

## ISWA Guidelines: Waste to Energy in Low and Middle Income Countries



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## ISWA GUIDELIENS: WASTE TO ENERGY IN LOW AND MIDDLE INCOME COUNTRIES

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## 1. FOREWORD

These guidelines aim to assist decision makers in the planning and implementation of Municipal Solid Waste (MSW) incineration facilities in low and middle income countries. The guidelines are initiated by ISWA and are prepared by ISWA's Working Group on Energy Recovery.

The intended users of the guidelines are primarily politicians, waste management authorities and institutions involved in the financing of public utility projects. The overall objective is to give an overview of the key pre-conditions which must be fulfilled in order to ensure short and long-term feasibility of MSW incineration. Also the guidelines include an overview of waste incineration technology as well as the necessary infrastructure.

The guidelines comprise the initial considerations that must be made when assessing the feasibility of a large-scale incineration facility. Specifically, the document includes guidance on the institutional and organisational framework, general remarks on the economics of waste incineration and suggested project phasing. Furthermore, considerations regarding the sustainability of waste incineration are made.

The guidelines comprise decision flow charts and figures to illustrate some of the key factors and criteria necessary for a successful implementation of an MSW incineration facility.

Implementation of a WtE facility is a huge investment and to be successful it is required that the infrastructure for collection of waste and sale of energy is present and strongly encourages and supported by the stakeholders. In particular it is recommended that an in-depth feasibility study is carried out before investing in MSW incineration.

When establishing WtE facilities in countries where WtE has not previously been developed the national regulations are often very limited. A comprehensive set of norms and standards for MSW incineration is developed by the European Commission and by the US Environmental Protection Agency. If no national set of standards exist ISWA recommends that the requirements set by the European Commission or by the US Environmental Agency are followed.

The international unit system (SI-units) is used throughout the document. The calorific value referred to is the lower calorific value.

As far the most of the WtE facilities worldwide are based on mass burn combustion this guidebook takes the basis in this. For other technologies reference is made to the ISWA White Paper on Alternative Waste Conversion Technologies issued by ISWA's Working Group on Energy Recovery in 2013.



## 2. MUNICIPAL SOLID WASTE INCINERATION

MSW incineration has successfully been implemented in high-income countries because it offers a number of advantages over other waste handling methods:

- Most efficient way of reducing the volume of the waste and thus the demand for landfilling.
- Can be situated close to urban areas, reducing the need for transportation.
- If the energy of the waste is recovered for power and/or heat or steam production, MSW can act as a substitute to fossil fuels.
- Environmentally beneficial compared to landfilling. In a landfill organic materials eventually decompose and create greenhouse gases such as carbon dioxide and methane. Methane is an aggressive greenhouse gas which is not produced when MSW is incinerated.
- MSW incineration bottom ash can generally be disposed of safely in construction work as aggregate – thus substituting virgin aggregates and further reducing the demand for landfills.



Globally, there are over 1200 Waste-to-Energy (WtE) plants in operation across more than 40 countries and is strongly developing in new countries along with a growing economy and along with the implementation of waste regulation. These plants recover the energy from the MSW for power and/or heat and can recover non-combustible solids such as glass and metals from the bottom ash.

On more than 1000 of the 1200 WtE plants there are no pre-treatment of the MSW before it is combusted using a moving grate. The hot combustion gasses are most often used in boilers to generate steam for electricity production. Excess energy that cannot be used for electricity production can potentially be used for industrial purposes, for desalination or for district heating/cooling.

Grate combustion is, by far, the leading WtE technology due to its reliability, robustness and simplicity. Other thermal treatment WtE technologies exist but have yet to develop and mature technically and commercially before they can be considered a real alternative to traditional combustion technology.

There are, however, a number of important challenges associated with incineration:

- Capital investment and operating costs are high.

- Increase in waste treatment cost may incentivise waste generators to seek alternatives to incineration, which is good if the alternative is for recycling, but not if it ends up in uncontrolled dumping
- There is a minimum requirement to the lower calorific value. In low to middle income countries it may be a challenge to achieve this
- Skilled staff is required for the operation and maintenance of the furnace, boiler, turbine/generator and the flue gas cleaning system
- There might be a public opposition against WtE. This can influence the political process when planning an MSW facility
- The NIMBY syndrome also exists for WtE

Implementing an MSW incineration facility in a poorly developed waste management system and without proper planning can lead to environmental and economic failure. The key risks are varying waste amounts delivered, too low calorific value, poor financial support, inappropriate choice of technology and inadequate institutional framework.

MSW incineration is therefore only considered suitable in "mature" waste management systems, where the waste collection is working properly, where the calorific value has a certain minimum level and where the required tipping fees are affordable.

In summary, incineration should generally only be considered as an option if:

- A mature and well operated waste management system already exists.
- MSW is already being disposed in controlled and well-operated landfills.
- The supply of combustible MSW should at least amount to 100,000 t / year. (Can be smaller in isolated areas).
- The lower calorific value must be, on average, at least 7 MJ/kg and never fall below 6 MJ/kg.
- The community is able and willing to pay for the increased treatment cost for example via management charges, tipping fees, tax based subsidies or high electricity feed-in tariffs.
- Skilled staff can be hired and maintained.
- The community planning system is stable and able to make appropriate long term planning (+15 years).

### 3. WASTE AS FUEL

The viability of any MSW incineration facility depends highly, and most importantly, on the quantity and calorific value of the waste. The economic state of the country/area is highly correlated to the calorific value of the waste. Countries with high degree of consumerism tend to have higher calorific waste composition due to plastics and cardboard for packaging of consumer goods etc.

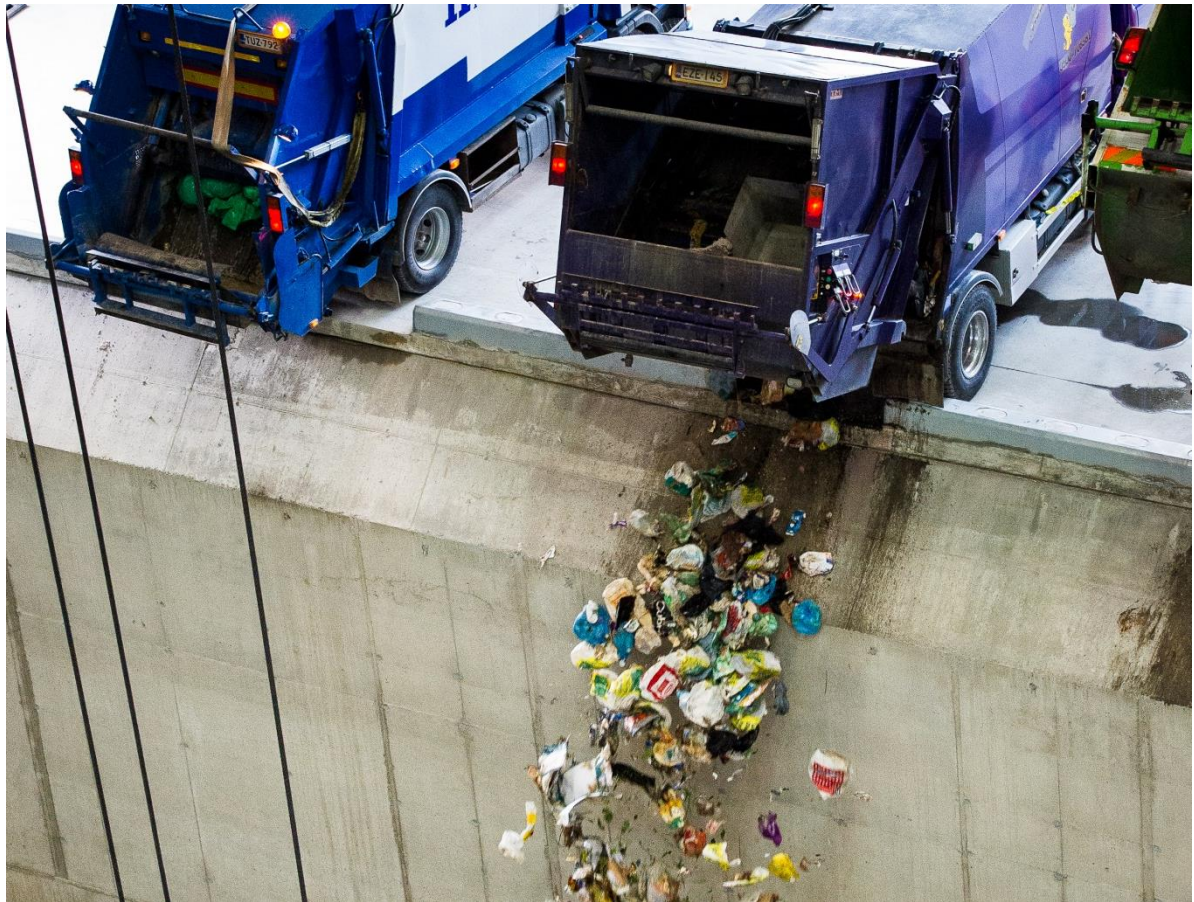
In low to middle income countries the content of plastics and cardboard waste is lower and the content of organic waste is higher. In some countries a large part of the wet kitchen waste (soup, boiling water, etc.) ends up in the waste bin resulting in high water content. In countries with much precipitation and heavy rainfalls the waste management system is often based on open waste containers and the collection is often carried out in open vehicles.

Some countries may have informal scavengers. Scavengers are informal recyclers who make a living by picking and sorting recyclable fractions for recycling. The scavengers may pick out waste from the waste collection points or, what is more common, from the landfill sites. Scavenging is connected with great health risks as no procedures are done to protect the scavengers from diseases. There is also a great risk of incidents when the trucks are unloading the waste as well as a risk of injuries from sharp objects. Implementing MSW incineration will significantly affect the lives of the scavengers as they will lose a source of income.

A change in scavenging activity might change the composition and thus the calorific value of waste. Thus the impact from scavenging must be carefully considered when assessing the suitability of waste as a fuel. It is important that the waste authority or the governmental body assist in the transformation from informal scavenging to organised and protected waste recyclers.

