Inter-American Development Bank

GUIDEBOOK

FOR THE APPLICATION OF
WASTE TO ENERGY TECHNOLOGIES
IN LATIN AMERICA AND THE CARIBBEAN

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EXECUTIVE SUMMARY

Introduction and Scope

The economic development and growth of urban population in the Latin America and the Caribbean (LAC) region have resulted in the generation of an increasing amount of municipal solid waste (MSW) that is surpassing the existing capacity of sanitary landfills. This situation has led governments to evaluate alternative options, such as waste reduction, recycling, and waste-to-energy (WTE), in order to divert the waste stream from landfills.

WTE is a thermal treatment technology with energy recovery, and has become one of the preferred choices in most northern European Countries, Japan, in several cities in the US, and increasingly in China. However, the high investment and operational costs of this technology, and the lack of information and communication with the population regarding the environmental impacts of WTE, have precluded its development in LAC.

The objective of this document is to provide a Technical Guidance Note, aimed at providing basic technological, financial, and environmental information about WTE facilities. It is expected that this Guidance Note will enable policymakers and SWM services managers in LAC to make informed decisions about the feasibility of this treatment option for any specific case. This Guidebook is divided in two parts: Chapters 1 to 6 describe the general aspects of WTE technologies and project development; chapters 7 to 10 present several cases studies of WTE application in the LAC region.

Technical Aspects of WTE

There are several approaches and technologies to enhance solid waste treatment practices, which range from reducing the generation of waste by better design of products and packaging, to recycling usable materials, composting green wastes, and combustion with energy recovery. Globally, over 80% of the total urban post-recycling MSW is landfilled (about 1 billion tons per year), and only 20% of this waste is disposed in sanitary landfills.

Following the Hierarchy of Waste Management, several of the most developed nations have established the goal of reducing solid waste landfilling, by increasing waste prevention, recycling and energy recovery rates as feasible options for waste management.

Chapter 1 of this WTE examines the factors that determine the chemical energy stored in the various constituents of MSW. Plastics and other petrochemicals consist mostly of carbon and hydrogen, and therefore, have the highest energy content. They are followed by biogenic materials, such as paper, food, and green wastes that also consist of carbon and hydrogen, but also contain about 50% oxygen. These are followed by metals and other inorganic compounds that have no usable energy. The moisture content of the MSW absorbs heat during combustion, and therefore decreases its heating value.

Chapter 2 describes the combustion technologies that have been developed for recovering energy from MSW. Broadly, they involve the combustion of "as-received MSW" on a moving grate (“grate combustion”), shredding of MSW and combustion on a moving grate or in a fluidized bed, and the mechanical-biological treatment of MSW.

Chapter 3 describes processes that use partial combustion of the MSW to produce a synthetic gas (“gasification”), or heat petrochemical wastes in the absence of oxygen to produce a liquid fuel (“pyrolysis”).

Chapter 4 examines the current state of the global WTE industry, including the number and types of plants using the various WTE technologies. About 80% of the world's WTE capacity is based on technologies of “grate combustion” and this includes the WTE plants that has been built worldwide in the past decade. This is mainly because of the simplicity of operation, high plant availability (e.g., for the number of hours at full operation per year -some providers of grate combustion furnaces guarantee over 8,000 hours/year), and the relatively low personnel requirements.

Environmental and Economic Aspects of WTE

Chapter 5 concentrates on the dominant WTE technology, i.e. combustion on a moving grate. The chapter provides detailed information on the operation of a WTE plant, the typical material and energy balance, the energy recovered per ton of MSW, the environmental controls (air pollution control systems used and the resulting emissions), and the management of the bottom ash and fly ash produced during the combustion process.

Chapter 5 also discusses the projected capital, operating costs, revenues and the land requirements for such plants. Additionally, it describes how to implement WTE in a municipality, including: the procedure to be followed for inviting providers of WTE technologies to bid on a new project, the stakeholders who are involved in this process, and other information to guide officials who are considering to build a new WTE facility.

Chapter 6 presents the conclusions drawn from developing this Guidebook.

Case Studies

On the basis of some hypothetical assumptions, Chapters 7 to 9 evaluate the feasibility of some specific WTE projects in three LAC cities: Valparaiso (Chile), Toluca (Mexico) and Buenos Aires (Argentina). The cities have been chosen taking into account: (i) economies of scale (considering that the cost per ton of thermal treatment decreases appreciably with plant size), and (ii) the economic capacity of these cities (considering the high investment and operational costs of this type of technology). The technology selected for the three cases is "grate combustion" because it is the most widely proven WTE technology.

The case studies show what information must be developed in order to build such a plant, including quality and quantity of MSW, the current and projected status of the MSW management system; the projected capital and operating costs, the projected sources of revenue, and calculations of the net present value (NPV) and internal rate of return (IRR).

The main conclusion from these case studies is that considering the gate fees for landfilling in Latin America, usually the WTE alternative will only be economically feasible if government support is provided. For example, for the WTE project in Chile to break-even after 20 years operation and at a 5% IRR, the required gate fee would be of 38 US$/tn. Additionally, it is concluded that to have an affordable gate fee for the WTE project, it is necessary to have a very high plant availability. This is connected to the quality and quantity of the MSW provided to the plant, i.e. the WTE solution must consider the collection and transportation rates and the robustness of the overall solid waste management system.

Chapter 10 examines the application of WTE in island settings, by describing three existing plants in the Caribbean islands and the North Atlantic.

Decision Making Process

This Technical Note proposes that national governments place the sustainable waste management high up in their essential infrastructure projects priority list, similarly to what has been done in the past with potable water, electricity and wastewater treatment infrastructure. Specifically for the WTE alternative, a short and long term analysis of its impact on the solid waste management system should consider costs and financial analysis, the quality and quantity of MSW needed to guarantee the continuous operation of the project, the addition of a renewable energy source, the amount of land conserved due to less waste being landfilled, and the environmental and greenhouse gas benefits of WTE, in comparison to other treatment and disposal alternatives.

