Decision Makers' Guide to

Municipal Solid Waste Incineration

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Foreword

The *Decision Makers' Guide to Incineration of Municipal Solid Waste* is a tool for preliminary assessment of the feasibility of introducing large-scale incineration plants into the waste management systems of major cities in developing countries.

The *Decision Makers' Guide* targets waste management authorities, as well as institutions involved in financing public utility projects. This guide identifies the most important factors in assessing short- and long-term viability of municipal solid waste incineration.

Fulfillment of the key criteria of the *Guide* (mandatory, strongly advisable, or preferable) does not necessarily mean that a project is feasible. Compliance with the key criteria simply allows the project proposer to proceed with a proper feasibility study with limited risks of a negative outcome.

Noncompliance with one or more of the mandatory key criteria, however, indicates a significant risk that the project is not institutionally, economically, technically, or environmentally feasible. Therefore, either the project should be redesigned, or the unfulfilled criteria should be studied in depth to clarify their influence on the project viability.

The supporting *Technical Guidance Report* provides the foundation for a much more detailed evaluation of all the aspects of a proposed project. The *Report* is specific and requires some prior technical knowledge (although not necessarily about waste incineration). It is thus intended mainly for the organizations supporting the decision-makers.

The *Guide* was prepared by Mr. J. Haukohl, Mr. T. Rand, and Mr. U. Marxen of RAMBØLL, and it was managed by Mr. J. Fritz of the World Bank. It was reviewed by Dr. C. Bartone of the World Bank and by Mr. L.M. Johannessen, long-term consultant to the Bank.

Legend

MSW:	Municipal solid waste (domestic and similar)
ISW:	Industrial solid waste
Mass burning:	Incineration of MSW as received
Incineration plant:	Treatment facility for solid waste with energy recovery and emission control

Key criteria identifying the factors influencing the decision-making process are listed in order of priority, using the following grading system:

✓ ✓ ✓	Mandatory key criteria
✓ ✓	Strongly advisable key criteria
✓	Preferable key criteria

If a mandatory key criterion cannot be expected to be fulfilled, further planning of a solid waste incineration plant should be stopped.

Note: Decision flow charts in the text can be applied to clarify whether a key criterion may be considered fulfilled.

Decision Makers' Guide to Municipal Solid Waste Incineration

Solid Waste Incineration

Municipal solid waste (MSW) incineration plants tend to be among the most expensive solid waste management options, and they require highly skilled personnel and careful maintenance. For these reasons, incineration tends to be a good choice only when other, simpler, and less expensive choices are not available.

Because MSW plants are capital-intensive and require high maintenance costs and comparatively higher technically trained operators, they are commonly adopted by developed countries. However, high capital and maintenance costs may make MSW incineration beyond the reach of many of the lesser developing countries. The *Decision Makers' Guide* aims to reduce such mistakes by clarifying some of the basic requirements for a successful incineration plant project.

Incineration Advantages

Incineration is an efficient way to reduce the waste volume and demand for landfill space. Incineration plants can be located close to the center of gravity of waste generation, thus reducing the cost of waste transportation. Using the ash from MSW incinerators for environmentally appropriate construction not only provides a low cost aggregate but further reduces the need for landfill capacity. In particular, incineration of waste containing heavy metals and so on should be avoided to maintain a suitable slag quality. (However, ordinary household waste does contain small amounts of heavy metals which do not readily leach under field conditions and which routinely pass USEPA TCLP tests.) The slag quality should be verified before it is used. Energy can be recovered for heat or power consumption.

All waste disposal alternatives eventually decompose organic materials into simpler carbon molecules such as CO_2 (carbon dioxide) and CH_4 (methane). The balance between these two gases and time frame for the reactions varies by alternative. Incineration provides the best way to eliminate methane gas emissions from waste management processes. Furthermore, energy from waste projects provides a substitute for fossil fuel combustion. These are two ways incineration helps reduce greenhouse gas emissions.

One of the most attractive features of the incineration process is that it can be used to reduce the original volume of combustibles by 80 to 95 percent. Air pollution control remains a major problem in the implementation of incineration of solid waste disposal. In the United States, the cost of best available technology for the incineration facility may be as high as 35 percent of the project cost. The cost of control equipment will, however, depend upon the air pollution regulations existing in a given lesser developing country.

Waste incineration may be advantageous when a landfill cannot be sited because of a lack of suitable sites or long haulage distances, which result in high costs.

Incineration Disadvantages

An incineration plant involves heavy investments and high operating costs and requires both local and foreign currency throughout its operation. The resulting increase in waste treatment costs will motivate the waste generators to seek alternatives. Furthermore, waste incineration is only applicable if certain requirements are met. The composition of waste in developing countries is often questionable in terms of its suitability for autocombustion. The complexity of an incineration plant requires skilled staff. Plus, the residues from the flue gas cleaning can contaminate the environment if not handled appropriately, and must be disposed of in controlled and well-operated landfills to prevent ground and surface water pollution.

Applicability of Incineration

MSW incineration projects are immediately applicable only if the following overall criteria are fulfilled.

- A mature and well-functioning waste management system has been in place for a number of years.
- Solid waste is disposed of at controlled and well-operated landfills.
- The supply of combustible waste will be stable and amount to at least 50,000 metric tons/year.
- The lower calorific value must on average be at least 7 MJ/kg, and must never fall below 6 MJ/kg in any season.
- The community is willing to absorb the increased treatment cost through management charges, tipping fees, and tax-based subsidies.
- Skilled staff can be recruited and maintained.
- The planning environment of the community is stable enough to allow a planning horizon of 15 years or more.