For these reasons, the overall calorific value (lower heating value) may be too low for combustion without the constant supply of auxiliary fuel, putting the viability of an MSW incineration facility at risk.





It may turn out, that the MSW is of poor calorific value and unsuited, whereas the industrial solid waste is of higher calorific value and very well suited. A mix of MSW and industrial solid waste may then also be suitable for incineration. However, this requires a well-managed waste management system to ensure that the industrial waste stream will not contain hazardous components. Table 1 shows approximate calorific values for common fractions of MSW.

Seasonal changes shall also be taken into consideration as well as religious traditions which may have implications to the calorific value of the waste.

In general, the average lower calorific value of waste should be at least 7 MJ/kg and must never fall below 6 MJ/kg. Please see Figure 2 for decision flow chart.

<b>Approximate calorific value</b>	
<b>Fraction</b>	<b>calorific value [MJ/kg]</b>
Paper	16
Organic material	4
Plastics	35
Glass	0
Metals	0
Textiles	19
Other material	11

**Table 1 Approximate calorific value for common MSW fractions**

Other factors, such as water content and ash content, also affect the calorific value of the waste. A thorough investigation of the average calorific value and the annual quantity is necessary in order to commence a comprehensive feasibility study. As these factors are highly dependent on socio-economic state and waste management system, data from countries alike can only be projected with a high degree of uncertainty. Table 2 shows waste generation rates for different regions.



Region	Waste generation per capita (kg/capita/day)		
	Lower Boundary	Upper Boundary	Average
Africa	0.09	3	0.65
East Asia and Pacific Region	0.44	4.3	0.95
Eastern and Central Asia	0.29	2.1	1.1
Latin America and the Caribbean	0.11	142	1.1
Middle East and North Africa	0.16	5.7	1.1
OECD	1.1	3.7	2.2
South Asia	0.12	5.1	0.45

**Table 2 Waste generation per region<sup>1</sup>**

Figure 1 shows the typical waste composition from four different income level countries.

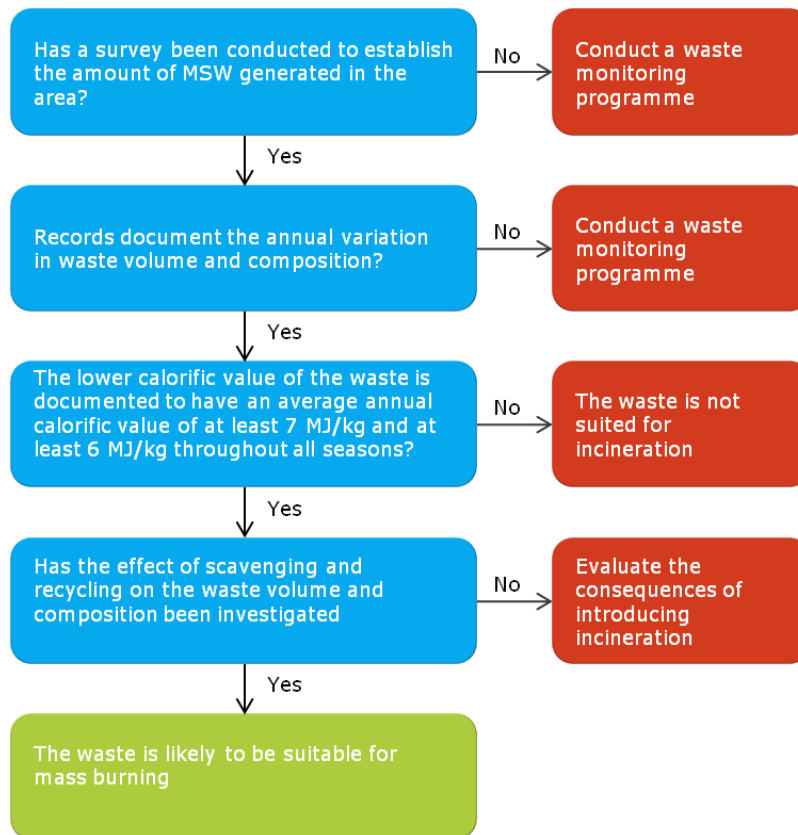


**Figure 1 - Typical waste composition for different income level countries<sup>2</sup>.**

<sup>1</sup> <http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/Chap3.pdf>

<sup>2</sup> <http://siteresources.worldbank.org/INTURBANDEVELOPMENT/Resources/336387-1334852610766/Chap5.pdf>

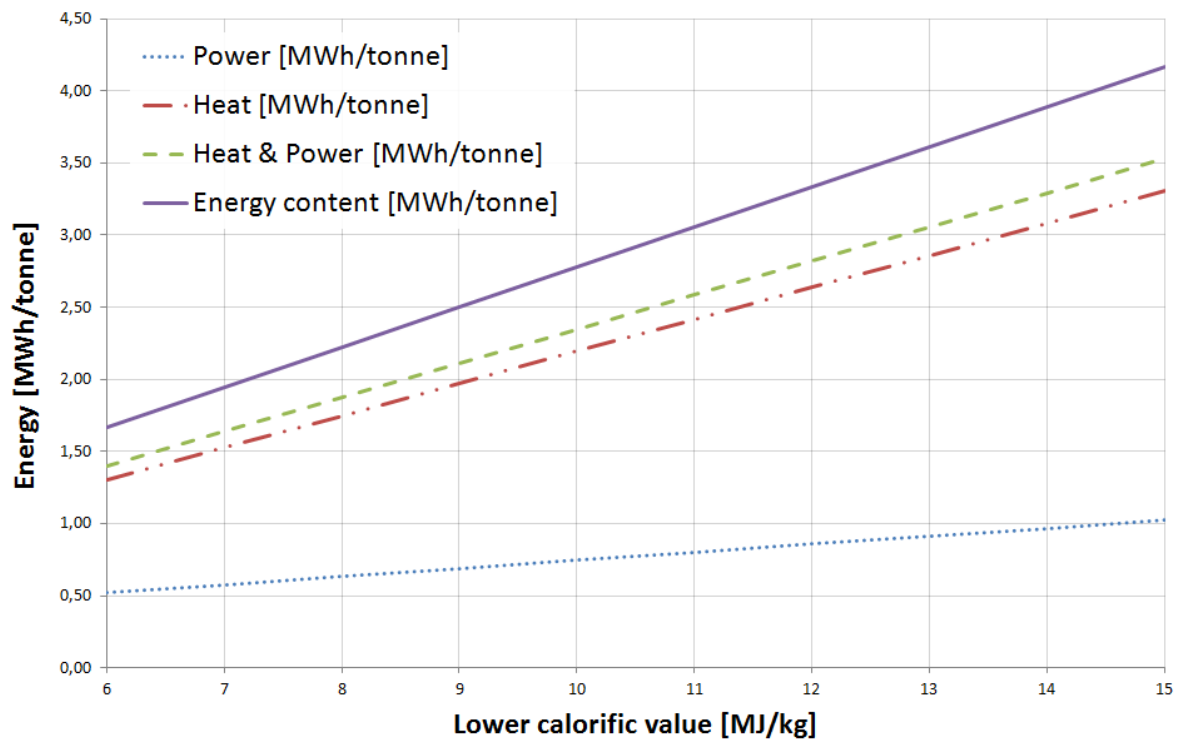
## Assessment of waste as fuel



**Figure 2 Assessment of waste as fuel**

The amount of energy which can be recovered from MSW incineration depends on the lower calorific value of the waste and the technology applied. In sole electricity production the thermal efficiency is highest, but the total efficiency lowest. The highest total efficiency is found when producing power and heat.

In general, electricity has a higher market value than heat. A combination of selling heat and power is therefore usually optimal. Please see Figure 3.

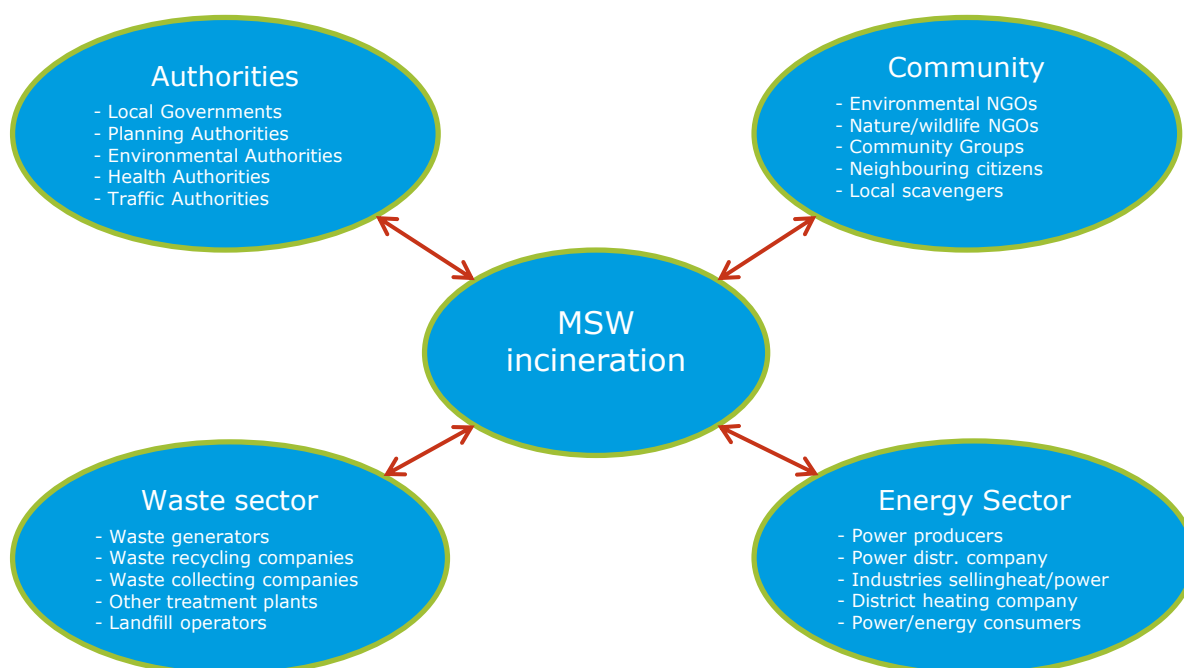


**Figure 3 Energy content and energy recovery potential of waste.**  
The actual results are also depended on plant design factors like steam parameters and plant size.