In the last two decades, the WTE industry in Europe, North America, and Asia has developed technologies capable of reaching acceptable emissions standards, representing feasible sources of thermoelectric energy. By far, the dominant WTE technology, practiced in over six hundred plants in over forty nations, is the "grate combustion" of "as-received MSW" with production of electricity and heat. However, alternative processes, such as circulating fluidized bed combustion, are being developed and it is possible that one or more of them may result in lower capital costs per ton of MSW processed, than grate combustion of as received MSW. Therefore, requests for proposals to build a WTE should be open to all technologies, provided they meet the required technical and environmental criteria.

The contractual arrangement for the construction of a WTE project must include the ironclad commitment of the general contractor that the plant will operate at the specified plant availability (hours per year at full capacity), deliver to the grid the specified rate of electricity per ton of MSW processed, and meet continuously the specified environmental standards. The host municipality is also contractually committed to collect and provide to the WTE plant the specified daily and yearly tonnage of MSW and that this material is within the specified range of calorific values.

Despite being an important treatment option, WTE usually is not economically feasible without some government support. However, as cities in LAC move from open dumps to sanitary landfills, the true cost of landfilling will be increased to the point that the WTE solution could be economically competitive, because of its energy recovery, much lower land requirement, and other potential advantages. Moreover, the economic comparisons developed in this Guidebook are based on a 20-year life of the WTE plant, while some of the existing WTE facilities have already reached their fortieth year and will continue operating in the foreseeable future. Therefore, investing in a WTE plant represents a patrimony by the municipality to future generations.

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Introduction

Economic development and rapid growth of urban population have resulted in the generation of enormous quantities of municipal solid waste (MSW) that cannot, any longer, be disposed in the makeshift landfills of yesteryear. This has led the E.U., U.S. and other developed nations to adopt the so-called "hierarchy of waste management" that gives priority to waste reduction, recycling, composting and waste-to-energy (WTE) over sanitary landfilling. Sanitary landfills protect surface and groundwater and reduce greenhouse gas (GHG) emissions to the atmosphere so they are preferable to open dumps. However, it has been estimated that only 20% of the global landfills are sanitary[1,2].

Sustainable waste management is an integral part of sustainable development and has become increasingly important in the urban environmental agenda of cities and nations in the Latin America and Caribbean region (LAC). Although considerable effort has been directed towards increasing recycling rates, i.e., the recovery of materials from MSW, international experience has shown that after all feasible recycling has been done, there remains a large fraction of solid waste that must be treated thermally to recover its energy content, also called waste-to-energy (WTE), or landfilled.

Since 1995, the Earth Engineering Center (EEC) of Columbia University has conducted many research studies on all aspects of waste management and published the results in over one hundred theses and technical papers. The mission of EEC, and its sister organizations in twelve nations, is to identify and help advance the most suitable means for managing solid wastes. This study by the EEC of Columbia University was undertaken at the request of InterAmerican Development Bank (IDB) and is addressed specifically to the examination and description of state-of-the-art thermal treatment technologies that may be used in cities of the LAC region.

A wide range of private sector firms visit governmental authorities in the IDB borrowing member countries, and offer various novel technologies for the thermal treatment of MSW. However, these officials may not be well informed about the fundamentals of thermal conversion, the commercially available technological options, their environmental impacts, and the associated capital and operating costs. Therefore, this Guidebook has the objective of bringing technical guidance to these countries in assessing the feasibility of implementing WTE projects.

The Guidebook is organized in two parts. Part 1 describes the need for sustainable waste management, the various forms of thermal treatment of MSW, the gasification technologies, the current state of WTE technologies, and guidelines for planning and building a WTE facility. The second part, Case Studies, presents three case studies of what could be the first WTE plants, in Chile, Argentina, and Mexico; and the potential for using waste-to-energy on the Caribbean islands. Purposely, the main part of the Guidebook was separated from the case studies because the material presented in Part 1 can be applied to any city while each case study refers to a specific city and nation and may differ from the other case studies presented in the Guidebook. They should be used by readers to guide them as to the kind of information they will need to develop and the kind of action they may take so as to advance sustainable waste management in their city and country.

An explanation of the acronyms used can be found at the very end of the Guidebook.

PART ONE

1 The need for sustainable waste management of solid waste

1.1 The present state of global waste management

Since the beginning of history, humans have generated solid wastes and disposed them in makeshift waste dumps or set them on fire. After the industrial revolution, near the end of the 18th century, the amount of goods used and then discarded by people increased so much that it was necessary for cities to provide landfills and incinerators for disposing wastes. The management of urban, or municipal, solid wastes (MSW) became problematic since the middle of the 20th century when the consumption of goods, and the corresponding generation of MSW, increased manifold.

In response, the most advanced countries developed various means and technologies for dealing with solid wastes. These range from reducing wastes by designing products and packaging, to recycling of usable materials, composting of green wastes, combustion with energy recovery, commonly called waste-to-energy (WTE), and sanitary landfilling that prevents aqueous and gaseous emissions to the environment. It has been estimated that the global post-recycling MSW amounts to over 1.2 billion tons, of which one billion are landfilled and 0.2 billion are treated by various waste-to-energy technologies. Also, only 20% the landfilled MSW is disposed in sanitary landfills that reduce aqueous and gaseous emissions to the environment[1,2].

1.2 Introduction to solid waste management

According to Christensen (2011), solid waste management is as old as human civilization, although only considered an engineering discipline for about one century. The change from the previous focus on public cleansing of the cities to modern waste management was primarily driven by industrialization, which introduced new materials and chemicals, dramatically changing the types and composition of waste, and by urbanization making waste management in urban areas a complicated and costly logistic operation.

Solid wastes can be classified into municipal (residential and commercial), industrial, construction and demolition, and other types of wastes. Municipal solid waste (MSW) is the most heterogeneous material on earth since they include the residues of nearly all materials used by humanity: Food and other natural organics, papers, plastics, fabrics, leather, metals, glass, etc.

It is important to realize that several systems are dealing with waste or items that could become waste.