Institutional Framework

The success or failure of an incineration scheme depends on the attitude of the multiple stakeholders and on the legislative and institutional framework currently in place.

Stakeholders in an MSW incineration plant project often have conflicting interests. The project therefore can become an environmental and economic issue with many groups.

The stakeholders' reaction to the project may differ depending on the institutional setting of the plant. The incineration plant can be located in the waste sector (preferable) or the energy sector, or it can be a fully privatized independent entity. In any case, the incineration plant must be an integral part of the waste management system.

Depending on the organizational affiliation of the plant, there is a need for strong irrevocable agreements regulating the supply of waste, the sale of energy, and the price setting.

A high degree of interaction, either through ownership or long-term agreements, between the different parts of the waste management system and the waste incineration plant is important to avoid environmental, institutional, or financial imbalances in the overall solid waste management system.

The Waste Sector

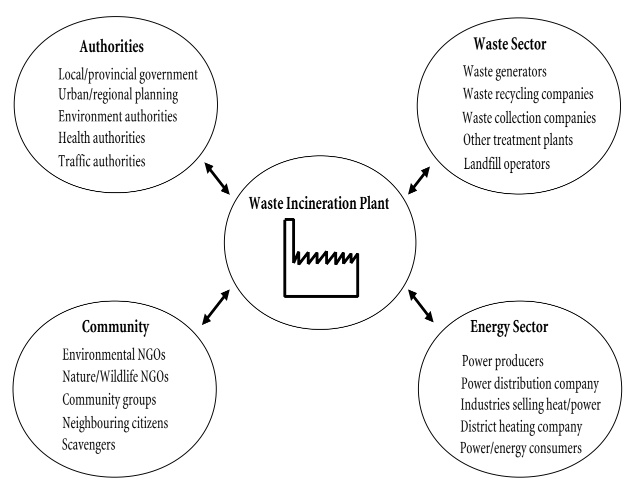
A well-developed and controlled waste management system is considered a prerequisite to an MSW incineration plant. Generators consider waste to be a nuisance and want to dispose of it at the lowest possible cost. However, many people who work formally or informally with waste collection, transportation, recycling, and disposal seek to maximize their profit or make a living.

Existing regulations and enforcement must therefore be highly efficient to ensure that all waste which cannot be recycled is disposed of at controlled and well-operated landfills. This goes for both municipal solid waste, often taken care of by a public waste management system, and industrial solid waste (ISW), generally handled by independent waste companies.

Overall control of the waste flow—including ISW, if part of the design volume—is important to ensure reliable supply of suitable waste to the waste incineration plant.

Mature solid waste management systems are highly integrated and operated efficiently under public financial and budgetary control. They include organizations

Figure 1 Relevant stakeholders



involved in the collection, transportation, and disposal of waste in environmentally controlled landfills. Costs for some systems are fully paid by the generators (although some are tax-supported or subsidized). Introducing new facilities into such a system calls for optimizing and controlling the waste flow and fee structure to maintain a balance between the different disposal options. In order of complexity, energy can be recovered as hot water, low grade steam, super heated steam for electricity generation, or a combination of the steam options.

Public awareness campaigns emphasizing waste minimization, recycling, and proper waste management are also part of a mature waste management system.

The Energy Sector

Incineration of MSW is significantly more expensive than controlled landfilling. For a plant to be economically feasible, costs must be minimized through sale of energy recovered.

The primary concern is the end use of the energy produced: district heating, steam, electricity, or any combination. Therefore, the characteristics of the energy sector play an important role when considering an MSW incineration plant.

Sale of energy in the form of hot water for district heating purposes—or in particular cases, low pressure steam to large-scale industrial consumers nearby, provided that sufficient contracts and guarantees can be arranged—minimizes plant construction costs and recovers a high percentage of energy. Sale of combined power and heat or steam results in a degree of energy recovery that is no higher, but the cost and the complexity of the plant are increased.

The energy sector is often heavily regulated. Concession to produce and sell electricity is generally granted to a limited number of public and private operators. An incineration plant established by another authority or a private organization may therefore encounter difficulties before gaining the necessary approvals and agreements. Early co-operation with the end user organizations is therefore useful.

It is most feasible when the energy can be sold to one consumer for its own use or resale. The consumer may be a utility company with an existing distribution network, for example.

Energy prices are often subject to taxation or are partly subsidized. Pricing may therefore be a political issue requiring a government decision. Also, in most developed countries, energy prices are controlled by fiscal measures to favor energy production based on biomass fuels.

Political and socio-economic considerations play an important role when fixing the price of waste-generated energy. A high price resulting in a reduction of the waste tipping fee favors the waste sector, and low energy prices favor the energy consumers.

Community Aspects

The community and NGOs where a new MSW incineration plant is to be established are often concerned about environmental impacts. These concerns may arise from a lack of knowledge, general resistance towards changes, or fear of the unknown, such as higher waste management charges, loss of subsistence, or fear of pollution.