## 4. STAKEHOLDERS IN WTE PROJECTS

Multiple stakeholders should be considered when planning and investigating the viability of MSW incineration as their interests and attitudes regarding waste incineration may not be fully aligned.

Successful establishment of an MSW incineration facility is also highly dependent on the laws, regulations and procedures implemented in the country in question.



**Figure 4 Stakeholders to be considered when planning and assessing the viability of MSW incineration**

The waste incineration facility can in principle be initiated by different sectors; e.g. the waste sector or the energy sector. In both cases the WtE facility can be in public or private ownership or it can be a mix of public and private equity.

In any case it is important that the incineration facility is an integrated part of the waste management system and that binding long term agreements regarding the tipping fees, the supply of waste and the sale of energy exist. The nature of these agreements varies depending on the organisational set-up.

### 4.1 Waste sector

As stated it is of crucial importance that a controlled and well managed waste management system exists when considering MSW incineration. People working with waste collection, transportation, sorting and recycling seek to maximise their profits, whereas waste generators wish to dispose of their waste in the easiest and cheapest possible way. When investigating the viability of MSW incineration it is important that regulations and enforcement exist such that non-recyclables are disposed of at landfills. Having an established system where all non-recyclables are actually disposed of at controlled locations makes the transition to MSW incineration more realistic as the waste sector can be assumed to provide a reliable supply of waste to a new facility. Control of the flow of MSW, and Industrial Solid Waste (ISW) if this is part of the design volume, is important as optimal operation of an MSW incineration plant rely on a continuous supply of waste with relatively small variations in calorific value.

The above-mentioned requirements are in general fulfilled in mature solid waste management systems. Collection, transportation and disposal may be handled by different organisations but the system as such is normally under public financial and budgetary control, and the cost for MSW is thus ultimately covered by the waste generators through payment of taxes and tariffs



The cost depends on the capital expenditures and the cost for operation and maintenance and the tipping fee income of the plant. The income depends on the sale and unit price for sale of the energy recovered. The energy of the waste can be recovered as electricity and/or steam or hot water which can be sold to the community or nearby industries. The income has an influence of the economy of the plant and an important factor in determining the resulting tipping fee and hereby examining the viability. Figure 5 shows a flow chart to determine whether or not the present waste management system is suitable for MSW incineration.

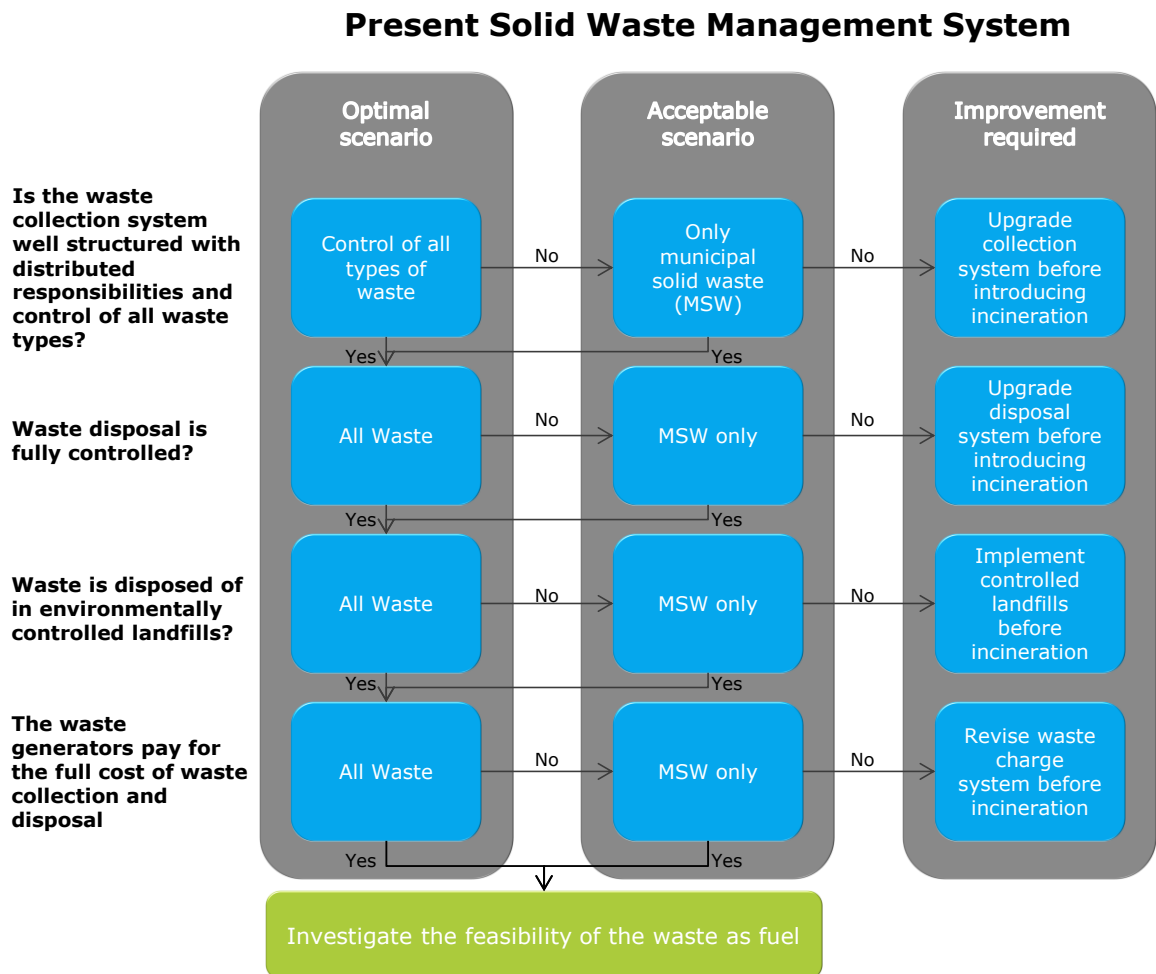


Figure 5 Evaluation of the present MSW management systems readiness for incineration

## 4.2 Energy sector

MSW incineration is expensive compared to disposal at controlled landfills. The possibility of selling the energy produced is therefore of vital importance, in order to keep tipping fees as low as possible. The energy produced can be converted into electricity, sold as low grade steam for industrial processes or utilised for district heating (only relevant in cold climates) or for cooling purposes or a combination of the above. The prospects of energy sale must be considered in a long term perspective when planning the establishment of an MSW incineration facility.

Sale of steam for industrial purposes or district heating allows for somewhat simple plant configurations, but requires contracts and guarantees from the off-taker. The combination of power and heat increases the complexity of the plant and the necessary capital investment but increases the income from sale of energy. The overall energy recovered in MSW incineration plants are typically in the order of 80-90% for combined heat and power plants and in the order of 20-25% for only power producing plants.

The energy sector may in some countries be regulated by taxation or subsidising specific energy technologies like renewable energy. WtE is in many cases part of this. The influence by increasing or decreasing taxation and subsidies needs to be carefully studied, however, it has to be taken into consideration that taxation and subsidies may be cancelled relatively sudden and so the financing of the facility should not depend too much on such subsidies but needs to be viable without.

Early co-operation between the energy off-takers and the MSW incineration organisation is favourable, as the viability of the plant highly depends on the energy sale. Most often the produced energy is sold to one single consumer such as a utility company that distribute the energy for resale.

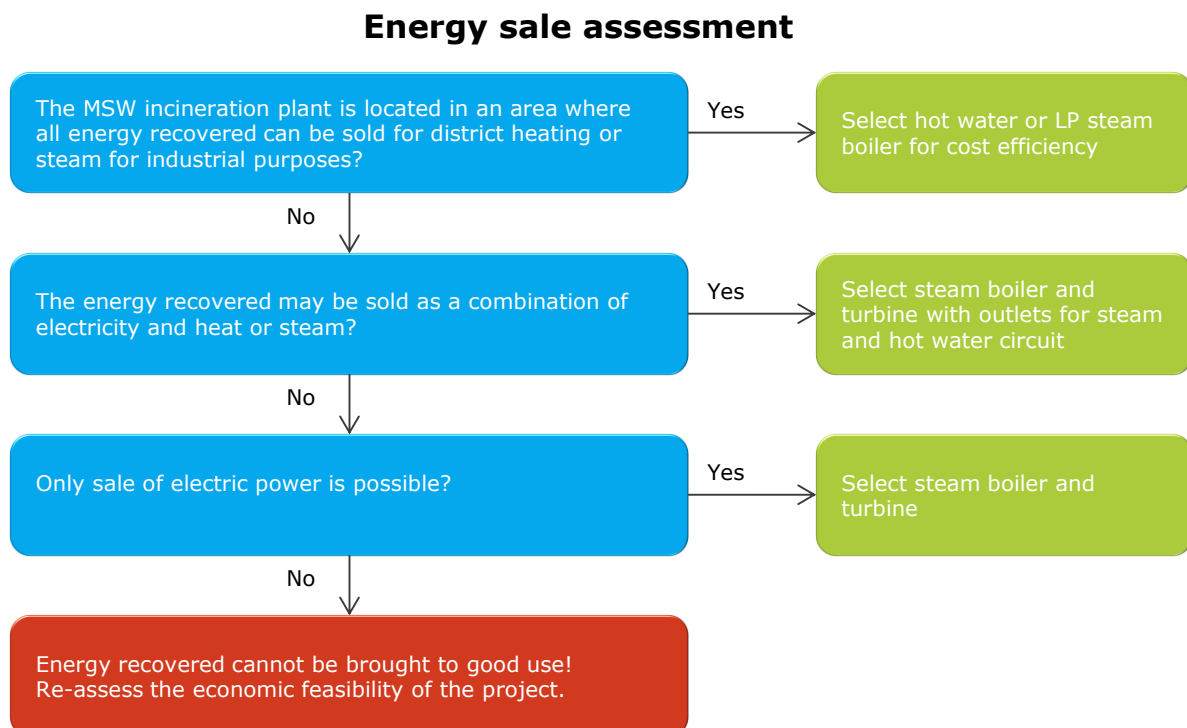


Figure 6 Assessment of the potential sale of recovered energy

## 4.3 The community

A modern WTE facility is equipped with advanced combustion control system as well as the flue gas treatment technology which reduces the pollutants from the waste to very low levels so that

it does not put any negative environmental or health implications to the community living nearby the facility.

