalities/local governments
- The county/regional government
- Private or public energy companies (for example, power or district heating companies)
- Private investors or a private investment association
- Suppliers, often in BOO or BOOT (build, own, operate, transfer) arrangements

For the owners, the most important issues are to ensure continued supply of the planned quality and quantity of waste; continued payment of tipping fees, revenues from energy sale and fulfilment of instalments on loans; and maintenance of the plant in good operating conditions under qualified management.

Figure 6.1 Typical Plant Organization Chart



The owners will normally be represented by a board that makes all crucial decisions based on sound recommendations of the plant management.

Normally, one managing director will ultimately be responsible for operating and maintaining the economy of the plant. Typically, the managing director will, in cooperation with the board, appoint a technical director and a financial director for the plant's day-to-day management.

It is important that the management group, which consists of the directors, have access to reliable and relevant operation and financial data for monitoring the operation and the financial, technical, and environmental performance of the plant each day.

Departments of the Plant

Typically, the plant will include the following departments:

- Plant operations
- Operation and maintenance
- Public relations
- Planning and forecasting
- Finance
- Personnel.

The actual organization, number of departments, staffing, and division of responsibilities among the departments may vary significantly. Also, plant management may choose to subcontract any of the following assignments to private companies:

- Removal and transportation of ash, slag. and other residues
- Cleaning and housekeeping
- Salary management and payment

- Operation and maintenance of specific units of the plant
- Periodic testing and analysis of effluents and emissions
- Specific planning and feasibility studies required for plant development.

Crucial Supplies and External Services

The following supplies and external services are crucial for continued operation of the incineration plant:

- Continuous and steady high-voltage power supply
- Water
- Removal of residues (slag, ash and air pollution control residues)—that is, availability of an engineered and sanitary landfill for residues
- Availability of spare parts—and sufficient local and foreign currency for purchasing spares
- Availability of consumables (such as lime, oil, and lubricants).

Typically, if the waste does not contain hazardous compounds, the quality of the slag and ashes will allow for recycling after sieving—for example, for roadfill. Hence, slag may be transported to a sorting area, rejected slag and ashes may be transported to a landfill, and APC residues may go to secure landfill sections.

In any case, the residues should be transported by suitable vehicles, in fully contained loads, thus avoiding littering or spreading of dust. Such vehicles can be purchased and operated by the plant, or the services can be subcontracted to a private company. It is important to make sure there is sufficient intermediate storage capacity and reliable and frequent transportation.

Training of Workers, Codes of Practice, and Occupational Safety and Health

The personnel or human resource development departments should be responsible for training workers. The skills and training courses in table 6.1 may be required.

Codes of practices or documented work procedures should be prepared for all key plant activities and facilities. Furthermore, there should be contingency plans in case of accidents or equipment failure.

The documentation should instruct the workers how to operate the equipment, and what to do if it fails or in case of accidents. Such documents can be used in new employee orientation, as well as a reference source for employees throughout the year.

Equipment suppliers should be required to submit work procedures as part of the contract. Ideally, these should be used for preparing an integrated work procedure for the entire plant. The integrated procedures should be available in the operator's room and with shift supervisors and other key personnel. Relevant excerpts should be placed at each machine or equipment.

Table 6.1 Required Skills, Education, and Background for Operating an Incinerator

Employees	*Number*	*Basic skills required*	*Additional training courses required*
Managing, financial, and technical directors	3	Documented management skills (such as previous experience and relevant education)	Public utility management
Economists, accountants, and office clerks	6	Documented skills in economy, finance, or accounting	Electronic information management systems
Plant operators	>14	Documented skills and certificates as chief facility operator or shift supervisors	Occupational safety and health (OSH), and plant operation
Crane operators	>7	Experience in machine operation	Sorting and homogenization of waste before feeding, and fire extinguishing
Shift supervisors	>7	Good management and planning skills; long experience with plant operation	OSH, first aid, and plant operation
Mechanics	>5	Qualified mechanics, qualified welders	OSH and first aid
Electricians	>2	Qualified electricians	OSH and first aid
General workers	30	Job-specific	OSH and first aid

7 Environmental Impact and Occupational Health

Key Issues

MSW incineration plants are generally located close to densely populated areas for economic reasons (e.g., sale of energy, transport distance). Any negative environmental effects of the plant can influence a great number of people. A combination of planning and technical measures is required to minimize such impacts.