Public awareness campaigns initiated in the early planning stages can alleviate this concern. Furthermore, a detailed discussion about the environmental protection measures included in the project—

Figure 2 Assessment of Waste Management System

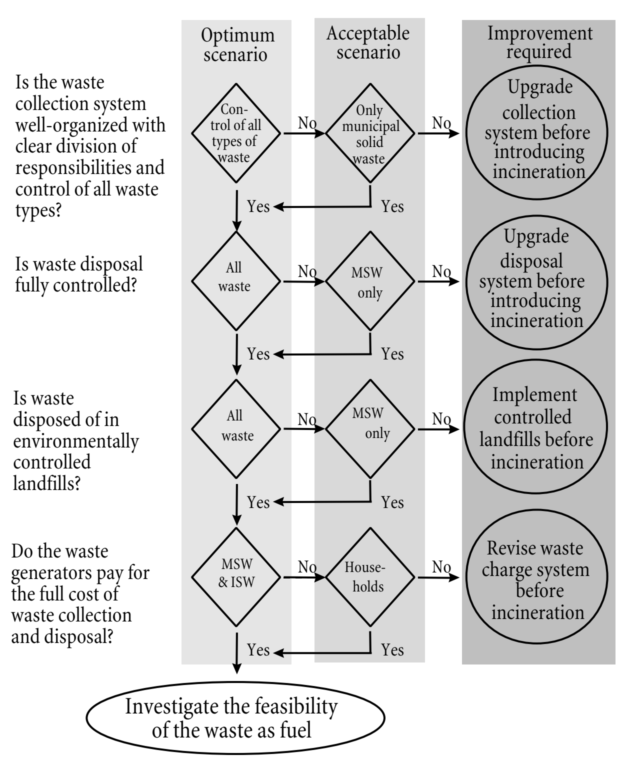
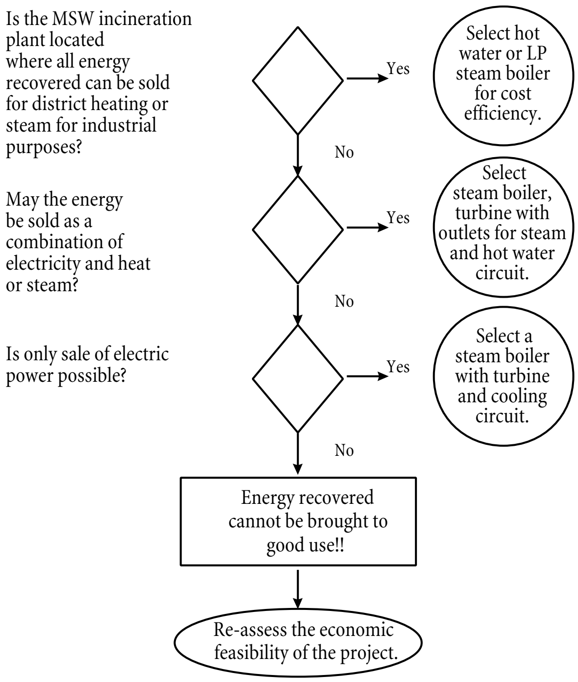


Figure 3 Assessment of Potential Sale of Energy



not only with the environmental authorities, but also with the organized NGOs—is necessary.

In the design phase, the environmental authorities are to establish standards for the plant emissions and handling of the residues. In the operational phase, the same authorities will need to control and enforce those standards.

The public concern may lessen if the environmental authorities and those in charge of the MSW incineration plant are truly independent of one another.

Plant Ownership and Operation

The number of stakeholders around an MSW incineration plant will result in diverging and conflicting interests. Depending on who owns the incineration plant, institutional borderline problems may arise regarding delivery of a sufficient quantity and quality of waste, the pattern and price of sale of energy or both. Problems must be solved at an early stage through detailed long-term agreements. Key agreements are those related to waste supply and energy sale.

Municipally operated incineration plants have many benefits. The municipality can control the collection and transport of waste to the facility (although this is not always the case). The public has some confidence that the municipality will ensure the environmental performance of the facility. In many cases the public energy distribution organization finds it easier to negotiate with another public body, which minimizes the potential for problems.

There must be a mechanism to ensure the long-term viability of the incineration facility. The risks involved in financing such operations relate to controlling costs and revenues. Waste tipping fees and energy sales provide revenues. Contracts that guarantee waste volumes and price over the life of the project are important, and must address the potential for short falls in waste receipts. Energy generation potential relates to both the quantity and quality of the waste received. The deterioration in waste quality can lead to decreased energy production—in which case, energy sales revenues will also decrease. The facility must have guarantees that allow operations to be sustained. The community where the facility is established will thus have to accept the economic risk.

Operation and maintenance of the plant requires skilled managers, operators, and maintenance staff, so staff recruiting and developing are important. The skills required are similar to those of the energy sector. The owner may choose to subcontract all or part of the operation and maintenance of the facility to private companies with long-standing practical experience.

Worldwide, there are few experienced manufacturers and builders of MSW incineration plants. Hence, foreign currency will be needed not only for the initial investment but also for certain spare parts. The plant must therefore be organized with unhindered access to procurement of spares and services paid for in both local and foreign currency.

Key Criteria for Institutional Framework

✓ ✓ ✓ A solid waste management system, comprising a controlled and well-operated landfill, has been functioning well for a number of years.

✓ ✓ ✓ Solid waste collection and transportation (MSW and ISW) are managed by a limited number of well-regulated/controlled organization(s).

✓ ✓ ✓ 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 are responsible for controlling, monitoring, and enforcing operations.

✓ ✓ ✓ A public guarantee is available for repayment of capital costs and operation costs

✓ ✓ 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 to the plant owner at affordable salaries. Otherwise, there must be long-term reliable operation and service contracts.

✓ The waste management authority owns the incineration plant.

Waste as Fuel

A most crucial factor in the feasibility of an MSW incineration plant is the nature of the waste and its calorific value. If the mandatory criteria for waste combustibility are not fulfilled, the project should be terminated.