Still, it is of utmost importance to ensure an open information programme with the community, NGOs or other groups that might have an interest in the WtE facility. Early initiated awareness campaigns and detailed dialogs regarding the environmental impacts and concerns that different groups may have will ease the implementation process. In many countries such dialogue is required as part of the environmental impact assessment programme. However, if this is not requested it is still recommended to run an information and awareness campaign.

The location of the WtE facility might be close to living areas and is a relative large building that might change the local landscape. In addition, the waste traffic might have an influence on the local infrastructure. All these need to be communicated to the local community.

The information campaigns need to be open, honest and presented in a laymen's language to be understandable to everyone.

Local opposition is in some countries strong and has been an obstacle for implementation of WtE facilities or have at least postponed the implementation of such plants. The experience from these countries shows that it is often efficient to appoint a local representative to participate in a reference group. Often the local representatives are better in doing the communication to his support base. The representatives could comprise, neighbours, environmental NGOs, scavengers, etc.

#### **4.4 Authorities**

The environmental authorities must establish clear standards for emissions from WtE facilities as well as standards for the bottom ash and the flue gas cleaning residues. If no local standards exist for WtE the standards implemented in the European Union or in the US could be a good basis as these are comprehensive and based on several years of studies. At the same time these standards are among the most stringent requirements to waste incineration facilities and it is the suggestion of ISWA that the users of this guide seek to meet these standards to ensure a high environmental standard of new WtE facilities.

As part of the environmental approval procedure the health authority might be relevant to be involved in order to ensure that the necessary health aspects are considered in the environmental impact assessment process.

In addition to the environmental permitting procedure also the local planning procedures need to be carefully considered to address all regulatory requirements set by the planning authority and the traffic authority. The location and the actual layout of the facility has to fulfil the planning authority's requirements on the distance to living areas and nature protection areas, requested green areas surrounding the plant, building height, noise level, etc.

## 5. ORGANISATIONAL OPTIONS

This section gives an overview of possible organisational options which exists for the introduction of WtE. Considerations regarding the organisational setup must be made as it affects location, ownership, financing, design/construction and operation. Each option has a number of advantages and disadvantages. An organisational options diagram can be seen in Figure 7.

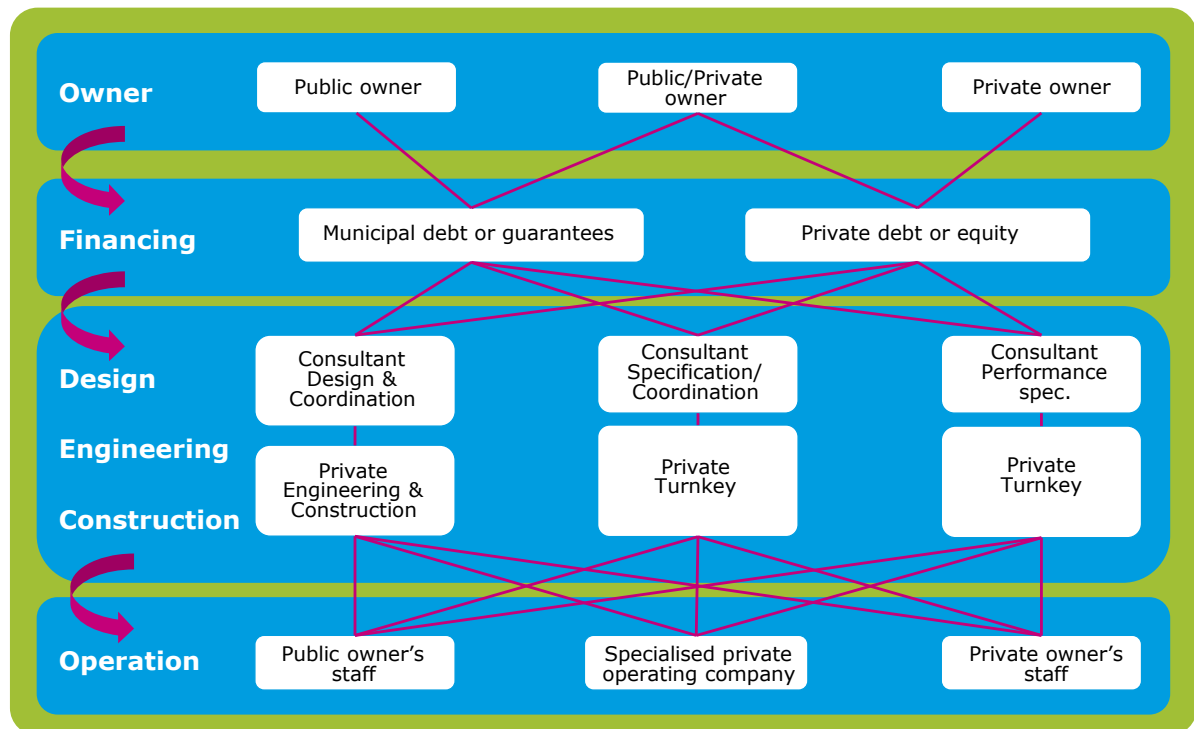


Figure 7 Organizational Options and Decisions Diagram

A wide range of options exists, ranging from completely public to fully private responsibility for ownership, funding, establishment, and operation.

The first decision to be made is the location of the plant. Considerations such as existing transportation possibilities, point of waste generation and energy consumers are key factors when defining the location of the facility.

### Ownership

Public ownership may – if the relevant public authority has a good credit rating - give access to low cost credit and international financing guaranteed by the government or the local authority.

A facility under direct public ownership, however, is likely to be subject to an annual public budgeting process which may result in lack of availability of resources for operation or maintenance. Direct public involvement in day-to-day operations can also be a disadvantage.

What is commonly used as an alternative to direct public ownership is a setup where a public owned institution is established and governed by overall rules given by the government or the local authority but with own budgetary responsibility. Along with the possibility of low cost project financing, a potential exists for easy execution of contracts with other public companies, e.g. electrical and district heating utilities.

Private sector ownerships may take over some of the risks in the project from the public sector and the private sector may be able to achieve some efficiency gains. However, the costs of private sector financing are normally higher compared to that available to the public sector.



Ownership can either remain with the private sector or it can be agreed that the private investor is to revert the facility to the public sector after an agreed term.

Finally the ownership can be a mix of public and private ownership.

### **Financing**

Financing of the WtE project depends on the chosen form of ownership. Publicly owned facilities may have the advantage of obtaining low cost financing against public sector guarantees - potentially through international financing institutions or in some cases by municipal bonds.

Privately owned facilities will not have the benefit of public sector funding/guarantees and therefore rely solely on the cash-flow of the project to cover the financing. The consequence of this is that funders in general want to have all risks contractually addressed in long term contracts for waste delivery and for the sale of energy. To achieve this is a complicated process and the mobilisation of private funding for WtE facilities is generally complex and time consuming.

In any case tipping fees (or agreed public budgetary transfers) and income from the sale of energy must be able to cover the cost of operation and maintenance as well as the financing cost of the facility with a reasonable margin.

### **Procurement, design and construction**

Both a public and private owner will need to carefully consider how best to procure, design and construct the facility. Three basic options exist as depicted in Figure 7.

The project can be designed and coordinated by a consultant hired by the owner of the facility. The approach is often referred to as EPCM (Engineering Procurement Contract Management). Under this approach the facility is procured via multiple packages, i.e. building package, thermal conversion package (incinerator and boiler), flue gas cleaning package and energy recovery package. The detailed engineering to fit the overall design set by the consultant is then carried out by the chosen contractors. This process ensures comprehensive control over quality and process via detailed specifications and the approach tends to be slightly cheaper than a turn-key project. The key challenge using this method lies in integration of different components and the risk of coordination is at the owner.

As an alternative the facility can be procured using a turnkey or an EPC (Engineering Procurement Contracting) contract. In such contract one single contractor takes the responsibility for the design and delivery of the facility. The turnkey contract can in principle be procured either using a comprehensive set of design specifications or based only on performance specification.

If choosing a turnkey with comprehensive design specifications, the consultant designs the plant to certain specifications. The consultant, acting on behalf of the owner, specifies the desired technology, e.g. a plant with moving grate incinerator, flue gas cleaning system etc. This approach ensures that the facility will meet a range of minimum requirements. A single contractor then takes responsibility of integrating the different components. Not all technology providers are willing or capable to take the EPC responsibility and there might be a risk that this approach might limit competition. The owner's influence on the detailed engineering process might also be limited as some requirements are difficult to be decided at the very beginning of a project.

When choosing a turnkey based on only performance specifications, the tendering process is relatively simple as very few performance specifications are made by the consultant. Performance specifications such as electricity output per tonne of waste and emissions meeting the environmental requirements are relevant. The disadvantage of this approach is that the owner has minimal control over the quality and performance of the construction.

**Operation**

Public operation of a new public owned facility will generally require the engagement of new and appropriately skilled staff which will need to be trained in plant operation and maintenance by the supplier of the facility. It is important for the success of public operation that key staff can be retained and hence that they should be given salaries which are appropriate for the type of function. The training of the operation staff is in this case normally an integrated part of the contract. One of the advantages by public ownership and public operation is a short link between the decision makers and the operation, which eases long term perspective optimisation due to changes in waste characteristics and the implementation of energy strategy or price setting.