Of the MSW incineration residues, only the slag can be considered environmentally safe to reuse. The flue gas cleaning residues are much more soluble than the original wastes and have to be disposed of in an appropriately designed and operated controlled landfill to avoid negative impacts on ground or surface waters.

MSW incineration plants may have a negative impact on the air quality of a fairly large area. The waste itself can create odor and dust in the immediate surroundings, and flue gases containing particles and vapors are spread over a larger area—reducing the overall air quality if insufficiently treated.

Municipal solid waste may contain hazardous and infectious matter (although it is not supposed to). Combined with the release of dust containing endotoxins, this risks the health of those employed at the reception area of the incineration plant. Special precautions have to be taken to minimize such risks.

Occupational health risk and protective measures for the rest of the plant are similar to those identified or required at places such as coal-fired power plants.

Key Criteria

✓ ✓ ✓ The flue gas treatment installation must be capable of removing dust at least as efficiently as a two-stage electrostatic precipitator (basic emission control, dust<30 mg/Nm3).

✓ ✓ ✓ A controlled and well-operated landfill must be available for the disposal of residues.

✓ ✓ To avoid noise, dust, and odor in residential areas, MSW incineration plants should be located in land-use zones dedicated to medium or heavy industry.

✓ ✓ The stack should be twice the height of the tallest building within 1.0 km, or at least 70 meters high.

Environmental Impact

The environmental impact of the construction and operation of an MSW incineration plant should be assessed according to the requirements laid down in the World Bank Operational Directive (OD) 4.01: *Environmental Assessment.* A waste incineration plant belongs to category A in the OD—and therefore, a full environmental assessment should be conducted.

The present guidelines do not substitute an environmental assessment carried out in accordance with OD 4.01, but describes the impacts to be expected from an incineration plant and a selection of measures that can be taken to remediate them.

A properly constructed and operated waste incineration plant is expected to be comparable to medium to heavy industrial activities as far as environmental impact, transport requirements and other infrastructure needs, and potential public nuisances.

Because a waste incineration plants is similar to medium to heavy industrial activities, it should be located within a zone dedicated for industrial activities. Besides, because it is similar to a power plant in its energy output and residues, it should be located near power plants, especially those that are coal fired.

This section describes possible environmental impacts and the measures designed to reduce them (elaborated on in the chapter on Plant Location).

Noise

Noise generated at incineration plants originates from transportation of waste and treatment residues to and from the plant, handling waste and residues within the plant premises, and noise emissions from the installed equipment.

Massive transportation of waste and residues will take place on the roads near the plant. This can hardly be avoided and is one reasons an incineration plant should be located within an industrial zone or estate well connected to the major roads of the waste catchment area. If the vehicles arriving at or leaving the plant are tempted to make shortcuts through residential areas, forced routes for the trucks may have to be introduced.

Waste and residue handling comprises unloading the waste into a reception and storage pit and handling and treating slag and flue gas cleaning residues from the combustion process. Waste should be unloaded within a confined or semiconfined building to prevent storm water from entering the pit and to keep wind from spreading dust and lightweight wastes. Confinement will also protect against noise emissions from these activities. Slag and fly ash should also be handled inside a building that protects against climate and emissions of noise, odor, dust, and the like.

Internal traffic on the premises and the noisy activities at ground level can be screened off by acoustic screens through soil barriers.

The main equipment installed at a waste incineration plant includes the overhead crane that feeds the waste into the hopper or furnace, the furnace with moving grate, the slag collection and cooling system, the boiler, the flue gas cleaning equipment, fans, and ventilators. Most of the equipment will be located inside the incinerator building, which muffles the noise emission. It may be necessary to specify wall and ceiling structures with an appropriate sound reduction or absorption index to keep noise from spreading via the building itself, and to safeguard the working environment in the buildings.

The draught fans and the flue gas fans are, together with the stack, the most significant sources of noise in the environment. Ventilators will often be located at the building roof and therefore also produce noise in the surroundings if not properly muffled. If the plant is located close to residential areas, it may be necessary to provide the ventilators with attenuators or acoustic enclosures. This is quite expensive and further proof that the plant should be located within an industrial area.

Except for the traffic to and from the plant, all of the sources of noise can be assumed to operate for 24 hours a day and 7 days a week all year round. If the incineration is combined with a plant for recycling of cinders and slag for construction purposes, the necessary treatment (mechanical sorting mainly) can be limited to the day shift.

Odors

The combustion process destroys all odor-emitting substances in the waste, and the slag and fly ash are sterile and odorless after cooling.