As a result of the socio-economic situation in many low to middle income countries or areas, only limited amounts of useful resources are wasted. Organized and informal recycling activities in the waste handling system tend to reduce the amount of paper, cardboard, and certain types of plastic in the waste. Additionally, the waste may have high ash and moisture content.

Municipal solid waste in such areas therefore often ends up with a low calorific value and its ability to burn without auxiliary fuel is questionable either year-round or in certain seasons. In areas with heavy precipitation, closed containers for collection and transportation should be used to avoid a significant increase of the water content of the waste.

Industrial, commercial, and institutional wastes (except from market waste) tend to have a significantly higher calorific value than domestic waste. Mixing different types of wastes may therefore make incineration possible. However, the collection system must be managed well to maintain segregated collection under these circumstances.

Waste generation depends highly on socio-economic conditions and the degree of urbanization and industrialization. In general, waste generation and composition data cannot be projected from one place to another. Introduction of advanced waste treatment facilities must therefore always be based on a comprehensive local waste survey.

Introduction of advanced waste treatment like MSW incineration will have a significant impact on existing informal recycling activities. For example,

Table 1:Waste generation

Area	*Waste Generation (kg/cap./year)* *Range*	*Mean*	*Annual growth rate*
OECD–total	263–864	513.0	1.9%
North America	n.a	826.0	2.0%
Japan	n.a.	394.0	1.1%
OECD–Europe	n.a.	336.0	1.5%
Europe (32 countries)	150–624	345.0	n.a.
8 Asian Capitals	185–1,000	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.

n.a. = Not applicable.
Source: cf. Technical Guidance Report

Table 2: Waste components

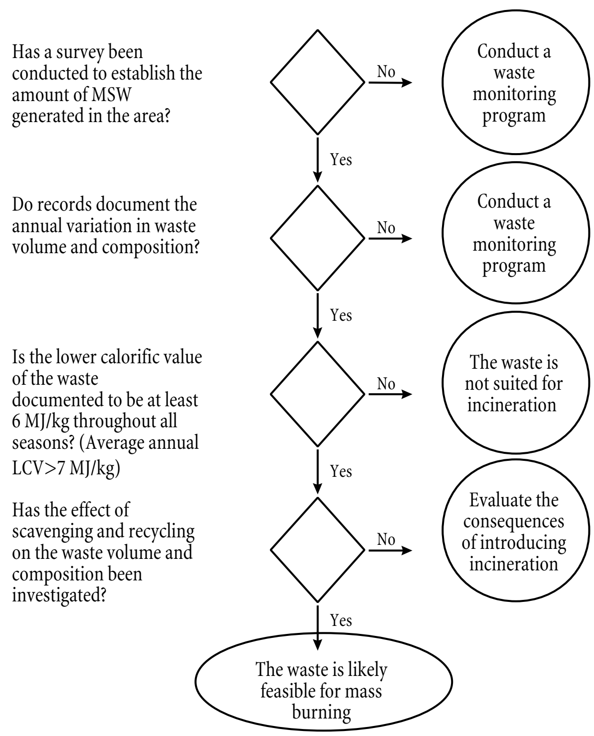
% of waste	*Guangzhou, China, 8 districts 1993*		*Manila 1997*	*22 European countries 1990*	
Fraction	*Range*	*Mean*	*Mean*	*Range*	*Mean*
Food and organic waste	40.1–71.2	46.9	45.0	7.2–51.9	32.4
Plastics	0.9–9.5	4.9	23.1	2–15	7.5
Textiles	0.9–3.0	2.1	3.5	n.a.	n.a.
Paper and cardboard	1.0–4.7	3.1	12.0	8.6–44	25.2
Leather and rubber	n.a.	n.a.	1.4	n.a.	n.a.
Wood	n.a.	n.a.	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, and so on)	14.0–59.2	40.2	0.8	n.a.	n.a.
Others	n.a.	n.a.	0.7	6.6–63.4	24.0

n.a. = Not applicable.
Source: cf. Technical Guidance Report

scavengers may lose their source of income. Even if these people are compensated for their loss of income, some of them will shift to the early stages of the handling system. This may alter the composition and combustibility of waste arriving at an incineration plant. Scavenging and other recycling activities must therefore be carefully managed.

The waste survey must account for the existing waste composition and calorific value and for expected changes during the adopted planning period. Annual variations must be carefully surveyed and assessed, for example, by conducting a year-long sampling program to establish waste constituents, trends, and seasonal variation, as well as variation between collection areas. The average annual lower calorific value must be at least 7 MJ/kg, and must never fall below 6 MJ/kg in any season.

Figure 4 Assessment of Waste as Fuel



Key Criteria for Waste as Fuel

✓ ✓ ✓ The average annual lower calorific value must be at least 7 MJ/kg, and must never fall below 6 MJ/kg in any season.

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

✓ ✓ Assumptions regarding 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 dispose of their waste at the incineration facility.

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

A preliminary feasibility assessment of using a particular waste as fuel can be made on the basis of the content of ash, combustible matter (ignition loss of dry sample), and moisture.

The maximum amount of energy recoverable through MSW incineration depends primarily on the lower calorific value of the waste, but also on the system applied for energy recovery. It is most efficient when both electricity and steam/heat are produced, and the yield is lowest when only electricity is generated and the surplus heat is cooled away.

Energy prices vary greatly from place to place, even within the same country. Electricity is a high-value energy form, so a low energy yield is, to some extent, compensated for through price differences.