Operation can also, independent of ownership, be carried out by a private operator. The operating firm then has the responsibility for provision and training of the required staff. Often private operation companies operate more facilities and hereby benefitting from existing operational experience. Competition among operators may increase efficiency, for example by optimising the staff between the plants. Disadvantages of private operation of public owned facilities may include less focus on the long term perspective and the state of the facility at the end of the operating contract. It is recommended to put great effort in defining the state of the plant at the end of the contract period.

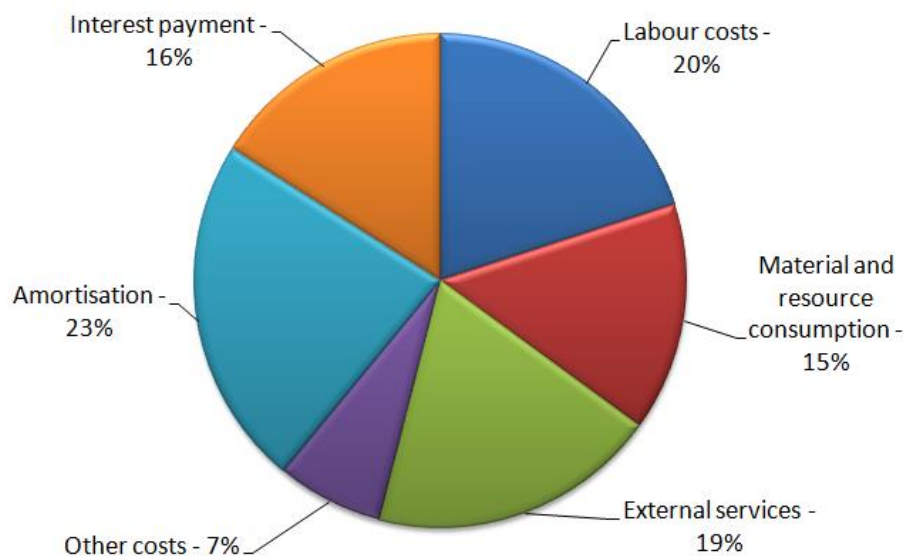
Both types of operation have successfully been implemented in several countries and there is no preference for the one or the other. It is very important to carefully evaluate the advantages and disadvantages in order to determine the most suitable organisational solution for the project. The best solution has to be seen in relation to the complete waste management system and who is in charge of the waste supply. And it shall be related to how similar infrastructural installations are typically operated in the specific country/region in question.

## 6. ECONOMICS AND FINANCE

As mentioned in section 0, access to foreign currency is a necessity as only a limited number of manufacturers of WtE technology exists on the global market. In addition to the capital expenditures, foreign currency should also be accessible during operation to acquire spare parts and especially skilled maintenance workers. The cost of implementing a WtE facility is high, as are the operating costs. On the total treatment cost income from sale of energy has to be taken into account.

The actual capital investment for a new WtE facility has to be based on an actual budget for the specific plant and comparison between plants are difficult as many factors will influence the cost. By collecting information from ISWA's members, investment cost have in general been seen in the magnitude of 300-500 USD/yearly tonnage capacity in low income countries with a low calorific value, a low need for structural protection of the equipment and a general low labour cost. For middle income countries with some requirements for structural protection of the plant, with slightly higher calorific value and higher labour cost, a typical capital cost per yearly tonne capacity is found to be around 400-600 USD. This should be compared to an investment cost typically in the range of 600-900 USD or even higher per yearly tonne capacity in European countries and in North America. The higher cost is mainly due to more stringent demands to the equipment and to the building. Often the buildings are requested to have a high architectural standard to become outstanding icons for the city.

A typical distribution of costs is shown in Figure 8. Local differences may occur and it is important that the cost calculation is done for the specific projects and based on the local cost level for both labour costs, consumables and for equipment.



**Figure 8 Typical distribution of waste incineration costs**

Due to the economy of scale it is in general more financially viable to build large WtE units. Mass burn units are in general built with a capacity from approx. 3 t/h up to approx. 40 t/h. For power producing facilities the minimum capacity should be approx. 10 tonnes of waste throughput per hour to make the investment in the turbine/generator equipment financially viable, however the breakeven shall be based on the actual income for sale of electricity and the cost for the equipment in the country in question. If the hourly capacity exceeds the maximum capacity for one unit or if there is a particular need to have more lines to ensure treatment of waste also in the period where the WtE unit is off for the yearly maintenance more units shall be established.

An additional factor to capital expenditure is the desired form of energy output. Utilising heat only (steam for industry or district heating), has a high degree of total efficiency and the least degree of complexity. Generating power requires the need for a steam cycle and makes the plant

much more complex. The most complex energy recovery system, but also the one with highest energy yield, is combined heat and power production. As the complexity of the plant increases, so do the capital expenditures and operating expenditures. However, it also results in higher income as energy recovery sale is one of the most important sources of revenue for the plant and may often pay for the higher investment.

Another important source of income is the disposal fee, commonly called "tipping fee". Usually, a disposal fee is also charged by landfills. The landfill tipping fee is usually cheaper compared to the tipping fee at the MSW incineration facility. This can be justified by MSW incineration being considered a long term sustainable solution. However, if the tipping fee is considerably higher than what is being charged at the landfills, waste producers may choose to seek alternative ways of disposing their waste, such as illegal dumping of waste. It is recommended to conduct a survey among the waste producers, determining the capability to pay increased disposal fees and if the gap between the actual cost and the capability to pay it is too large, it should be considered if the waste management system is sufficiently mature for setting up the WtE facility, or other incentives should be considered to direct the waste to the WtE. In some countries tax on waste to landfills has been an instrument to direct waste from landfill to energy recovery.

Alternatively, increased tipping fees can be partly or fully subsidised by the government/local municipality and thereby part of the state/city budget.

Other possible revenues for a WtE facility include carbon credits, from selling of recyclable ferrous and non-ferrous metals recovered from the bottom ash, and they can also come from ash used as construction material. A decision flow chart for the project economy can be seen in Figure 9.

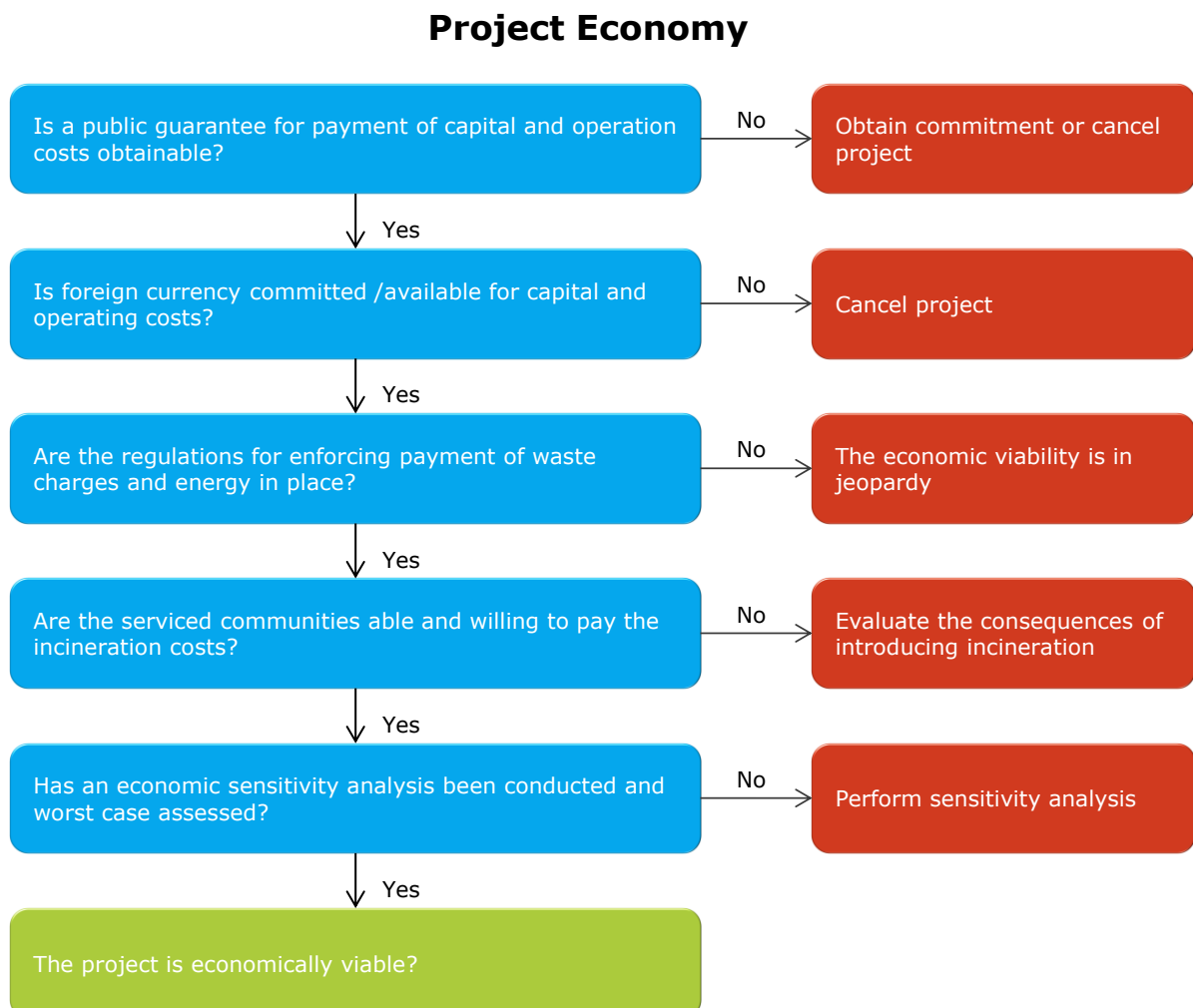


Figure 9 Assessment of project economy



## 7. PROJECT PHASES

The implementation of a new WtE facility has three main phases:

- Feasibility assessment phase
- Preparation phase
- Implementation phase

At the end of each phase, the project shall always be evaluated to ensure that all preconditions are still fulfilled.