MSW incineration plant odor is thus emitted mainly from handling and storing waste before combustion. The main sources are the unloading activities and the waste storage pit. The pit or hopper serves as a buffer to equalize the feeding of the furnaces, and will thus always contain a variable amount of waste. Some of the waste may be in the pit for several days before being fed to the furnace. In this period, the putrescible waste will degrade under anaerobic conditions—especially at high ambient temperatures—and emit an unpleasant smell.

The necessary handling of the waste in and around the pit will create odor—and will make bacteria and toxins airborne.

To avoid emitting foul air into the environment, the waste pit and the feeding section of the plant hopper area must be enclosed with roof and walls. The air for the combustion process must be abstracted from the top of this more or less open room (that is, from the crane or hopper deck) to generate an induced air flow into the room and keep foul-smelling substances from escaping.

Besides this, the unavoidable spillage must be cleaned and the general area must be kept tidy. This must be specified in the staff training program and in the plant's operation manuals.

Air Emissions

Airborne pollutants from the combustion process are emitted through the stack. Assuming an optimal combustion process for complete destruction of particles and gases, the applied flue gas cleaning and the height of the stack are decisive for the resulting contribution to the air quality. The anticipated emissions, as a function of cleaning technology, are described in detail in the chapter on Air Pollution Control.

To reduce the pollution load on the atmosphere from the combustion process, various measures can be applied, as follows (described withan increasing degree of complexity, cost, and efficiency).

A two-field electrostatic precipitator (ESP) is considered the minimum requirement for flue gas cleaning at an MSW incineration plant. The ESP will remove the dust from the flue gas to a level of 20 to 30 mg/Nm^3. Most of the heavy metals adhering to the dust, such as lead, will be removed rather efficiently from the flue gas. The advantage of the ESP is that it is robust, inexpensive to operate and may even function (as a settling chamber)if the power supply is interrupted. It also operates at rather high flue gas temperatures and thus requires limited cooling of the flue gas only.

A bag-house filter will clean the flue gas better for the smallest particles, and better remove heavy metals, than the ESP. The disadvantages of the bag-house filter are the cost of operation and the vulnerability—as the flue gas must be cooled before the filter to around 150° C, and there is a risk that sparks from the combustion will burn the bags. Thus, bag-house filters require a flame and spark arrestor. Bag-house filters are also vulnerable when the combustion starts and closes, as the flue gas will be cool and moist and must bypass the bag filter.

Both an ESP and a bag-house filter may be combined with various scrubbers in which dry or wet lime is injected in the flue gas stream, thus further reducing the content of dust and heavy metals (particularly mercury, which is only poorly removed by dry filters). The scrubbers will also remove the flue gas content of acid substances, including hydrogen fluoride (HF), hydrogen chloride (HCl), and sulfuric acid (H_2SO_4). An environmental drawback of the wet systems is the output of heavily polluted waste water, which requires advanced treatment to remove substances such as heavy metals before discharge.

The requirements for air pollution reduction must depend on the general environmental requirements of the country. There should be a reasonable relation between the requirements for municipal waste incinerators and the requirements for other industrial processes.

The stack height is decisive for the dilution of the flue gases in the environment. A minimum height is required to prevent the plume from reaching the ground or entering tall buildings. This minimum height will depend on the local atmospheric conditions, the topography (flat or hilly), and the height of the buildings within a radius of at least 1.0 km. The stack height should be decided on the basis of computer modeling, and should never be less than 70 meters.

Waste Generation and Access to Landfill

In the combustion process, the volume of the waste will be reduced by approximately 90 percent and the weight by 70 to 75 percent. The output (residue) from the combustion process will mainly be bottom ash (slag), and the boiler and fly ash will account for only a small percent of the waste incinerated.

In addition to the slag, and boiler and fly ash, the plant may generate residues from more advanced dry, semi-dry and wet flue gas cleaning processes. The amount and its environmental characteristics will depend on the technology applied.

The slag from a well-operated waste incinerator will be burnt out, with only a small amount of organic material. Besides, the heavy metals in the slag, which are normally leachable, will to some extent become vitrified and thus insoluble. The slag may therefore be used as road construction material, reducing the landfill capacity requirement.

The boiler and fly ash and other residues will, however, need to be disposed of in a controlled landfill, as will the incombustible waste generated in the area. It is therefore absolutely necessary to have a well-engineered and operated landfill available for these types of waste.

Water Supply

Supply of water is necessary for feed water to boilers and for various processes at an MSW incineration plant: cleansing, slag cooling, flue gas scrubbers (if implemented), and staff sanitary purposes.