Six different systems can be conveniently identified:

- In-house waste handling: 'Waste' may be utilized on the premises or in an industrial symbiosis; the latter is when one industry directly uses 'waste' from another industry as a resource in its production. For example low quality wood chips could be used for in-house generation of power. In principle this is not a 'waste' according to our definition, but in-house waste handling could be an important initiative in promoting waste minimization or waste prevention, as later discussed.
- Littering/unmanaged waste handling: Common littering in terms of waste thrown away in the countryside, along transportation lines or in public areas is found everywhere, although on a variable scale. Littering is usually in the form of packaging and newspapers, but also infrequently arising waste (such as waste from building renovation and old white goods) may appear 'dumped' in the countryside or in derelict areas. Littering and dumped waste may later demand public cleansing of the affected areas and thereby become a part of the public waste management system.
- Return system: Used products may be returned to the store where bought or to a similar store depending on business structure. Returnable beverage bottles and cans with a deposit are common. The recovery of the deposit is the economic incentive for the consumer to return the items. Return systems may also exist without deposits as a part of voluntary agreements between environmental authorities and business chains, as an element in the environmental profiling of a branch or as part of legally enforced producer responsibility. Such systems could for example involve batteries, medicine, car tires and electronic equipment.
- Municipal waste management system (public or private): Organized handling of municipal waste is usually a public issue, although many of the elements in the system may be privately owned and operated. Municipal waste is the waste that is generated by citizens and civil work and similar waste from small businesses and industry. The public is the governing authority.
- Industrial waste management system: The term industrial waste is used for waste of industrial origin that is found in large quantities of special composition or in smaller

quantities but hazardous. The latter usually is handled in the hazardous waste management system. Industrial waste is often dealt with case-by-case because the large quantities and special features determine the ways of disposal. Systems for managing the waste at an industry may be an integrated part of the authorities' environmental approval or licensing of the industry.

- Hazardous waste management system: The nature of the hazardous waste calls for special ways and rules of collecting, storing and transporting the waste. Also the treatment and disposal facilities have special features and regulations. This typically leads to a higher cost per ton than the common cost for municipal solid waste.

Waste Management Criteria

The view of Christensen (2011) is that the ideal waste management system does probably not exist, but it may be useful to identify some of the main criteria that waste management as service and a public obligation should consider and try to balance. The following criteria should be considered in all waste management planning:

- Provide a customized and robust handling of all waste with a minimum of effort for the customer and the citizen.
- Ensure the lowest possible load on the environment in terms of noise and contamination of air, water and soil.
- Provide a maximum of resource recovery from the waste while minimizing use of resources in the waste handling.
- Be a safe and healthy occupation for the workers offering non monotonous work and achievable challenges.
- Provide only little impact on the city with respect to traffic, vehicle exhaust, noise, traffic accidents and spill of waste.
- Include aesthetic and architectural considerations in establishing waste collection and treatment facilities.
- Respect as a minimum current laws, regulations and code of practice.
- Be economically acceptable and fair.

These ideal criteria are partially in conflict: for example, fulfilling environmental criteria increases cost. All waste management systems must identify which criteria are the most important and then reach an acceptable compromise. No simple relation can combine these partly contradictory criteria into one single criterion function to be optimized, unless all criteria are forced into economical terms.

The Need for Appropriate Planning

The most common mistake when designing a solid waste management system is to consider it only as a technical issue, as something referred to public works, infrastructure and funding. This mistake usually results in plans full of technicalities, independent of local conditions and unrealistic. Even more, it results in plans that ignore the importance of social interactions and the specific role of communication. In contrast, there is a need for multi-dimensional view that will address all the aspects of SWM, namely the technical, the social, the economical and the political issues.

UNEP states that worldwide, there is a growing need for sustainable and coherent solutions to solid waste management problems. SWM seems to be more complex in developing and transitional countries, where the increase volume and type of wastes, as a result of economic growth, urbanization and industrialization, is becoming a burgeoning problem for national and local governments, making tougher to ensure an effective and sustainable management of waste.

Waste Treatment Technologies

The choice of treatment technology may play an important role in the fulfillment of most of the above criteria and it determines in great extent the success of a solid waste management system. However, there is no waste treatment technology that fits excellent to all areas and to all types of waste.

Below they are briefly presented the most common solid waste treatment technologies.

- **Recovery of materials:**

Sustainable management of MSW requires that every feasible effort be made to separate recyclable materials, e.g. paper fiber, metals, and some types of plastics and glass, from the MSW stream. Recyclable materials should be separated at the source, i.e. at households, businesses and institutions. The cost of recycling is then shared by the citizens (time and effort to separate the recyclables) and by the municipalities (separate collection vehicles and processing systems). Experience at many communities has shown that single stream collection and processing of recyclable materials results in appreciably higher recycling rates and is also more economic than multiple stream collection. The recyclables to be sorted out are specified by the community on the basis of available markets; in general, metals, paper and cardboard and certain types of plastics and glass are recyclable. The collected recyclables are then transported to a Materials Recovery Facility (MRF) where they are sorted out, mechanically or manually, to marketable materials and to a non-usable residue that is either landfilled or used as fuel in a WTE plant. Mechanical treatment is considered by many people as pre-treatment method because it is usually used with biological or thermal waste treatment. Its aim is to recover valuable materials from waste streams, to remove contaminating items, to separate one waste stream into more streams or to homogenize the waste in order to optimize other processes.

- **Mechanical pretreatment:**

It is considered by many people as pre-treatment method because it is usually used with biological or thermal waste treatment. Its aim is to recover valuable materials from waste streams, to remove contaminating items, to separate one waste stream into more streams or to homogenize the waste in order to optimize other processes.