### 7.1 Feasibility assessment phase

As project failure will be very costly, proper feasibility studies are required. It is suggested to conduct a preliminary study which is based on existing literature, data and experience from other projects. Following a positive outcome, a comprehensive feasibility study can commence. The comprehensive study should assess maturity of the waste management system, the waste supply and quality should be quantified and a detailed study of plant finance options shall be assessed. The desired technology plays an important role in the plant economics and also in the public's perception of the plant.

	PHASE + STEP	PURPOSE AND ISSUES TO CONSIDER	Duration
Feasibility Phase	Pre-feasibility study	Waste quantities, calorific values, capacity, siting, energy sale, organisation, costs and financing.	¼ year
	Political Decision	Decisions on further investigations or abort the project.	¼ year
	Feasibility study	Waste quantities, calorific values, capacity, siting, energy sale, organisation, costs and financing in detail.	½ year
	Political Decision	Decision on willingness, priority and financing of incineration plant and necessary organisations.	½ year
Project Preparation Phase	Establishment of an Organisation	Establishment of an official organisation and establishment of institutional support and framework.	¼ year
	Tender + Financial Engineering	Detailed financial engineering, negotiation of loans or other means of financing + selection of consultants.	¼ year
	Preparation of Tender Documents	Reassessment of project, specifications, pre-qualification of contractors and tender documents.	¼ year
	Political Decision	Decision on financial package, tender documents and procedures in detail and final go-ahead.	¼ year
Project Implementation Phase	Award of Contract & Negotiations	Pre-qualification of contractors. Tender documents. Select most competitive bid. Negotiate contract.	½ year
	Construction and Supervision	Construction by selected contractor and supervision by independent consultant	2 ½ years
	Commissioning + Start Up	Test of all performance specifications, settlements, commissioning, training of staff+ start up by constructor	½ year
	Operation + Maintenance	Continuous operation and maintenance of plant. Continuous procurement of spare parts and supplies	20+ years

Figure 10 A typical implementation plan

## **7.2 Preparation phase**

Early on in the preparation phase, the appropriate project organisation must be set up.

The project organisation is responsible for developing the necessary agreements between stakeholders in all aspects of erection, financing and operation. Such agreements include, but are not limited to, security of energy sale, disposal of residues, financing of plant and security of waste supply. It is also the project organisation's responsibility to carry out the necessary environmental impact assessment.

The preparation phase requires a wide variety of expertise. Therefore, independent experts with suitable experience and references from former projects within waste incineration should be hired. They should carry out the design of the facility, prepare the necessary tender documents and assist in negotiation with the winning tender(s).

## **7.3 Implementation phase**

The final institutional affiliation plays an important role in regard to project implementation. A publicly owned and operated plant must not only monitor progress and ensure the contractor's fulfilment of contractual agreements, but also recruit skilled staff and ensure proper training prior to commissioning of the facility. Training of staff can often be included in the supplier's contract.

## **7.4 Public involvement**

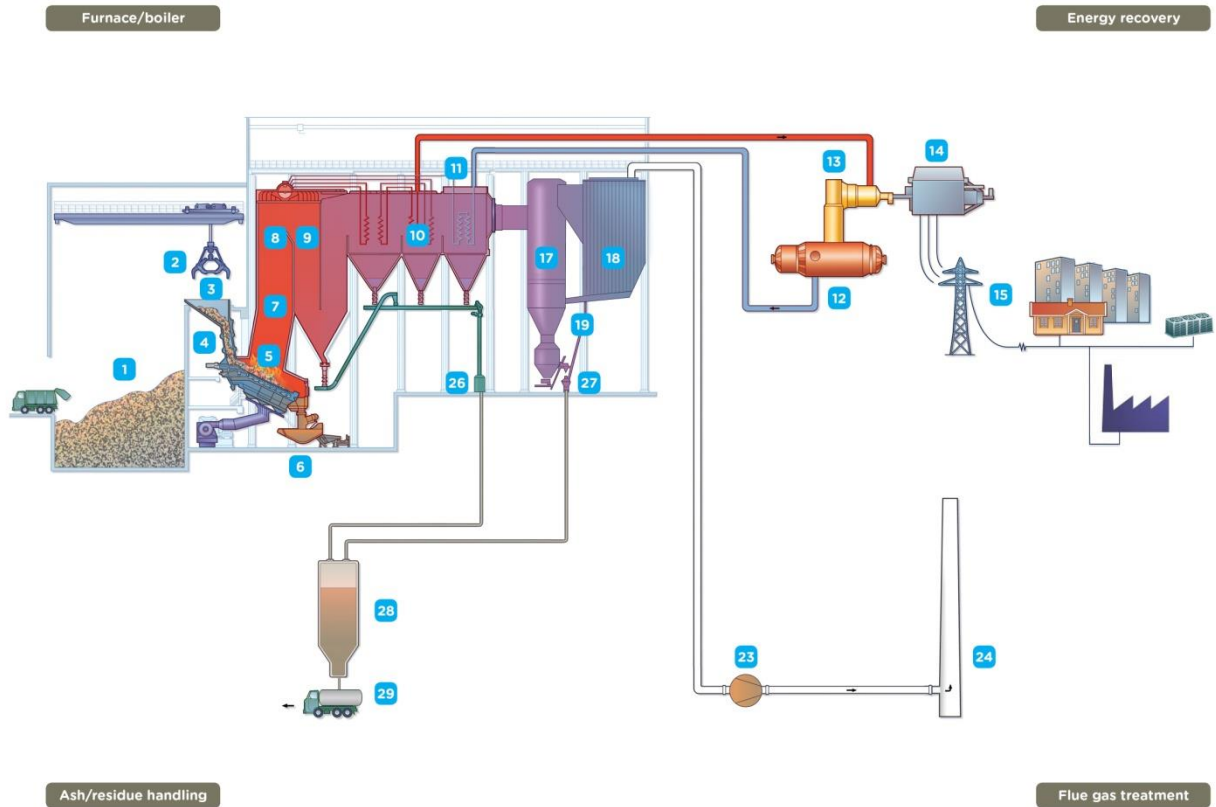
Involving the public throughout the entire project cycle is important for a positive perception and to some degree the success of the plant. When introducing a new technology, education of the public is necessary through public awareness campaigns. Major decisions which may impact the local community in any way should be dealt with in collaboration with the public as mentioned in chapter 3.

However, involvement of the public throughout the entire lifetime of the facility is of utmost importance and is in many countries used for awareness raising especially among the younger generation. Often, education centres are established at the WtE facility and school children can visit the plant and learn about sustainable waste management.

## 8. INCINERATION TECHNOLOGY

This section serves as an overview of the typical processes in modern waste to energy (WtE) facilities. MSW is received without pre-treatment, such as mechanical fine sorting or chemical treatment.

Figure 11 shows a cross-section of a WtE facility with a semi-dry flue gas treatment system.



**Figure 11 Cross-section of a dry/semi-dry WtE facility (Power production only).**

### Legend:

#### Furnace/boiler:

1. Bunker 2. Waste Crane 3. Hopper/feed chute 4. Feeder ram 5. Grate 6. Bottom ash discharger 7. Furnace 8. Afterburning chamber 9. Radiation part 10. Convection part 11. Economiser

#### Energy recovery:

12. Condenser 13. Turbine 14. Generator 15. Electrical output

#### Flue gas treatment:

17. Reactor for acid gas absorption 18. Bag house filter 19. Residue recirculation 23. ID fan 24. Stack

#### Ash/residue handling:

26. Boiler ash conveying system 27. Flue gas cleaning residue transport system 28. Ash/residue silo 29. Ash/residue discharge.

The chapter is divided into subsections, each describing concepts and major components of a WtE facility following the flow of the process.

### 8.1 Furnace/boiler

The tipping hall is where the MSW is unloaded from collecting trucks. In order to determine the amount of waste delivered, a weighing station is installed prior to the tipping hall. To avoid unpleasant odours to the local community, the tipping hall and building shall be kept at pressure slightly under atmospheric conditions.

**Waste bunker**

The size of the bunker depends on the planned capacity of the plant. The bunker should be able to hold about a week of MSW in order for the plant to cope with maintenance, or any other halt in operation.

**Waste feeding**

The waste crane serves multiple purposes. Firstly, it can pick up waste that is too large to enter the waste feeder directly such as a large mattress.

Secondly, it mixes the incoming waste to ensure the waste fed to the combustion unit is as uniform as possible as it gives the most stable combustion and hereby the highest energy efficiency.

Lastly, the crane distributes the waste evenly in the waste hopper. The waste is led to the combustion zone through a chute which also functions as an air seal to avoid uncontrolled air leaks to the combustion chamber. Generally, the chute shall be designed to handle objects with a length of up to 1 meter.

**Grate**

The grate serves two purposes:

- Transportation, agitation, stirring, mixing, distribution and levelling of the waste on the grate
- Distribution of primary combustion air to the waste layer





Various grate designs and makes are available, usually characterised by their respective principles of movement. These principles include an inclined or horizontal grate with forward or backwards moving grate sections.

The average residence time of the waste on the grate is about one hour.

### **Furnace**

The furnace, where primary combustion occurs, is cooled by water walls with steam later used for energy recovery. The steam runs through gas-tight membrane tube walls forming the walls and ceiling of the furnace. This part of the furnace must be highly resistant to corrosion as the very high temperature of the flue gas makes acidic and alkaline components extremely aggressive.

Through an arrangement of nozzles above the waste, secondary air is supplied to complete the reactions of combustion. An additional function of supplying secondary air is to mix the combustion gasses and ensure a uniform temperature of the flue gas.

Typically, 40% of the total combustion air is supplied as secondary air and 60% as primary air.

The furnace shall be equipped with at least two auxiliary burners to be used during start-up and shut-down of the plant and for maintaining the temperature should sudden temperature drops occur.

The combination of high temperature and alkaline in the flue gas makes the flue gas aggressive. The tube walls of the furnace and the boiler tubes must therefore be coated with the corrosive and temperature resistant alloy Inconel, or with a refractory lining to avoid direct contact between the flue gas and the boiler tubes. Typically the corrosion protection must be applied until a point in the boiler where the flue gas temperature is approx. 850-900°.