Economics and Finance

MSW incineration is an advanced waste treatment technology which is costly to implement, operate, and maintain. A significant amount of foreign currency must be available for the initial procurement of equipment and spares, and for replenishing stocks of spares and for expatriate expert plant overhauls later.

Normally, MSW incineration furnaces are designed with a capacity limit of about 20 to 30 metric tons/h. The recommendation is 10 to 20 metric tons/h. It is recommended to divide the total plant capacity into two or more identical incineration lines, thus improving the plant's flexibility and availability—for example, when one line is closed for maintenance.

The investments in an MSW plant depend to a great extent on the required form of energy output. The least expensive plants are those equipped with hot water boilers only. Production of steam and electricity makes the investments in mechanical plant and civil works much higher (about 40 percent). The

Figure 5 Energy Recovery

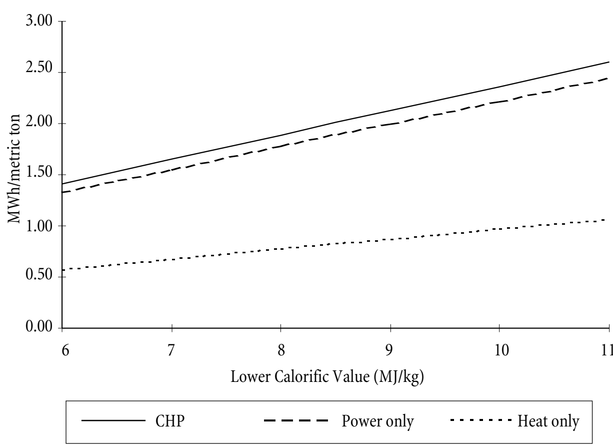


Figure 6 Value of Energy Sale (Based on an electricity price of $35/MWh and a heat price of $15/MWh)

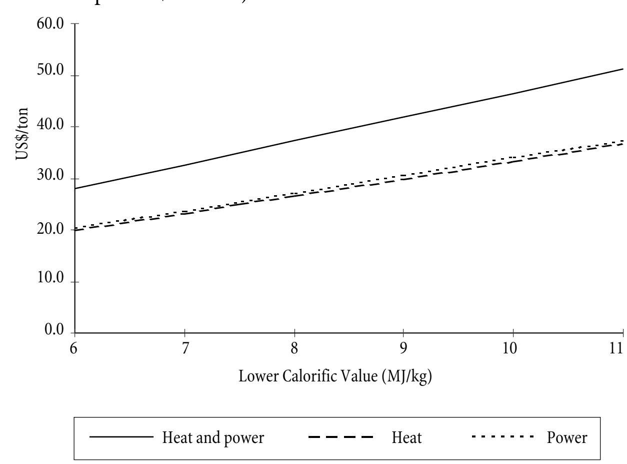


Table 3: Fuel characteristics of MSW

		Guangzhou, China			*Manila,*
		8 districts, 1993		*5 districts, 1994*	*Philippines, 1997*
Parameter	*Units*	*Range*	*Mean*	*Mean*	*Mean*
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	2,555–3,662	3,359	5,750	6,800

operating costs are also higher for electricity producing facilities.

Figures 7 and 8 indicate estimated investments and net operating costs as of mid 1998 as a function of the annual amount of waste processed at power generating plants. It is, furthermore, assumed that the plants are equipped to meet medium level emission standards (see next section). Compliance with basic emission control allows only a 10 percent investment reduction. The assumed operating time is 7,500 hours annually. The curves are valid only for plants designed for waste with a lower calorific value of less than 9.0 MJ/kg. Furthermore, the electricity sale price is assumed to be $35/MWh.

The figures indicate a significant scale of economy with respect to investment as well as net treatment costs.

The net treatment costs of an MSW incineration plant are rather sensitive to fluctuations in the quantity and quality of waste treated. The net costs sensitivity graph indicates the resulting change in treatment costs if the waste has a reduced calorific value or if the supply of waste falls short of the design load.