- **Aerobic and anaerobic composting:**

Garden and park wastes, also called "green" or "yard" wastes, can also be separated at the source and composted aerobically (i.e., in the presence of oxygen) in open windrows, in covered piles through which air is injected (Gore Cover system), or "in-vessel" reactors. The compost product has a small nutritional value and can be used as soil conditioner in gardens and parks. The usual practice is for citizens to bring their green wastes to the composting plant and take away the compost product for use in their gardens. Green waste composting is used extensively in the U.S. with nearly 50% of these wastes composted aerobically[3].A few communities also collect food wastes separately and compost them in specially designed Anaerobic Digestion (AD) reactors, i.e., in the absence of oxygen, thus recovering a biogas containing about 50% methane and a "cake" that, after curing in air for a few weeks, is also used as soil conditioner[3]. Food wastes can also be composted aerobically in closed systems that are equipped with bio filters or other devices to avoid the emission of unpleasant odors to the surroundings[4]. Collection and processing of food wastes is much more costly than for green wastes and is practiced in few communities. For example, less than 3% of the food wastes generated in the U.S. are processed in this way. The solid wastes remaining after recovery of materials and a compost product are called post-recycling wastes. They can be treated thermally to recover their chemical energy content or disposed in landfills, as discussed below.

- **Recovery of energy:**

Most of the post-recycling wastes are organic chemical compounds made of hydrogen (H) and carbon (C) and can be used as a fuel. When they react with oxygen at a relatively high temperature (called "combustion"), they form water vapor (H2O) and carbon dioxide (CO2) and release a large amount of energy. Therefore, it can be stated that PRW contain chemical energy that, during combustion, is transformed to thermal energy. The chemical energy stored in post-recycling MSW is typically 10 MJ/kg (mega Joule per kilogram) or 2.8 MWh/ton (megawatt-hours per ton), although there is a wide variation from this value. The simplest, and most common, way for recovering the stored energy of MSW is by complete oxidation, i.e. combustion, in specially designed furnaces. However, there are other thermal treatment ways, namely partial oxidation and formation of a synthetic gas ("gasification"), or heating of the PRW to convert it to synthetic oil ("pyrolysis"). Collectively, all the thermal treatment methods for recovering energy or a fuel from solid wastes are called waste-to-energy (WTE).

- **Mechanical and Biological treatment (MBT):**

MBT is a relatively new method (developed in the 1990s) to treat solid waste and it is basically used to treat unsorted or residual waste (after some recyclables removed at the source). The concept was originally to reduce the amount of waste going to landfill, but MBT technologies are today also seen as plants recovering fuel as well as material fractions. As the name suggests the technology combines mechanical treatment technologies (screens, sieves, magnets, etc.) with biological technologies (composting, anaerobic digestion).

Two main technologies are available: Mechanical biological pretreatment (MBP), which first removes an RDF fraction and then biologically treats the remaining waste before most of it is landfilled, and mechanical biological stabilization (MBS), which first composts the waste for drying prior to extraction of a large RDF fraction. Only a small fraction is landfilled. The latter technology is also referred to as biodrying. Within each of the two main technologies, a range of variations is available depending on waste received and routing of the RDF fraction. (Christensen, 2011)

- **Landfilling:**

Post-recycling wastes that are not thermally treated must be landfilled. This is the ancient way of dealing with solid wastes by humanity and is still used by an estimated 80% of the global population. There are two major problems associated with traditional landfills: Rain precipitation and biochemical reactions within the landfill form leachates containing organic acids that, if they escape to the environment, can contaminate surface and ground water for many decades; also, the biogas generated by these reactions contains as much as 55% methane (CH_4) and contributes an estimated 3% of the greenhouse gases (GHG that are believed to result in climate change[5].

In recognition of this condition, several nations have implemented sanitary landfills that are equipped for collecting and treating the liquid effluents and for capturing as much as possible of the landfill gas.

Integrated Sustainable Waste Management (ISWM)

Klundert and Anschutz consider that integrated Sustainable Waste Management is a dynamic tool including aspects that range from policy-making and institutional development to technical design of integrated solutions for the handling and disposal of waste.

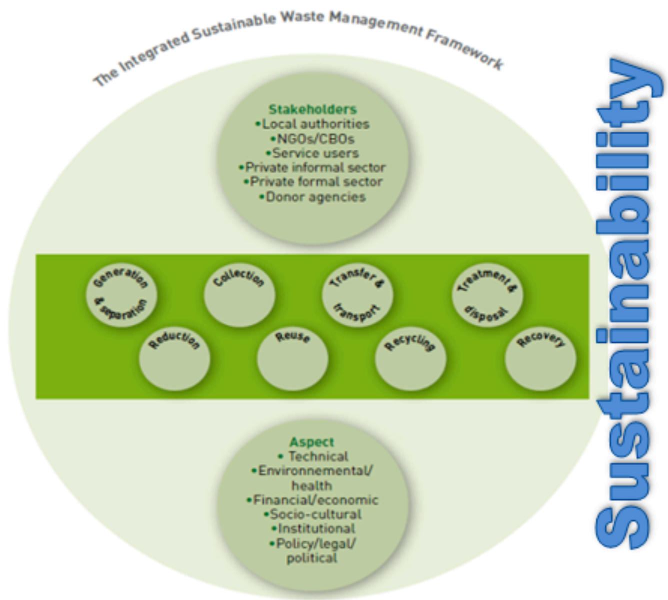

Figure 1: Integrated sustainable waste management

The concept of ISWM differs a lot from the conventional approach towards waste management by seeking stakeholder participation, covering waste prevention and resource recovery, including interactions with other systems and promoting an integration of different habitat scales (city, neighborhood, household). ISWM does not cope with waste management as just a technical issue, but also recognizes the political and social factor as equally important. (Klundert and Anschutz, 1999).

ISWM Dimensions

As it is shown at Figure 1, the ISWM framework of analysis consists of three dimensions:

- the Stakeholders (upper circle of Figure 1);
- the physical Waste System Elements e.g. generation, storage, collection etc. (box in Figure 1).; and
- The aspects, e.g. technical, environmental etc. of the SWM system (lower circle in Figure 1).

A stakeholder is a person or organization that has a stake, an interest in - in this case-waste management. Stakeholders by definition have different roles and interests in relation to waste management; the challenge of the ISWM process is to get them to agree to co-operate for a common purpose, that of improving the waste system.