Slag cooling water has no quality requirements, so polluted river water or groundwater can be used. The water consumption for slag cooling can be assumed to be in the magnitude of 0.05 to 0.01 m^3/metric ton of waste if state-of-the-art slag extractors are applied.

Water will also be used if flue gas scrubbers or semidry reactors are installed. Drinking water quality is not required for this process, but the water must have a relatively low solid content, so lime can be diluted in it and sprayed through nozzles into the flue gas stream. The water consumption will depend on the technology applied, ranging from about 0.1 m^3/metric ton of waste in the semidry absorption process (which does not generate wastewater) to about 0.25 to 0.4 m^3/metric tons of waste in the wet process (which generates 0.07 to 0.15 m^3 of wastewater per metric ton).

Wastewater Discharge

The wastewater generated from wet processes will have high concentrations of salt (mainly as chloride) and soluble heavy metals. Cadmium can be assumed to be the most important of these with regard to emission limits. The actual concentrations will depend on the composition of the combusted waste.

The recipient must therefore be relatively robust (that is, the discharge must be highly diluted). The level of discharge will depend on the technology applied, ranging from almost none if water is only used for slag cooling (in which case, almost all of the water will evaporate) to 0.3 m^3/metric ton of waste if wet flue gas scrubbers are installed.

Aside from the wastewater discharged from the processes at the incineration plant, cleaning water and storm water will be discharged from the area. This water can be assumed to be contaminated with waste residues (spills) and thus have a relatively high concentration of organic substances—at the same level as household effluents.

Occupational Safety and Health

Solid waste handling exposes staff to dust, microorganisms including gram-negative bacteria, fungi, and endotoxins, and gases and odor from biological decomposition of the waste. MSW incineration plants further involve a risk of exposure to combustion products—for example, gases and particles at various stages of the process and applied chemicals.

Combustion products can be inhaled or ingested. The incineration plant must be designed, operated, and maintained to minimize human exposure. This requires application of a combination of permanent installations and personal protection equipment.

Airborne Pollution

Workers in the waste reception hall are exposed to exhaust fumes from the trucks delivering the waste. During any manual unloading, the engines should be turned off to minimize such exposure. The air quality in the reception hall is also negatively influenced by odor, dust, and micro-organisms released during unloading. Decomposition of waste in the pit/hopper further degrades the air quality. Prolonged storage of large volumes of waste may result in anaerobic conditions followed by depletion of oxygen and formation of methane.

Leaks in the furnace, flue gas, and duct systems will emit dust and flue gases inside the buildings. At the end of the plant, handling of slag, and fly ash and lime used for advanced flue gas treatment increases the amount of suspended matter in the air.

Generally, exposure to these health hazards must be minimized through proper design of buildings, equipment, and installations. The building layout should avoid direct connection between high-risk areas and permanently staffed rooms. Surfaces must be easy to clean and designed to prevent deposition and accumulation of dust, especially in hard-to-reach places. Plenty of taps should be installed for washing and hosing down floors (rather than sweeping).

Maintaining a slightly elevated air pressure in permanently manned rooms (such as the crane operator and control rooms), as well as offices, canteens, and kitchens, will reduce the dust and gases entering these areas.

The operation manual for the plant must call for routine checks for, and repair of, leaks in the equipment. Cleaning and maintenance can increase exposure and should be countered through application of personal protection devices.

Masks for protection against micro-organisms (type P3) should be used in the waste reception area. In dusty areas with concentrations of dust larger than $3mg/m^3$, type P2 masks should be applied.

Heat

The temperature in the furnace hall may be elevated considerably above ambient temperature and even become uncomfortable. Working in this area induces a risk of dizziness, sickness, visual disturbance, and headaches.

The room temperature and heat radiation should be reduced through ventilation and insulating or covering hot surfaces. Efficient ventilation consists of vents for exhaust of warm air from the ceiling above the furnaces and supply of fresh air through openings or forced ventilation vents.

Drinking water should be available throughout the plant.

Vibrations

The vibrations and sound pressure emitted from numerous machines and activities may reach a level of concern to occupational health and safety. Vibration dampers should be applied whenever required. Noisy equipment such as turbines and compressors must be shielded or placed in special rooms with sound-absorbing cladding on the walls. Large ventilators should be located where the noise level is of no concern or equipped with noise-reducing intake and outlet units.

In areas where the noise level exceeds 85 dB(A), ear plugs or equivalently efficient protection should be mandatory.