Figure 9 Sensitivity of Incineration Costs

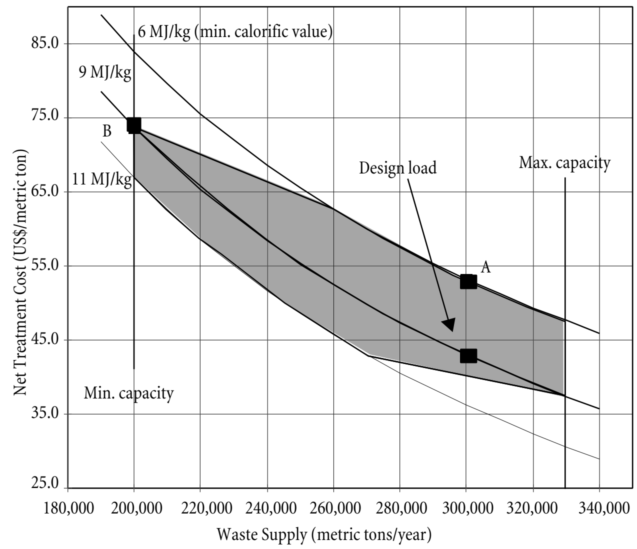


Figure 7 Estimated Cost of Incineration Plants

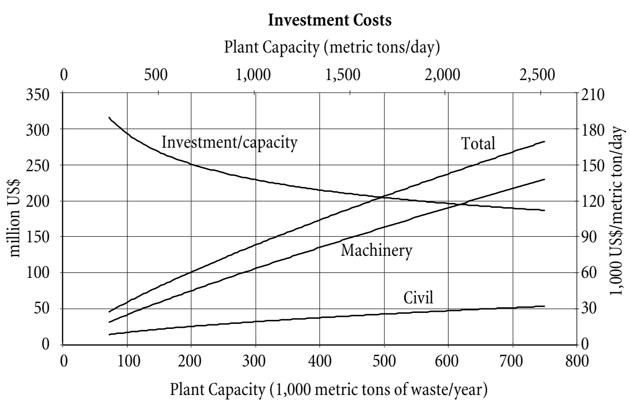


Figure 8 Estimated Net Treatment Costs

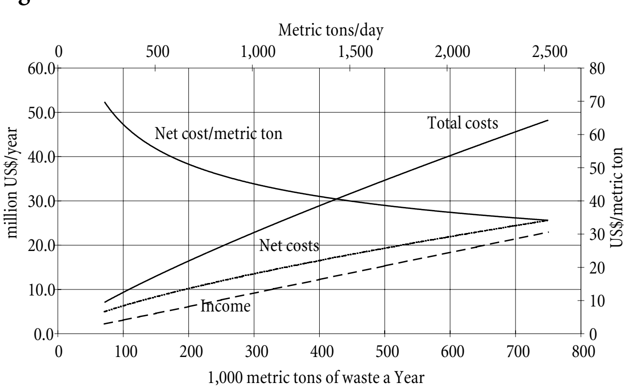
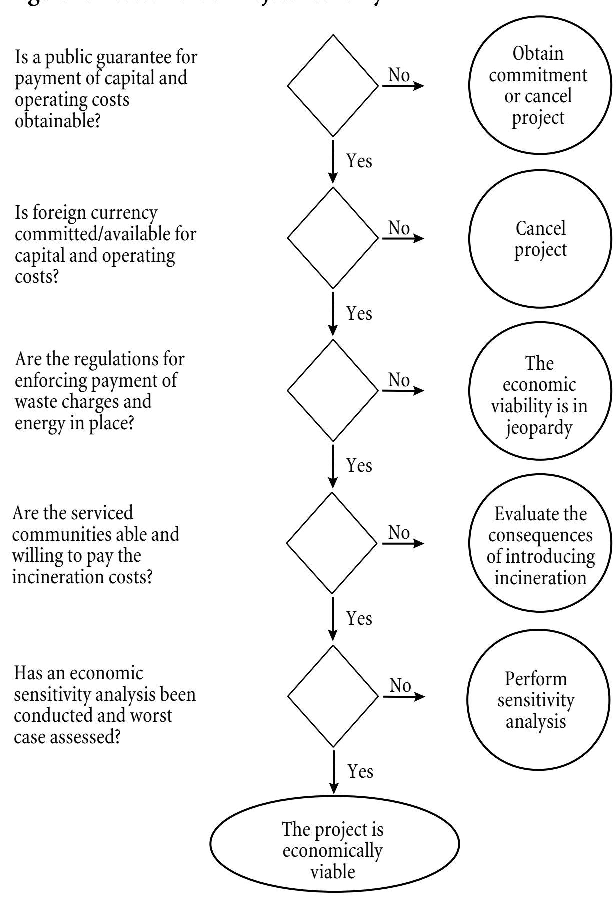


Figure 10 Assessment of Project Economy



Waste with a lower calorific value of 6 MJ/kg only has a net treatment cost of 30 percent above that of waste with a lower calorific value of 9 MJ/kg. If the plant processes only two-thirds of the design load because of a shortage of waste or extended periods of maintenance, the treatment cost increases significantly.

Any forecast of the net costs of MSW incineration should be conservative and accompanied by a sensitivity/risk analysis. The economic risk, even for fully privatized plants, will end up with the society serviced by the plant.

The net cost of MSW incineration is significantly higher than for landfills established according to strict environmental standards. Therefore, the question which must always be asked about any incineration project is—why not landfill? Only in situations where landfill is not viable (for example, if there is no land, as is the case in Singapore, or if there is no political will to site a landfill) will WTE be a good choice.

From a strict financial point of view, it may be difficult to justify the increased costs of waste disposal. A full cost benefit analysis is therefore required to assess whether the locally obtainable benefits justify the costs.

Recovering the costs of an MSW incineration plant in low to medium income countries is difficult. Depending on the family size, each household may easily generate from 1 to 2 metric tons of waste for incineration annually. The net tipping fee at the incineration plant will therefore amount to at least US$ 50 to 100 per year per household. Hence, in some regions, the waste service charge could be comparable to other public supply charges such as power and heating. It is important to assess the ability and willingness of the population to pay such a treatment charge in addition to the cost of collection and transportation.

The cost of incineration may be recovered through a combination of a tipping fee usually paid by trade and industry and a general waste management charge usually paid by households and such. The general charge may be collected directly as a waste management charge, or together with other public service bills (such as electricity or water), or property taxes, and so on. The charges may, however, become so great that the normal market mechanisms or waste disposal system are distorted. The plant may therefore need to be subsidized via the budget of the city. Otherwise, it might take strict enforcement to ensure that waste is taken to the incineration plant rather than disposed of indiscriminately.

It is important to design an affordable and publicly acceptable fee policy, which ensures sufficient income for operating, managing, and developing the plant, as well as a suitable waste flow matching the treatment capacity of the plant. Various fee policies are possible with adequate support from a combination of fiscal and legal measures. Establishing regional or intermunicipal waste management co-operations may provide economies of scale that should be compared against the increased costs of transport.