Waste system elements refer to how solid waste is handled and where it ends up. Particularly this last has important environmental implications and for this reason a number of national environmental ministries have taken the idea of a waste management hierarchy as an operational policy guideline. The waste management priorities, shown in Figure 2, is also a cornerstone of the ISWM approach and gives priority to waste prevention, minimization, recycling and other forms of recovery of materials

The third dimension of ISWM refers to sustainability aspects. These aspects can be defined as principles, or lenses, through which the existing waste system can be assessed and with which a new or expanded system can be planned. (UN-HABITAT, 2010, Klundert and Anschutz, 2001) In order the new or the expanded system to be sustainable, it needs to consider all of the technical, environmental, health, financial-economic, socio-cultural, institutional, legal and political aspects (See Box 1).

The preferred order of priority of the different methods of managing wastes is shown graphically in the “Hierarchy of Waste Management” (Figure 2). Of course, as in any rule, there can be exceptions. For example, nearly 90% of the plastics generated in the U.S. are not recycled for various reasons; it is much more preferable for the non-recycled plastics (NRP) to be treated thermally rather than landfilled. Also, a Columbia University study showed that the California (U.S.) practice of using green wastes as daily cover in sanitary landfills, in place of soil, is environmentally preferable to windrow composting of this material[3]. The Hierarchy of Waste Management (Figure 2) places sanitary landfills that use the captured biogas to produce electricity above landfills that burn the biogas in flares that, at least, avoid the emission of methane to the atmosphere.

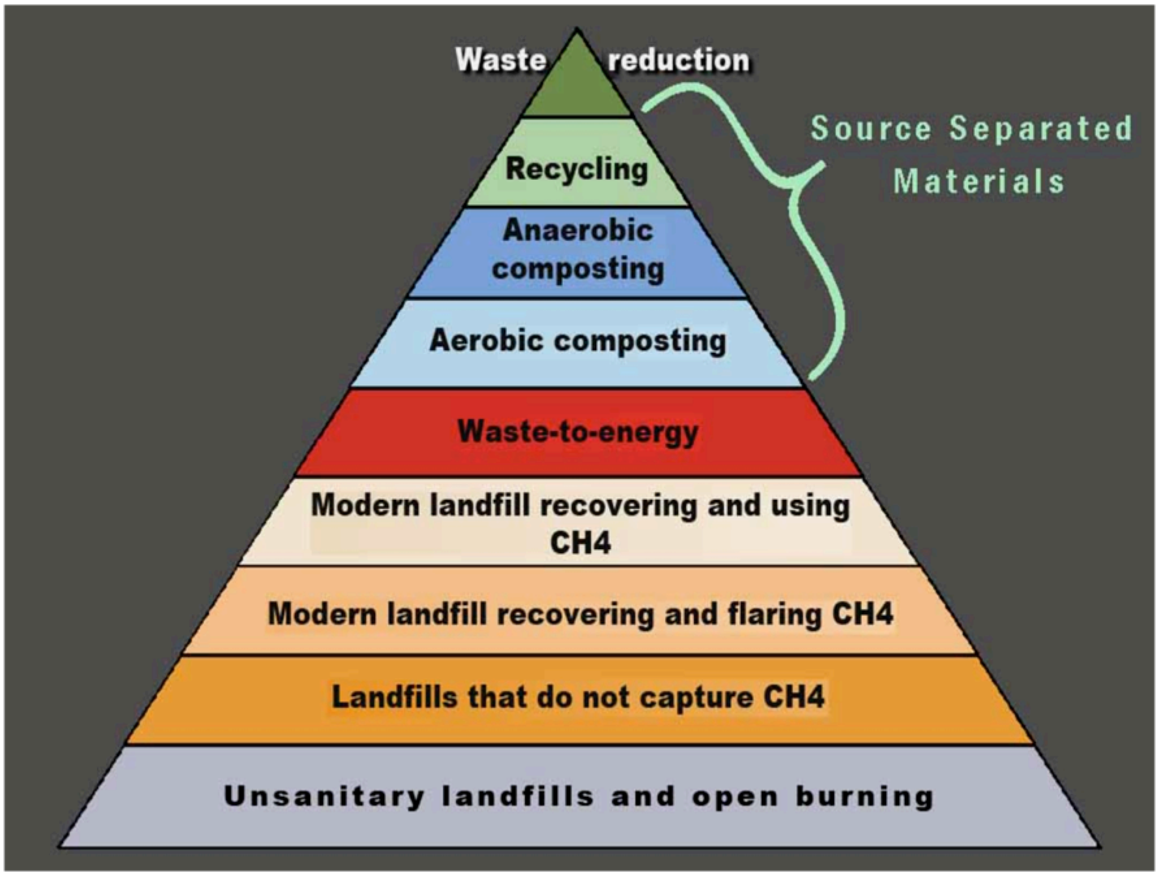

Figure 2 The Hierarchy of Waste Management[6]

Box 1: Waste System Aspects

Technical aspects concern the observable practical implementation and maintenance of all of the waste elements: what equipment and facilities are in use or planned; how they are designed; what they are designed to do; whether they work in practice; and how clean the city is on a consistent basis

Environmental aspects focus on the effects of waste management on land, water and air; on the need for conservation of nonrenewable resources; pollution control and public health concerns.

Health aspects have to do with the fact that WM is closely related with the protection of human health, since inappropriate, inefficient or non existing WM poses a severe danger for society

Financial-economic aspects pertain to budgeting and cost accounting within the waste management system and in relation to the local, regional, national and international economy. Some specific issues are: privatization; cost recovery and cost reduction; the impact of environmental services on economic activities; the commodities marketplace and how the recycling infrastructures connect to it; efficiency of municipal solid waste management systems; macroeconomic dimensions of resource use and conservation; and income generation.

Socio-cultural aspects include the influence of culture on waste generation and management in the household and in businesses and institutions; the community and its involvement in waste management; the relations between groups and communities, between people of various age, sex, ethnicity and the social conditions of waste workers.