### **Boiler**

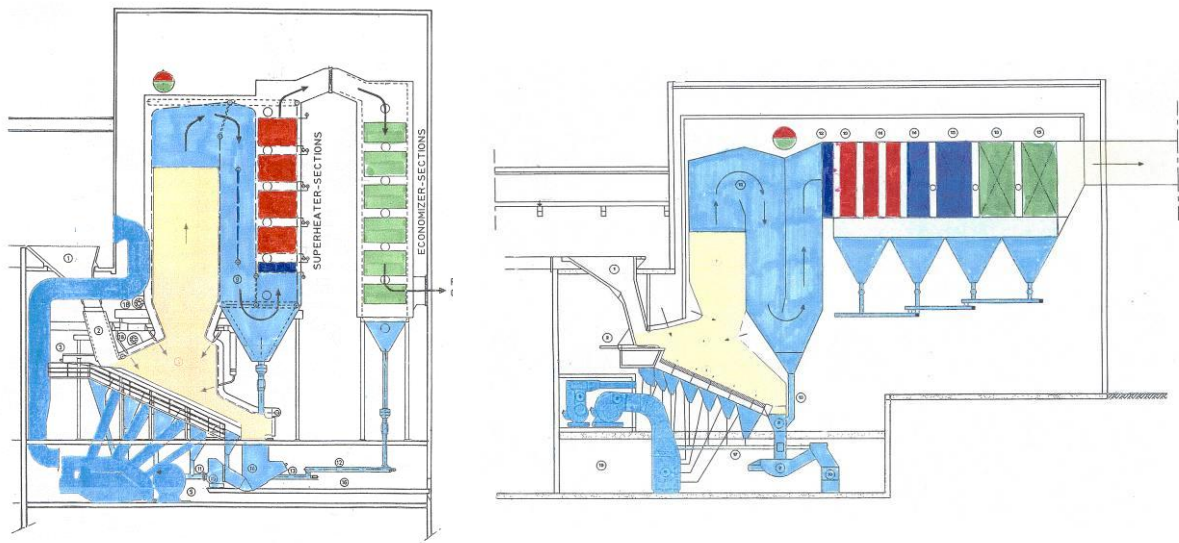
The overall efficiency of the boiler is highly dependent on the temperature and the pressure of the steam. Optimal steam parameters depend on a balance of two adverse design criteria:

- The higher the temperature and pressure the more electricity production
- The higher the temperature and pressure the higher risk of corrosion and thus increase in maintenance costs.

Most WtE facilities operate with a steam pressure between 40-60 bar and a steam temperature between 400-425 C.

Principally two basic boiler designs exist, vertical and horizontal design. The vertical boiler design has vertical passes in both the radiation and the convection part (incl. the economizer). The horizontal boiler design has vertical radiation passes followed by a horizontal convection pass with pre-evaporator, super heater, evaporator and economizer sections.

The different solutions are illustrated in Figure 12 and (left) and Figure 13



**Figure 12 Vertical boiler design (left) and Figure 13 Horizontal boiler design (right)**

The horizontal boiler requires more space than the vertical solution and is slightly more expensive than the vertical boiler solution. Horizontal boiler design has the advantage of possibility of mechanical cleaning, where the super heater tubes are cleaned by a rapping device to remove the ash deposit. The vertical boiler design uses soot blowing for cleaning. This process consumes steam and is sensitive for local wear from the soot blowers.

The height of the boiler is independent of boiler configuration as it for both solutions is important to keep a high first pass to ensure the flue gas temperature is reduced before the flue gas turns into the second draft.

## 8.2 Energy recovery

Energy can be recovered to produce power and/or steam. The choice of energy recovery system depends on the local energy infrastructure, the end-use consumption of the region and prices of energy alternatives.

For combined heat and power plants, one tonne of waste with a lower calorific value of 10 MJ/kg can be converted to approximately 2 MWh heat and 2/3 MWh electricity. Please see Figure 14.

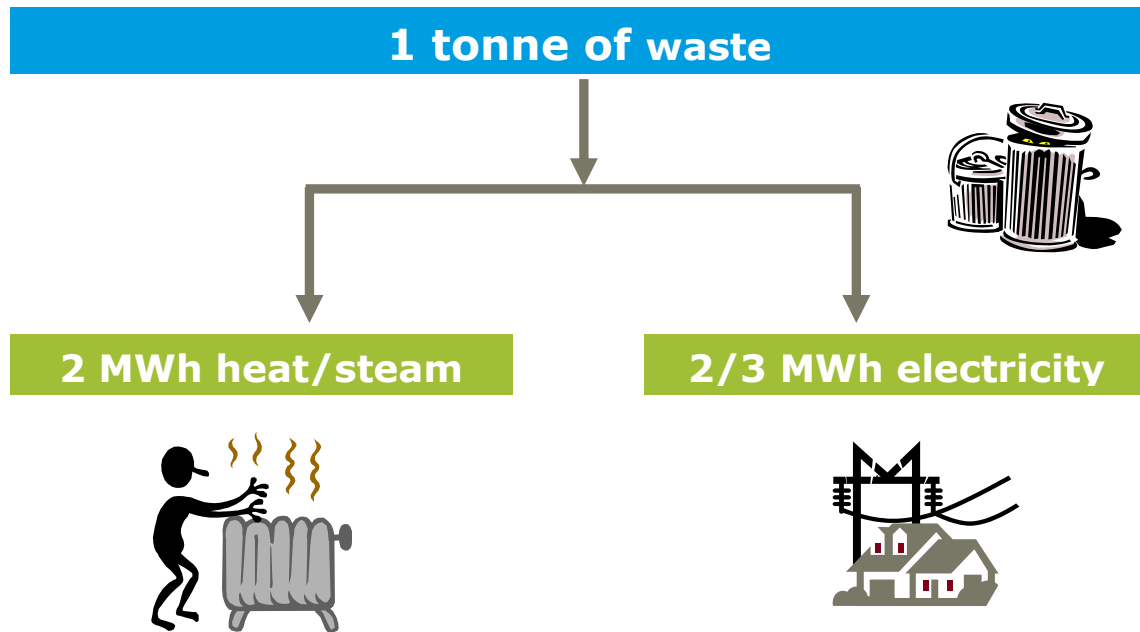


Figure 14 Energy recovery from one tonne of MSW with a lower calorific value of 10 MJ/kg

If only electricity is produced, the energy output can be expected to rise to approximately 0.70-0.75 MWh per tonne of waste with a lower calorific value of 10 MJ/kg.

The energy production per tonne of waste varies proportionally with the calorific value. Please see Figure 3.

### 8.3 Flue gas treatment

Flue gas contains the pollutants from the waste and requires treatment before being emitted to the atmosphere.

Various treatment methods exist – from the dry solutions to the more complicated wet solutions.

Principally all processes are based on a reaction between lime injected in a reactor and the acidic components in the flue gas converting them to solid compounds. These compounds are removed – together with the dust (fly ash) – in a downstream bag house filter. By adding activated carbon between the reactor and the bag-house filter it is possible also to remove dioxins and mercury (Hg).

All combustion processes produce NO<sub>x</sub>. The amounts are affected by temperature and molecular composition of the air supply. Partly, the NO<sub>x</sub> content can be controlled by the control of the combustion process, however in order to fulfil the requirements in Table 3, active NO<sub>x</sub> removal is necessary.

The two most common systems are SNCR (selective non-catalytic reduction) and SCR (selective catalytic reduction). Both systems reduce NO<sub>x</sub> to N<sub>2</sub> by supplying ammonia to the raw flue gas.

In the SNCR process, ammonia is injected into the raw flue gas in the furnace at a location where the temperature is around 850-900°C.

In the SCR process, the reaction between ammonia and the flue gas occurs on a catalytic surface normally situated downstream of the APC. SCR is normally used only for plants which are under tight NO<sub>x</sub> regulatory limits or if a financial incentive to reduce NO<sub>x</sub> emissions exists.

### Emission standards

Table 3 shows the European limits and the BAT (Best Available Techniques) operational levels for flue gas emissions from WtE facilities measured in half hour and daily average.

	<b>Half hour average in mg/Nm<sup>3</sup></b>		<b>Daily average in mg/Nm<sup>3</sup></b>	
	Limits 2000/76/EC	in BAT	Limits 2000/76/EC	in Bat
Total dust	20	1-20	10	1-5
Hydrogen Chloride (HCl)	60	1-50	10	1-8
Hydrogen Fluoride (HF)	4	<2	1	<1
Sulphur dioxide (SO <sub>2</sub> )	200	1-150	50	1-40
NO <sub>x</sub> using SNCR	400	30-350	200	120-180
Gaseous and vaporous organic substances, expressed as TOC	20	1- 20	10	1-10
Carbon monoxide (CO)	100	5-100	50	5-30
Mercury and its compounds (as Hg)	n/a	0,001-0,03	0,05	0,001-0,02
Total cadmium and thallium	n/a	0,005-0,05 <sup>1)</sup>	0,05	0,005-0,05 <sup>1)</sup>
Sum of other metals	n/a	0,005-0,5 <sup>1)</sup>	0,5	0,005-0,5 <sup>1)</sup>
Dioxins and Furans (in ng TEQ/Nm <sup>3</sup> )	n/a	0,01-0,1 <sup>1)</sup>	0,1	0,01-0,1 <sup>1)</sup>
Ammonia	n/a	1-10	n/a	<10

<sup>1)</sup> from Non-continuous samples

**Table 3 European flue gas emission limit values (ELV) and BAT operational levels.**

#### 8.4 Ash/residue handling

The volume of the MSW after combustion is reduced to about 10% of its original volume and about 20% based on weight. This is a combination of bottom ash, fly ash and residues after the flue gas treatment process.

The bottom ash quality, i.e. remaining organic content, is measured in order to evaluate the combustion process and should be lower than 3%.