Chemicals

The Chemicals Convention should be followed—including assessing all applied hazardous chemicals in respect to safe usage and taking necessary labor protection measures.

Safety Data Sheets must be provided by the suppliers of hazardous chemicals. The employer should ensure that all necessary precautions are taken.

Physiology

Work stations should avoid torsion and bend-forward positions. Work must be executed in front of and close to the body—that is, the level of the footbridges should be adjusted according to the level of the actual site of work.

Ergonomic strain caused by lifting, pulling, and pushing of heavy parts should be minimized through lifts and cranes. The floors should be level, with sufficient slopes for drainage of cleaning water only.

Risk of Accidents

Experience shows that the main risks of accidents at an incineration plant are falls from great height (into the pit or down from the footbridges), collisions with trucks transporting waste or residues, accidents at rotating equipment, scalding by hot water or steam, equipment failure, explosions, and fire.

Footbridges and elevated platforms must be equipped with safety rails—if not, access must be restricted.

Motor traffic must be separated from pedestrians wherever possible.

Machinery must be shielded against moving and rotating parts—and should be unable to operate if these shields are not installed properly. Emergency stops must be installed in case of accidents.

Emergency response and evacuation plans must be established.

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Municipal Solid Waste Incineration Checklist

The checklist below is intended to serve two purposes:

First, the checklist is to be used in the planning process, when a decision is to be made on whether to build an incineration plant or not. A range of questions should be answered before the decision is made. These questions are generally the ones in sections 1-5 below, plus the initial questions in sections 8-10.

Second, the checklist is intended for use in feasibility studies in relation to outline projects for incineration plants. In this context, all of the questions in the checklist should be answered and appropriate action taken.

The checklist is constructed as a simple table with options. Option A is the best and option D the poorest. Often, checking the item in column D will result in a "no-go" decision. Those questions deemed most crucial for the decision (the "killer" answers) are shadowed in column D (and in some instances column C).

Throughout the checklist, LVC means Lower Calorific Value; MSW means Municipal Solid Waste, which includes waste similar to MSW from commerce, trade, and industry; and SWM means Solid Waste Management.

PARAMETER	A	B	C	D
Explanation	A check in column A means that the conditions are close to optimal for establishing a MSW incineration plant	A check in column B means that although the conditions are not optimal, establishing a MSW incineration plant could be considered further	A check in column C means that conditions for establishing a MSW incineration plant are doubtful. Some (shadowed) assumptions may be "killer" answers	A check in column D means that conditions for establishing a MSW incinerator are poor. The shadowed answers are "killer" answers
1. Waste as Fuel				
Waste characteristics	The characteristics of the waste are fully established by sampling and analysis ❑	The characteristics of the waste are assessed by representative sampling and analysis ❑	The characteristics of the waste are assessed from grab samples and standard data ❑	The characteristics of the waste are not known ❑
Annual variation in characteristics	The annual variation is fully established by sampling and analysis ❑	The annual variation is assessed by representative sampling and analysis ❑	The annual variation is assessed from grab sampling ❑	Nothing is known about annual variation ❑

PARAMETER	A	B	C	D
Calorific value of waste	The LVC is more than 8 MJ/kg all year round ❑	The LVC is 8 MJ/kg or more 80% of the time and never less than 7 MJ/kg ❑	The LVC is 6 MJ/kg or more all year round and the annual average is 7 MJ/kg or more ❑	The LVC is periodically less than 6 MJ/kg or the annual average is less than 7 MJ/kg ❑
Amount of waste	The annual amount of waste is more than 100,000 metric tons ❑	The annual amount of waste is around 100,000 metrtic tons ❑	The annual amount of waste is more than 50,000 metric tons ❑	The annual amount of waste is less than 50,000 metric tons ❑
Weekly variation of amount	Variations do not exceed 20% ❑	Variations are 20% to 30% ❑	Variations are 30% to 50% ❑	Variations are 50% or more ❑
Forecasts of waste generation	Forecast is based on survey on waste amounts and composition (including LVC) for the next 10 years ❑	Rough forecast exists on waste amounts and composition (including LVC) ❑	Rough forecast on waste amounts exists ❑	No forecast exists ❑
2. Institutional Framework, Waste				
Main solid waste management organization	More than 10 years old ❑	5 to 10 years old ❑	0 to 5 years old ❑	Not yet implemented ❑
Regulations	Effective regulations exist regarding collection and disposal of all types of wastes ❑	Regulations are in force regarding household and hazardous wastes only ❑	Regulations exist regarding collection and transport of household wastes only ❑	Solid waste regulations exist but enforcement is weak ❑
Solid waste ownership	The waste management organization has ownership of all waste ❑	The waste management organization has full ownership of all waste in dedicated dust bins and containers ❑	The waste management organization has ownership of waste placed on public roads. ❑	Waste belongs to the generator, who can dispose of it freely, e.g., by transferring ownership. ❑
Solid waste collection	A single organization is managing the collection of all solid waste ❑	Household and commercial wastes collection is managed by one organization. Large operators are found in the industrial sector ❑	Household waste collection is managed by one or a few organizations, and some large operators exist in the commercial and industrial and sector ❑	Waste collection is performed by multiple independent operators ❑
Present organized waste treatment	Incineration ❑	Composting in mechanical plant ❑	Sorting and recycling activities ❑	No organized waste treatment ❑
Present recycling	Recycling is organized and based on source sorting ❑	Recycling is organized for industrial waste only ❑	Scavengers are active in the waste collection stage ❑	Scavengers are present at the landfill site ❑