Institutional aspects relate to the political and social structures which control and implement waste management: the distribution of functions and responsibilities; the organizational structures, procedures and methods implicated; the available institutional capacities; and the actors such as the private sector who could become involved. Planning is often considered the principal activity in relation with institutional and organizational aspects.

Policy/legal/political aspects address the boundary conditions in which the waste management system exists: setting goals and priorities; determination of roles and jurisdiction; the existing or planned legal and regulatory framework; and the basic decision making processes.

Source: http://www.greengrowth.org/partners.asp

1.3 Recovery of materials ("recycling") and energy ("WTE")

As noted above, sustainable management of MSW requires that every possible effort be made to separate recyclable or compostable materials from the MSW stream. These materials should be separated from the rest of the MSW at the source, i.e. at households and businesses, because once they are mixed with food wastes, disposable diapers and other "wet" wastes, separation becomes very difficult and the value of the recyclable materials is decreased appreciably. However, it is very important that the municipality decides, and informs the public, as to which materials are marketable; otherwise, the "recycled" wastes will end up in landfills. An example of the lack of markets for certain waste materials is the fact that, despite a lot of effort by communities and companies, only 7% of the plastic wastes generated in the U.S. are recycled[7].

Some people believe that a new WTE plant will reduce the recycling rate in a community. Actually, the opposite is true: Communities who are willing to spend money and effort on recycling soon realize that there are material properties and economic limits as to how much MSW can be recycled. Then, they look for the next available means for reducing their dependence on landfilling: Energy and metals recovery by WTE. This effect is made obvious in the "Ladder of Sustainable Waste Management" of the Earth Engineering Center (EEC) that is based on Eurostat[8] and Columbia/BioCycle survey[9] data (Figure 3). This graph clearly shows that the nations who have reduced or even eliminated landfilling, have done so by a combination of materials and energy recovery.

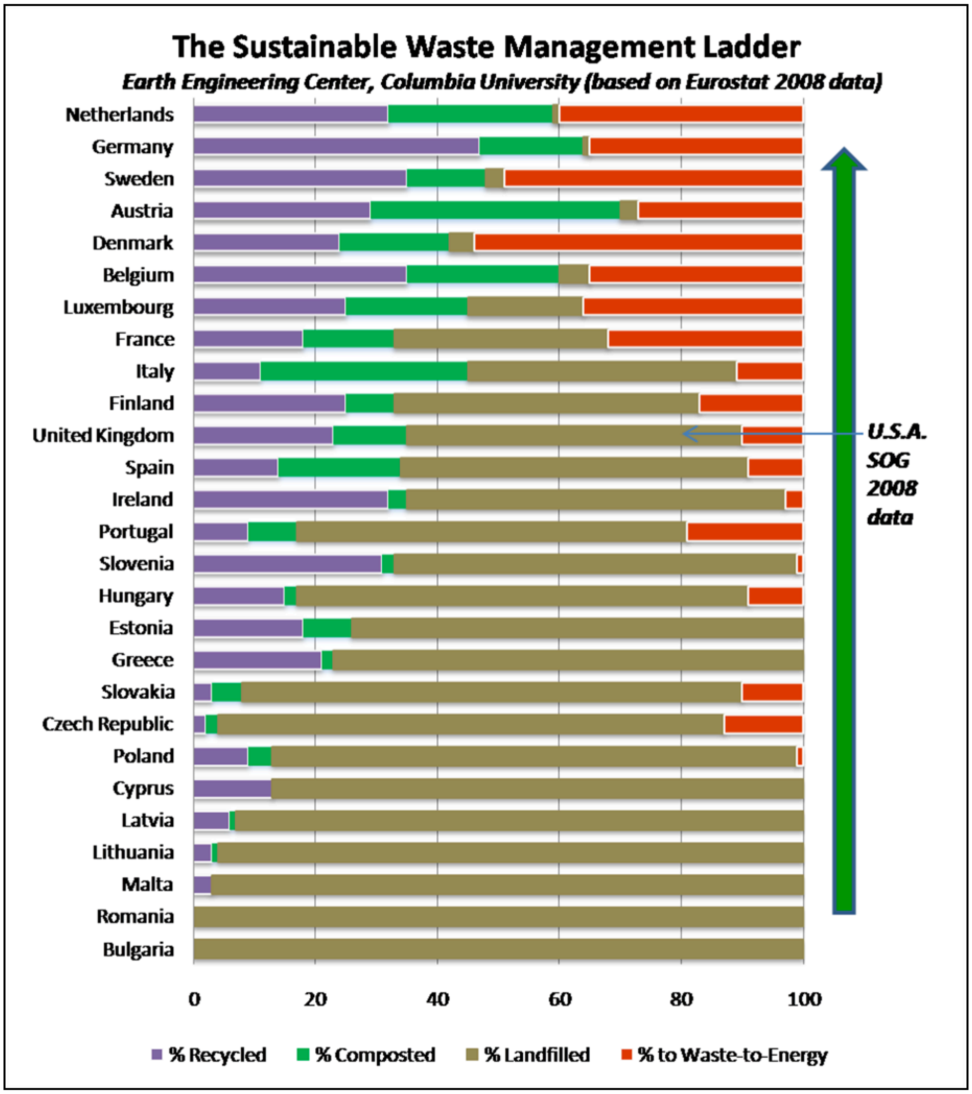

Figure 3 Up the Ladder of Sustainable Waste Management by recovering both materials and energy from MSW[8,9]

2 Thermal treatment technologies

2.1 The chemical heat stored in MSW

Post-recycling MSW that is not landfilled can be the fuel of a WTE furnace and, therefore, it is necessary to know its calorific value. Using chemical composition data for a "typical" MSW by Tchobanoglous et al[10], and the atomic weights of the respective elements, Themelis et al[11] showed that the chemical formula $C_6H_{10}O_4$ closely approximates the mix of organic compounds in MSW. By coincidence, there are ten organic compounds, such as adipic acid and ethylene glycol diacetate, which have the same molecular formula. The heat of formation of these organic compounds is about 960 MJ/kilomol. Full combustion of the organic compounds in MSW is represented by the following chemical equation:

$$C_6H_{10}O_4 + 6.5O_2 = 6CO_2 + 5H_2O$$

This reaction is highly exothermic and at the combustion temperature of 1000°C the calculated heat of combustion is 2.7 MJ/kilomol of organic compound. Since the molecular weight of $C_6H_{10}O_4$ is 146 kg/kilomol, the "theoretical" heat of reaction (i.e. in the absence of non-combustible materials and moisture) is calculated to be 18.5 MJ/kg.