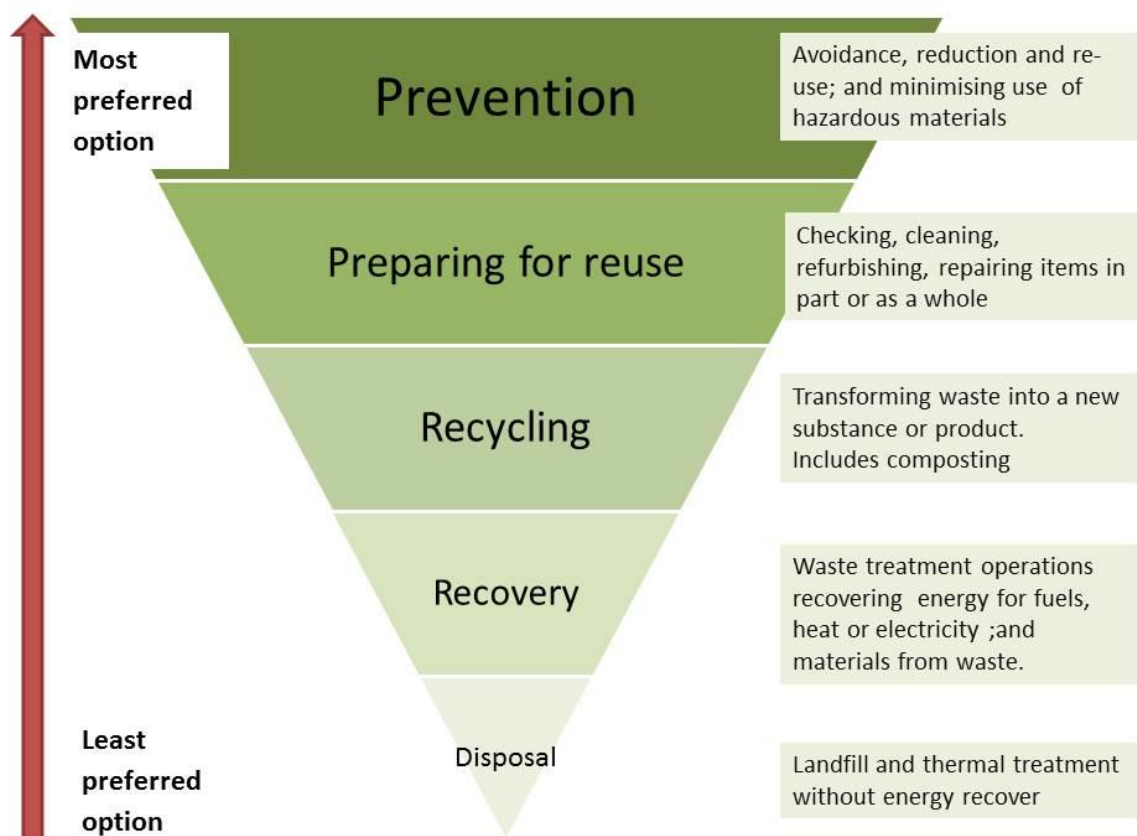
The bottom ash may be used in for construction purposes instead of gravels after metals are sorted out for recycling.

Fly ash and flue gas residues are considered hazardous waste and must be treated accordingly.

## 9. SUSTAINABILITY CONSIDERATIONS

As any other technology which involves decomposition of waste, pollutants are emitted into the atmosphere during MSW incineration.

Economic growth and population increase has worldwide led to an increase in the generation of MSW. Additionally, the increase in MSW can no longer be disposed of at landfills as the required area is too vast and results in emission of aggressive greenhouse gasses such as methane. Therefore, many nations have adopted a so-called "hierarchy of sustainable waste management" that places WtE plants above landfilling. Figure 15 below depicts the EU waste hierarchy.



**Figure 15 Hierarchy of sustainable waste management.**

A comprehensive study conducted by the International Energy Agency Bioenergy (IEA Bioenergy) in 2003 aimed to determine the positive and negative impacts of renewable energy technologies. One of the technologies in the study conducted was MSW incineration using mass burn combustion<sup>3</sup>. The study used a Life Cycle Assessment (LCA) approach, thus including emissions upstream as well as downstream.

The result of the study showed that the life cycle CO<sub>2</sub> emissions of MSW incineration were lower than more traditional technologies. Please see Table 4.

<sup>3</sup> Position paper available at [http://www.ieabioenergy.com/media/40\\_IEAPositionPaperMSW.pdf](http://www.ieabioenergy.com/media/40_IEAPositionPaperMSW.pdf)

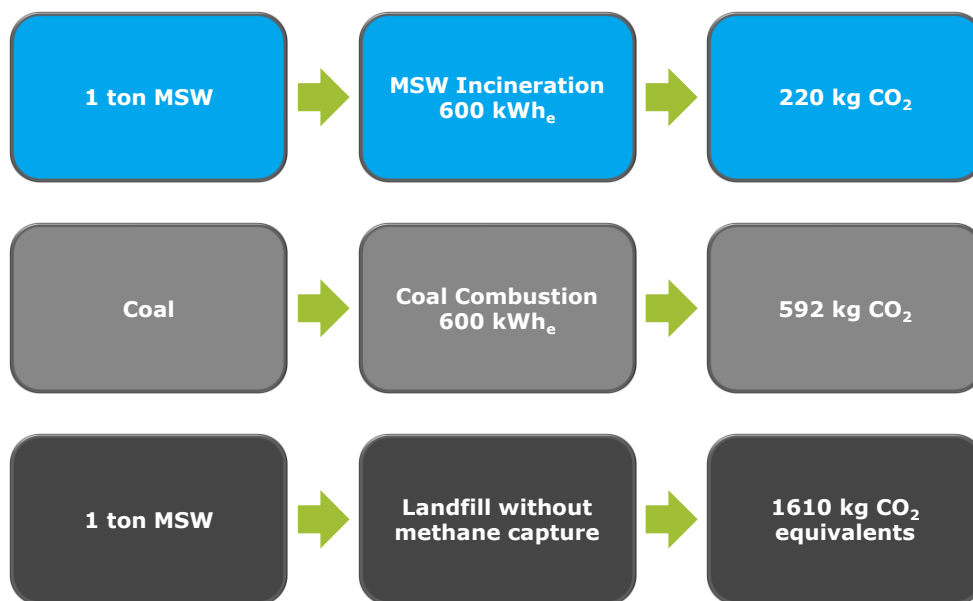


Life Cycle CO <sub>2</sub> emission [g/kWh <sub>e</sub> ]	
Coal	987
Gas	446
MSW	367

**Table 4 Life Cycle CO<sub>2</sub> emissions for every produced unit of electricity. IEA 2003**

It should be noted that most of the MSW combusted at WtE facilities derive from different resources. Some resources are carbon neutral when combusted, e.g. paper and cardboard. This applies since these resources are biogenic, thus meaning that the CO<sub>2</sub> emissions released during combustion amounts to that captured during the growth of the respective resource.

However, if the MSW is landfilled instead of combusted, methane is released into the atmosphere. Methane is a far more potent GHG contributing 23 times more to global warming than carbon dioxide. The CO<sub>2</sub> balance of MSW compared to a condensing coal power plant is shown in Figure 16, taking the alternative of landfilling into account.



**Net CO<sub>2</sub> reduction: 220-592-1610 = -1982 kg**

**Figure 16 Net CO<sub>2</sub> reduction of MSW incineration when replacing coal combustion. IEA 2003**

Clearly, MSW incineration is a solution far more sustainable than coal with regard to CO<sub>2</sub> emissions. This is mainly due to substitution of landfilling, but also because combustion of biogenic waste is carbon neutral. The degree of CO<sub>2</sub> emissions of MSW incineration highly depends on the waste composition and plant technology.

Local noticeable impacts from MSW incineration include traffic, noise, unpleasant odours and visual intrusion. These local impacts can, however, be minimised and are almost unnoticeable, if the design of infrastructure and operation is optimised.

Below is a list of symbols as well as a table showing conversion factors to common non-SI units.

## Abbreviations and symbols

cap	- capita	g	- gram
h	- hour	mg	- milligram ( $10^{-3}$ g)
t	- tonne (1000 kg)	ng	- nanogram ( $10^{-9}$ g)
d	- day	Nm <sup>3</sup>	- Normal cubic metre
GHG	- Greenhouse gas	L	- litre
APC	- Air Pollution Control	kWh <sub>e</sub>	- kilowatt hour of electricity
NGOs	- Non Governmental Organisations	MWh	- Megawatt hour (3600 MJ)
kg	- kilogram ( $10^3$ g)	TOC	- Total Organic Compound
		TEQ	- Toxic Equivalents

## Chemical abbreviations

2,3,7,8-TCDD - dioxin	2,3,7,8-Tetrachlorodibenzo-p-	Mo	- Molybdenum
As	- Arsenic	Na	- Sodium (Natrium)
Ca	- Calcium	Ni	- Nickel
Cd	- Cadmium	NO <sub>x</sub>	- Mono-nitrogen oxides
CH <sub>4</sub>	- Methane	Pb	- Lead (Plumbum)
Cl	- Chlorine	Sb	- Antimony (Stibium)
Co	- Cobalt	Se	- Selenium
CO	- Carbon monoxide	Sn	- Tin (Stannum)
CO <sub>2</sub>	- Carbon dioxide	SO <sub>2</sub>	- Sulphur dioxide
Cr	- Chromium	SO <sub>4</sub>	- Sulphate
Cu	- Copper	SO <sub>x</sub>	- Sulphur oxides
HCl	- Hydrochloric acid (in water)	Tl	- Thallium
HF	- Hydrofluoric acid (in water)	V	- Vanadium
Hg	- Mercury	Zn	- Zinc
K	- Potassium (Kalium)	IPA	- Iso Propyl Alcohol
Mn	- Manganese		

## Conversion factors to common non-SI units

1 kg	- 2.2 lbs	1 m <sup>3</sup>	- 35.3 cubic feet
1 Tonne	- 2204.6 lbs	1 MJ	- 947.8 Btu

10 MJ/kg lower calorific value waste is approximately equal to 5000 btu/lb higher heating value.

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