PARAMETER	A	B	C	D
Present waste disposal	All solid waste is disposed of in controlled and well-operated landfills ❑	75% of all waste is disposed of in controlled and well-operated landfills ❑	Household waste is disposed of in a controlled and well-operated landfill ❑	A significant part of the waste from all sectors is disposed of in uncontrolled or illegal dumpsites. ❑
MSW incinerator organizational position	The MSW incinerator is an integrated part of the SWM system ❑	The MSW incinerator is an independent MSW treatment plant with close formal relations to the SWM system ❑	The MSW incinerator is an independent MSW treatment plant with informal relations to the SWM system ❑	The MSW incinerator is an independent MSW treatment plant without links to the SWM system ❑
MWS incinerator ownership	Owned by public SWM company ❑	Owned by public/private utility company (power or heat production) ❑	Owned by private SWM company ❑	Owned by private large energy consumer, e.g., a large industry ❑
MSW incinerator rights and duties	The MWS incinerator is granted right to receive all combustible waste and obliged to ensure the necessary capacity ❑	The MWS incinerator is granted right to receive all combustible household waste and obliged to ensure the necessary capacity ❑		The MSW incinerator is an enterprise with no rights and duties in relation to MSW ❑
3. Institutional Framework, Energy				
Energy buyer/ distributor	One single public/private utility company ❑	One power company and one district heating company ❑	Many small power and/or district heating companies ❑	Individual energy supply ❑
Availability of distribution networks	District heating system and power lines ❑	District heating system ❑	Power lines ❑	Network to be established ❑
Incineration energy	All recovered heat can at all times be utilized for district heating purposes ❑	Most recovered energy can be utilized for a combination of power and heat ❑	Some energy will be used for power generation; the remaining will be cooled off ❑	A substantial amount of the surplus energy will be cooled off ❑
4. Incineration Plant Economy				
Cost and expense stability	Stable, predictable plant expenses and revenues can be assumed ❑	Uncertainty about expenses or revenues ❑	Uncertainty about expenses and revenues ❑	Severe cost and revenue instability ❑

PARAMETER	A	B	C	D
Waste supply stability	Long-term contracts on delivery of all waste to incineration plant; 100% capacity utilization ❑	Contracts on waste delivery corresponding to 80% of plant capacity ❑	Contracts on waste delivery corresponding to 60% of plant capacity ❑	No or little waste supply security ❑
Current waste management charges	All costs of waste collection and disposal are paid by users ❑	Households pay a waste management fee. A tipping fee is collected from other users of, e.g., landfills ❑	Costs of waste management is paid partly by users and partly from the public budget ❑	All costs are paid from the public budget ❑
Incineration charges	Costs of incineration are covered by the budget. The authorities charge a waste management fee on households and commercial activities ❑	The incineration plants collects a tipping fee, which covers all costs ❑	The incineration plant collects a tipping fee; remaining costs are covered by the public budget ❑	The incineration plant must collect its own tipping fee from individual users ❑
Competitive charges	MSW incineration tipping fee is smaller than the tipping fee for, e.g., landfilling ❑		MSW incineration tipping fee is equal to or a little higher than the tipping fee for, e.g., landfilling ❑	MSW incineration tipping fee is considerably higher than the tipping fee for, e.g., landfilling ❑
Energy sale agreement(s)	Government-approved agreement or firm contract available ❑	Agreement signed but not yet approved or contract agreed but not signed ❑	Letter of intent available ❑	No agreement reached ❑
Budget	Plant will have its own budget and special privileges regarding foreign currency procurement ❑	The plant will have its own budget ❑	Plant economy will be part of a public budget ❑	All expenses must be approved of in advance by the funding agency ❑
Cash flow	Plant budget and revenue allows for purchase of necessary and sufficient spare parts and consumables ❑			Plant budget and revenue does not allow for purchase of necessary and sufficient spare parts and consumables ❑
Foreign currency availability	Unrestricted access to foreign currency for spare parts purchase ❑			No access to foreign currency for spare parts purchase ❑