2.2 Effect of moisture and inert materials on heating value of MSW

The moisture and non-combustible materials contained in MSW decrease its calorific value. To quantify these effects, let us assume that the WTE plant provides steam to a standard power plant and that the exhaust gases leave the boiler system at 120°C and 0.135 MPa. Accordingly, the heat loss in the water moisture in the feed is calculated to be 2.6 MJ/kg of moisture in the MSW. The non-combustible materials in the feed, mainly glass and metals, end up mostly in the bottom ash. If it is assumed that the ash exits the combustion chamber at about 700°C, the corresponding heat loss to inorganic materials fed with the combustibles is estimated to be as follows:

- Glass and other inorganic materials: 0.63 MJ/kg of glass in the MSW
- Iron and other metals: 0.54 MJ/kg of metals in the MSW

Therefore, the non-combustible materials affect the heating value of the MSW as follows:

Heating value of mixed MSW = (heating value of combustibles) x ($X_{combustibles}$) – (heat loss due to water in feed) x (X_{H2O}) - (heat loss due to glass in feed) x (X_{glass}) – (heat loss due to metal in feed) x (X_{metal}) MJ/kg

Where $X_{combustibles}$, X_{H2O}, etc., are the fractions (% mass) of combustible matter, water, etc. in the MSW.

Substituting numerical values for the heat of combustion and for the water and inorganic heat losses:

$$\textit{Heating value of mixed MSW} = 18.5X_{combustibles} - 2.6X_{H2O} - 0.6X_{glass} - 0.5X_{metal}\ MJ/kg$$

The thick line in Figure 4 is a plot of the above equation versus the percentage of moisture. It can be seen that this equation corresponds well with experimental data on the heating value of MSW from various sources. The other straight lines are similar plots for other organic materials.

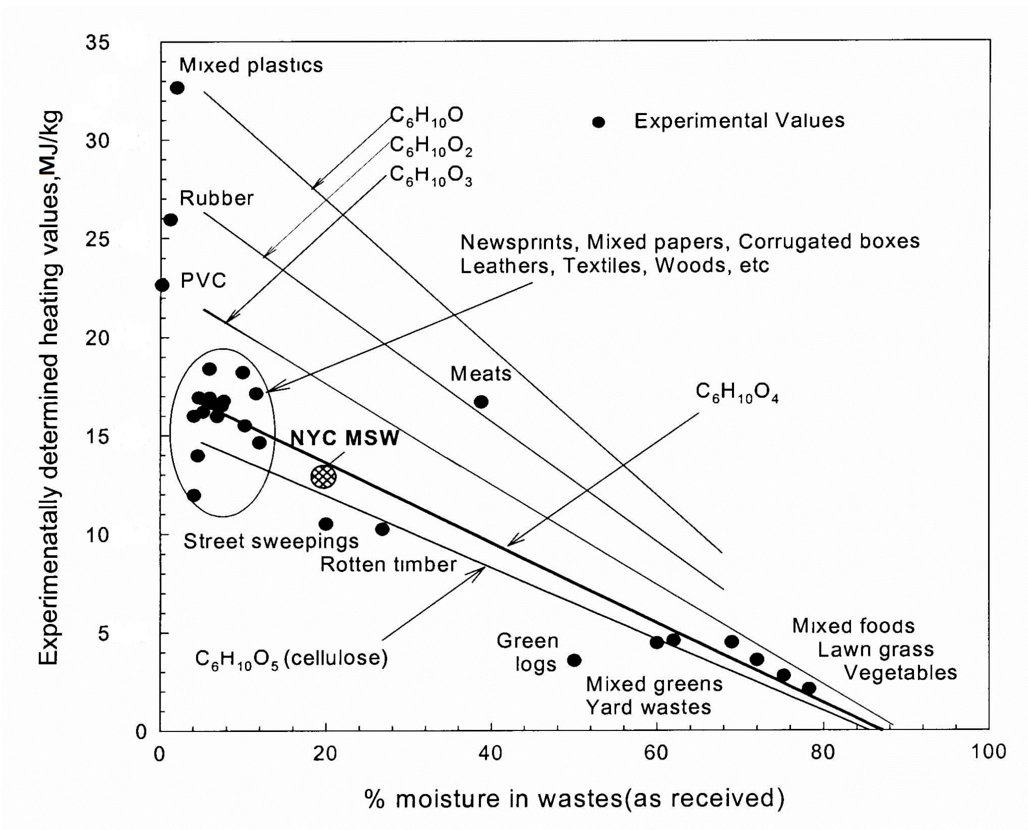

Figure 4 Effect of constituents and moisture on calorific value of MSW[11]

Of course, the calorific value of MSW can vary widely from country to country and city to city. This can be seen in Figure 5 that shows the calorific values of solid wastes combusted in 97 WTE plants across Europe[12]. Heating values range from a low of about 8 MJ/kg to a high of over 14 MJ/kg. The high values correspond to plants burning a mix of MSW and industrial wastes; the low values to high moisture MSW. The average weighted value for all 97 WTE plants is 10 MJ/kg. It should be noted that lignite coal, still used in many parts of the world, has a calorific value in the same range, or lower.

The value of 10 MJ/kg corresponds to about 2.8 MWh (megawatt-hours) of thermal energy per ton. This number should be kept in mind when sales people may propose processes that can recover more energy than is chemically stored in MSW.