Key Criteria for Incineration Economy

✓ ✓ ✓ There must be a stable planning environment with predictable prices of consumables, spare parts, disposal of residues, and sale of energy. Furthermore, the capital costs (large share of foreign currency) must be predictable.

✓ ✓ ✓ The financing of the net treatment cost must ensure a waste flow as intended in the overall waste management system. Consequently, the tipping fee at the waste incineration plant must be lower or at least correspond to the tipping fee at the landfill site. Willingness and ability to pay must be thoroughly addressed.

✓ ✓ ✓ Foreign currency must be available to purchase critical spare parts.

✓ ✓ 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.

✓ To be economically feasible, the individual incineration units should have capacities of at least 240 t/d (10 t/h), and there should be at least two separate units.

✓ If a regular market for sale of hot water (district heating or similar) or low pressure steam is present, the plant should be based on sale of heat only. This is preferable 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.

Project Cycle

The project implementation cycle of MSW incineration plants involves three main phases: feasibility assessment, project preparation, and project implementation. At the end of each phase, the project should be reevaluated for feasibility.

Figure 11 Typical Implementation Plan

Phase	Step	Purpose and Issues to Consider	Duration
Feasibility Phase	Pre-feasibility Study	Waste quantities, calorific values, capacity, siting, energy sale, organization, costs, and financing	6 months
	Political Decision	Decide whether to further investigate 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 tender documents	6 months
	Political Decision	Decision on financial package, tender documents and procedures in detail, and final go-ahead	3 months
Project Implementation Phase	Award of Contract and Negotiations	Prequalify contractors, tender documents, select most competitive bid, negotiate contract	6 months
	Construction and Supervision	Construction by selected contractor and supervision by independent consultant	2 1/2 years
	Commissioning and Start Up	Test all performance specifications, settlements, commissioning, training of staff, and start up by constructor	6 months
	Operation and Maintenance	Continuous operation and maintenance of plant. Continuous procurement of spare parts and supplies.	10–20 years

It is important to involve the public throughout the project cycle—through awareness campaigns in the mass media and public hearings on major decisions with a direct community impact. Public participation beyond what is recommended for urban planning and environmental impact assessment may be useful in dissolving public resistance to the project.

Feasibility Assessment

The feasibility of MSW incineration projects in developing countries is highly questionable. Therefore, the feasibility assessment should be conducted in two stages: preliminary and comprehensive. The preliminary assessment can be based on existing information, including properly adapted relevant data from literature. The comprehensive assessment will involve comprehensive collection of local data on waste generation and composition, a detailed study of plant finance and a full environmental impact assessment, for example. Early on, the performance criteria should be established for the plant's air pollution control system.

Project Preparation

An appropriate project organization must be established early in the project preparation phase. In addition, the institutional framework of the facility must be clarified early on.

The project organization will develop appropriate agreements regarding project financing, waste supply, energy sale, and disposal of residues, as well as perform the necessary environmental impact assessments.

The project organization will, furthermore, develop project tender documents and negotiate contracts with successful tenderers.

Since the project organization's tasks cover a wide range of expertise, independent experts with suitable experience in the implementation of waste incineration projects must be hired.

Key Criteria for the Project Cycle

✓ ✓ ✓ A skilled independent consultant with experience from similar projects should be employed at an early stage.

✓ ✓ ✓ To avoid conflicts, the public should be involved and informed during all phases but especially in the planning phase (feasibility assessment and project preparation phase).

Project Implementation

The role of the project organization during implementation will depend greatly on the final institutional affiliation of the MSW incineration plant. For a fully privatized facility, the project organization must monitor project progress and control the contractor's fulfillment of all obligations.

For a publicly owned and operated plant, the project organization will have to not only monitor and control the progress of the actual plant implementation but also establish the plant management organization. Staff has to be recruited and trained well ahead of commissioning the facility. Start-up assistance, including training of staff and understanding of the operation manual, is often included in the supplier's contract.

Incineration Technology

There are many options for MSW incineration plant technology. The range of equipment varies from experimental to well-proven, though only the well-proven are recommended. Development problems with new technology are complicated and costly to solve, as developing countries lack the internal technical expertise to overcome them. Such problems could cause the entire project to fail.

Based on the intended application, incineration plant equipment may be grouped in four main categories:

- Pretreatment
- Combustion system
- Energy recovery
- Flue gas cleaning

The flow diagrams on the last three pages of this *Guide* provide a simplified view of how various types of equipment may be combined. The diagram on energy recovery shows that energy end use is decisive even for the choice of boiler type. The Air Pollution Control diagrams indicate the options for meeting various air pollution standards.

Pretreatment

Mass burning of "as received" and heterogeneous waste requires little or no pretreatment such as size reduction, shredding, or fine sorting. Mass burning systems are typically based on a movable grate.

Mass burning incineration with a movable grate incinerator is a widely used and thoroughly tested technology for waste incineration. It meets the demands for technical performance and is capable of accommodating large variations in waste composition and calorific value. Another, but less widely applied, mass burning alternative is the rotary kiln.

Some technologies pretreat the waste stream to remove non-carbonaceous materials, such as metal and glass—for example, for production of "refuse derived fuel." These technologies offer some benefits in terms of reduced furnace size and improved energy efficiency. However, the front end processing that shreds and mixes the wastes is demanding and expensive. Therefore, the incineration technologies for burning pretreated and homogenized waste are of limited use—and historically, such technologies have typically failed.