PARAMETER	A	B	C	D
5. Plant Localization				
Air quality impact	Windy area, inversions nonexistent ❑	Few inversions and smog situations ❑	Occasional but short inversion and smog situations ❑	Frequent and prolonged inversion and smog situations ❑
Zoning of plant locality	Heavy industry ❑	Medium to heavy industry ❑	Medium to heavy industry ❑	Light industry ❑
Distance to residential areas/zones	> 500 meters ❑	300-500 meters ❑	200-300 meters ❑	< 200 meters ❑
Main access roads	Existing major roads and thoroughfares ❑	Planned major roads ❑	Main roads ❑	Local roads only ❑
Distance to waste generation center	< 1/2 hour by truck ❑	1/2-1 hour by truck ❑	1 hour by truck ❑	> 1 hour by truck ❑
Sufficient capacity public utilities (water, power, and sewers)	< 500 meters from site ❑	500-1,000 meters from site ❑	1,000-2,000 meters from site ❑	> 2,000 meters ❑
Connection point for surplus energy is available	< 1,000 meters from site ❑	1,000-2,000 meters from site ❑	2,000-3,000 meters from site ❑	> 3,000 meters from site ❑
6. Incineration Technology				
Waste pretreatment	The waste can be fed into the incinerator "as received" after mixing in waste pit ❑	Mechanical sorting out and crushing of large items is necessary ❑	Manual sorting out and crushing of large items is necessary ❑	The waste needs extensive pretreatment (sorting, crushing, homogenizing) before incineration ❑
Furnace technology	The incinerator concept is based on mass burning principle ❑		The incinerator concept is a rotating kiln ❑	The incinerator concept is fluidized bed or other technology unproven in MSW combustion ❑
Incinerator line capacity	Each incinerator line has a capacity between 10 and 20 metric tons/hour ❑	Each incinerator line has a capacity higher than 20 metric tons/hour ❑	Each incinerator line has a capacity between 6 and 10 metric tons/hour ❑	Each incinerator line has a capacity of less than 6 metric tons/hour ❑
Number of incinerator lines	The MSW incineration plants has two or more incineration lines ❑		The MSW incineration plants has one incineration line ❑	

PARAMETER	A	B	C	D
Flue gas burnout	The flue gas is fully burnt out in an after-burner, resulting in emission concentration of $CO < 50\ mg/Nm^3$ $TOC < 10\ mg/Nm^3$ ❑			The requirements in A are not met ❑
Startup and support burner	The furnace is provided with burners to heat the incinerator during startup and keep afterburner temperatures up in case of low calorific value of waste ❑			The furnace has no startup and support burners ❑
Supplier's experience	The supplier has extensive experience in MSW incineration and numerous references ❑	The supplier has good experience in MSW incineration ❑	The supplier has some experience in MSW incineration ❑	The supplier has no experience in MSW incineration ❑
7. Energy Recovery				
Flue gas temperature after boiler	The flue gas temperature is below 150°-200° C to allow for optimum energy recovery and flue gas cleaning ❑			The flue gas temperature is above 200° C ❑
Energy recovery system	The recovered energy is converted to hot water for district heating or low-pressure steam for industrial purposes ❑	The recovered energy is converted to steam for power production or industrial use and for district heating ❑	The recovered energy is converted to steam for power production ❑	The energy is cooled away ❑
8. Incineration Residues				
Landfill	Controlled and well-operated landfills exist for all types of waste including hazardous materials ❑	Controlled and well-operated landfills exist except for hazardous wastes ❑	Controlled and well-operated landfills exist for domestic waste. Extension with section for incineration residues feasible ❑	No controlled and well-operated landfills exist ❑
Residue utilization	Most residues can be utilized for industrial or construction purposes ❑	Slag can be utilized in construction; flue gas cleaning residues must be landfilled ❑	No utilization options for residues ❑	