Theoretically, a fluidized bed may be applied for combustion of pretreated and homogenized municipal solid waste. The fluidized bed technology has a number of appealing characteristics in relation to combustion technique. The advantages are, however, not thoroughly proven on municipal solid waste, and the fluidized bed is therefore not recommended. The fluidized bed may be good for special types of industrial waste, and for this purpose it is widely applied—for instance, in Japan.

Combustion System

When implementing a new municipal solid waste incineration plant, the technology must be based on feasible and well-proven technology. At present, only the mass burning principle with a movable grate fulfills this criterion. Furthermore, suppliers with numerous reference plants that have been successful for a number of years, preferably in low and middle income countries, should be chosen.

The design of the combustion system must hinder the formation of pollutants, especially NO_x and organic compounds such as dioxins, as much as possible.

Energy Recovery

A main benefit of solid waste incineration is the possibility of reusing the waste as fuel for energy production. The flue gases carrying the energy released in a waste incineration furnace have to be cooled in a boiler before the air pollution control system. The boiler is also a necessary technical installation for energy recovery. The feasible type of boiler, however, depends on how the energy will be used: as hot water for district heating, process steam for various types of industries, or electricity.

The choice between the various end use possibilities depends on the local energy market conditions, including:

- Existing 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 relatively 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 high-price energy, whereas hot water for district heating is considered cheap energy with a high overall thermal efficiency and low cost and technical installation complexity.

The obtainable energy recovery efficiencies appear on the flow diagram at the back of the *Guide*.

Flue Gas Cleaning

Incinerating municipal solid waste generates large volumes of flue gases. The flue gases carry residues from incomplete combustion and a wide range of pollutants. The pollutants and their concentration depend on the composition of the waste incinerated and the combustion conditions. Ash, heavy metals, and a variety of organic and inorganic compounds can be found in varying quantities.

The pollutants are present in the form of particles (dust) and gases such as HCl, HF, and SO_2. Some harmful compounds such as mercury, dioxins, and NO_x can only be fully removed by applying advanced chemical treatment technologies that increase the overall investment considerably.

The selection of the flue gas cleaning system depends primarily on the actual emission 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, in which only the particulate matter is reduced, is simple to operate and maintain and the investment cost is relatively low. At the same time, a significant part of the most harmful substances are also retained because dust particles (fly ash) and pollutants absorbed on the surface of the particles can be removed by equipment such as electrostatic precipitators. Basic emission control is a minimum requirement.

By applying relatively simple dry or semidry scrubbers, medium level emissions can be controlled.

The state-of-the-art flue gas cleaning systems (advanced emission control) applied in, for instance, Europe and the United States, are very complex and the benefits in terms of reduced emissions should always be compared to other emission sources.

Table 4: Emission control levels

Emission control level	*Parameters controlled*	*Saving/cost compared to plant designed for medium control level*
Basic	Particles only—for example, < 30 mg/Nm^3.	–10% of total investment
Medium	Standard for particle emission. Additional standards for HCl, HF, SO_2, and the heavy metals of 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 as well as dioxins.	+15% of total investment

Table 5: MSW incineration flue gases

		Emission standard (mg/Nm^3, dry, 11% O_2)		
Parameter	*Raw flue gas*	*Basic*	*Medium*	*Advanced*
Particles	2,000	30	30	10
HCl	600	n.a.	50	10
HF	5	n.a.	2	1
SO_2	250	n.a.	300	50
NO_x (as NO_2)	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

Removal of dioxins and furans has received much public attention in Europe and North America, which has increased installation investments and treatment costs.

Incineration Residues

The main residue from MSW incineration is slag. The amount generated depends on the ash content of the waste. In the combustion process, the volume of waste from high income cities will by experience be reduced by approximately 90 percent and the weight by 70 to 75 percent. For low income areas the amount of ash in the waste can be high—for example, in areas using coal, wood, or similar for heating.

In addition to the slag, the plant generates residues from more or less advanced dry, semidry, or 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 well burnt out, with only a minor content of organic material. Besides, the heavy metals in the slag, which are normally leachable, will to some extent become vitrified and thus insoluble. Much of the slag may there-

Table 6: Salts in leachate from MSW incineration residues

Concentration level	*Slag*	*Fly ash and dry + semidry product*	*Wet product + 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, Se	As	As, Cr, Zn
Very Low[e]	Cr, Hg, Sn	Hg	Pb, Cd, Cu, Hg

Max. leaching of ions from incinerator residues, indicative
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

fore be used as road construction material or something similar after sorting.

The other residues must, however, be disposed of. Therefore, a well-designed and well-operated landfill, preferably located in abandoned mine shafts or other places where leaching with rainwater can be prevented must be available.

Proper disposal of fly ash and other flue gas cleaning residues is the subject for another study. However, in general, it should be treated as hazardous waste and disposed of according to leachate properties.

The fine particle size of the residues calls for special precautions during handling at the plant and the landfill.

Key Criteria for Incineration Technology

✓ ✓ ✓ The technology should be based on the mass burning principle with a movable grate. Furthermore, the 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 flue gases from the furnace must be cooled to 200°C or lower before flue gas treatment.

✓ ✓ ✓ The flue gas cleaning equipment must be at least a two-field ESP (basic emission control, dust<30 mg/Nm^3).

✓ ✓ ✓ A controlled landfill must be available for residue disposal. Full leachate control must be exercised at the landfill.

✓ ✓ 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 waste incineration plant should not exceed 20 percent.

✓ ✓ Municipal solid waste incineration plants should be 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.

✓ See *Technical Guidance Report.*