PARAMETER	A	B	C	D
9. Operation and Maintenance				
Availability of staff	Qualified staff available in sufficient numbers ❑	The authorities assign staff with the necessary skills ❑	An HRD organization is in place for staff training ❑	Competition for qualified staff is fierce ❑
Salaries	The incineration plant can pay market price salaries ❑	Market price salaries are paid to managers and skilled staff ❑	Incentives in addition to the basic salaries prevent excessive staff turn-over ❑	The plant is unable to pay competitive salaries for skilled staff ❑
Plant implementation organization	A builder's implementation organization is established with skilled staff and consultants experienced in MSW incineration ❑	A builder's implementation organization is established with staff and consultants ❑	A builder's implementation organization is established ❑	No implementation organization is established ❑
Plant organization	A clear and well-structured plant management organization exists ❑	An outline plant management organization is drafted and approved ❑	An outline plant management organization is drafted ❑	No plant organization is established ❑
Operation and maintenance manuals, training of staff, plant monitoring	The supplier or an independent consultant will provide organizational setup, relevant manuals, staff training at all levels, and the SMW organization will utilize it ❑	The supplier or an independent consultant will provide organizational setup, relevant manuals, staff training at all levels ❑	The suppler will provide training of staff on management level ❑	None of the provision under A will be made ❑
10. Environmental Issues	**(includes air pollution control)**			
Environmental standards		Emission standards for incineration plants at medium level ❑	Emission standards for incineration plants at basic level ❑	Emission standards for incineration plants do not exist ❑
Environmental administration	Independent public authority responsible for environmental permit, supervision, and enforcement ❑	Nearly independent public authority responsible for environmental permit, supervision, and enforcement ❑		The public authority responsible for environmental permit, supervision, and enforcement owns the MSW incinerator ❑

PARAMETER	A	B	C	D
Flue gas treatment	The flue gas treatment plant meets national emission standards ❑	The flue gas treatment plant meets medium emission standards with respect to dust (<30mg/Nm^3) and HCl (<50mg/Nm^3) ❑	The flue gas treatment plant meets basic emission standards with respect to dust (<30mg/Nm^3) ❑	No flue gas treatment plant present ❑
Flue gas emission	Stack is sufficiently high to avoid exceeding ambient air standards ❑	Stack height results in few and minor instances of exceeding ambient air standards ❑	Stack height results in frequent instances of exceeding ambient air standards ❑	Flue gas is emitted from a low stack and causes major instances of exceeding ambient air standards ❑
Odor emission	The plant is constructed and operated so that odor inconveniences do not appear ❑	The plant will result in occasional odor emissions in the neighborhood ❑	The plant will result in frequent odor emissions in the neighborhood ❑	The plant will cause unacceptable odor emissions in the neighborhood ❑
Wastewater discharge	Wastewater discharge meets national standards ❑			Wastewater is discharged untreated and does not meet national standards ❑
Noise emissions	Noise emission is sufficiently muffled to avoid any inconveniences in the neighborhood ❑	Noise emission will lead to minor inconveniences in the neighborhood ❑	Noise emission will lead to major inconveniences in the neighborhood ❑	Noise emission will lead to unacceptable noise level in the neighborhood ❑
Monitoring	A monitoring system for all relevant environmental parameters is established ❑	A monitoring system for basic environmental parameters is established ❑		No monitoring foreseen to take place ❑
11. Occupational Health Issues				
Building layout	Same as B plus adequate emergency access/exits. Labor protection and physiological measures fully included in the design ❑	Same as C plus separation between roads for vehicles and pedestrian passages ❑	Separation between permanently staffed rooms and production areas. Showers and dressing rooms for staff ❑	Direct access from furnace hall, and waste reception area to control room ❑
Ventilation	Same as B plus maintenance of elevated pressure in all permanent work stations and recreational rooms ❑	Same as C plus additional point-source ventilation at critical places, e.g., where chemicals are handled ❑	Forced ventilation in all rooms with frequent work. Combustion air is drawn from waste pit area ❑	Ventilation of permanent work stations only ❑

PARAMETER	A	B	C	D
Mechanical plant	State-of-the-art equipment, e.g., low noise and elaborate safety measures ❑	Low-noise equipment with basic protection devices ❑	Basic occupational health and safety measures included ❑	Occupational health and safety not considered ❑
Manual of operation and safety	Same as B plus regular emergency response exercises ❑	Same as C plus HRD organization for enforcement of regulations and training of new staff ❑	Basic manual exists; organizational responsibilities established at all levels ❑	No operation and safety manual available ❑

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