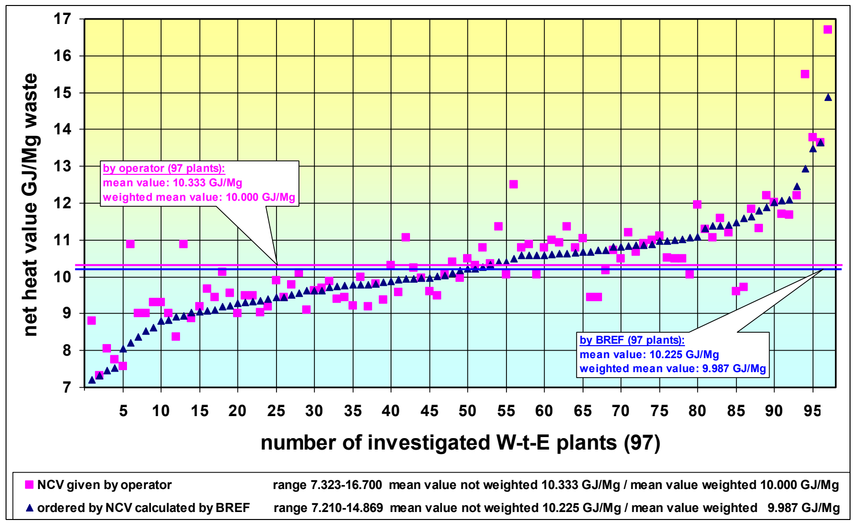

Figure 5: Net Calorific Value (NCV) (Reimann 2005)
- calculated by BREF-formula as well as indicated by operator including NCV mean values weighted and not weighted for 97 W-t-E plants (status 2001-2004)

Figure 5 Variation of heating value of MSW to European WTE plants[12]

As stated earlier, the only proven alternative to landfilling for post-recycling MSW is combustion or gasification to recover electricity, heat, syngas and metals. Worldwide, there are over 800 thermal treatment plants, most of them in E.U., Japan, the U.S., and China. Some of the most thermally efficient WTE facilities are in northern Europe because they recover 0.5 MWh of electricity plus over 0.5 MWh of thermal energy for district heating. With regard to electricity only facilities, the average U.S. facility recovers 0.55 MWh of electricity (net) per ton of MSW processed, while new facilities, e.g. AEB Amsterdam, provide to the grid over 0.7 MWh of electricity per ton of MSW.

2.3 Grate combustion

In grate combustion WTE, the MSW bags and other wastes are discharged from the collection vehicles into the waste bunker in a fully enclosed building (Figure 6). Typically, the waste bunker is large enough to hold over a week's feedstock. An overhead claw crane loads the solids into the feed hopper of the WTE furnace and a ram feeder at the bottom of the hopper pushes the wastes onto the moving grate. The grate can be inclined or horizontal and either air-cooled or water-cooled. The mechanical motion of the grate, and also the gravity force in the case of an inclined grate, slowly moves the bed of solids through the combustion chamber. The high temperature oxidation in the combustion chamber reduces objects as large as a big suitcase to ash that is discharged at the lower end of the grate.

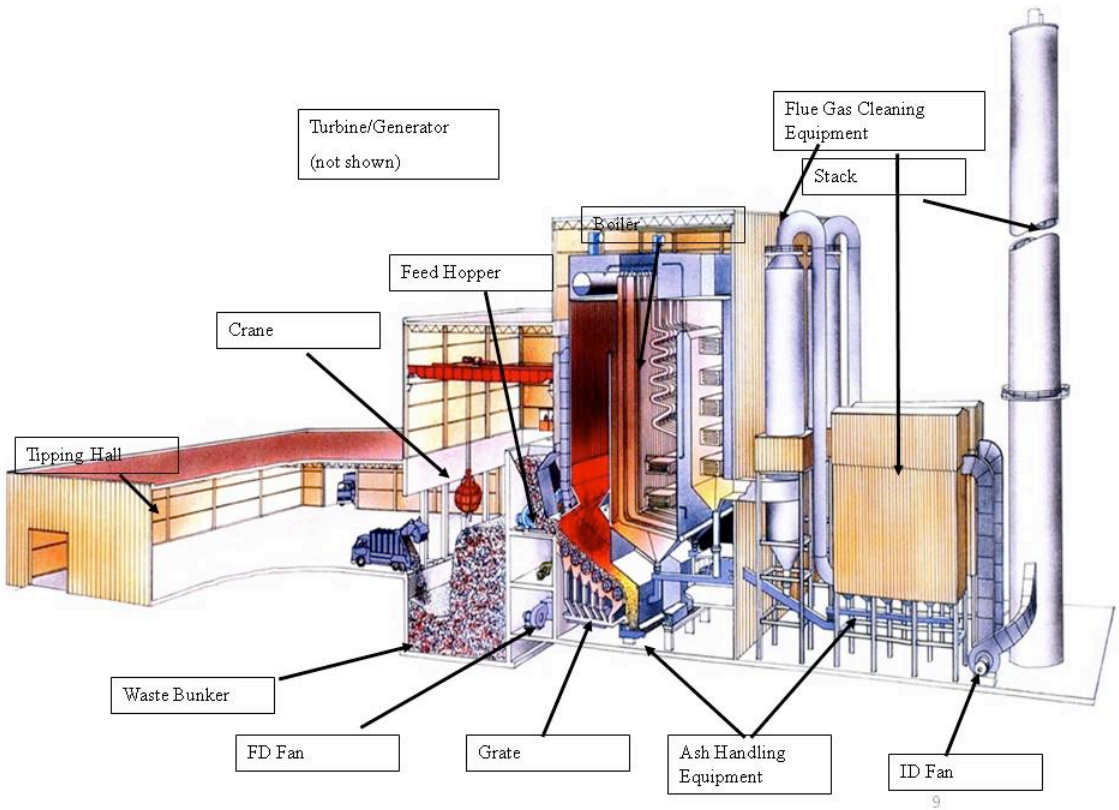

Figure 6 Parts of a WTE grate combustion plant (Koralewska, R., Martin GmbH, presentation at WTERT Bi-annual meeting, October 2006)

Figure 7 shows the flow diagram of a WTE facility and the approximate material and energy inputs and outputs.

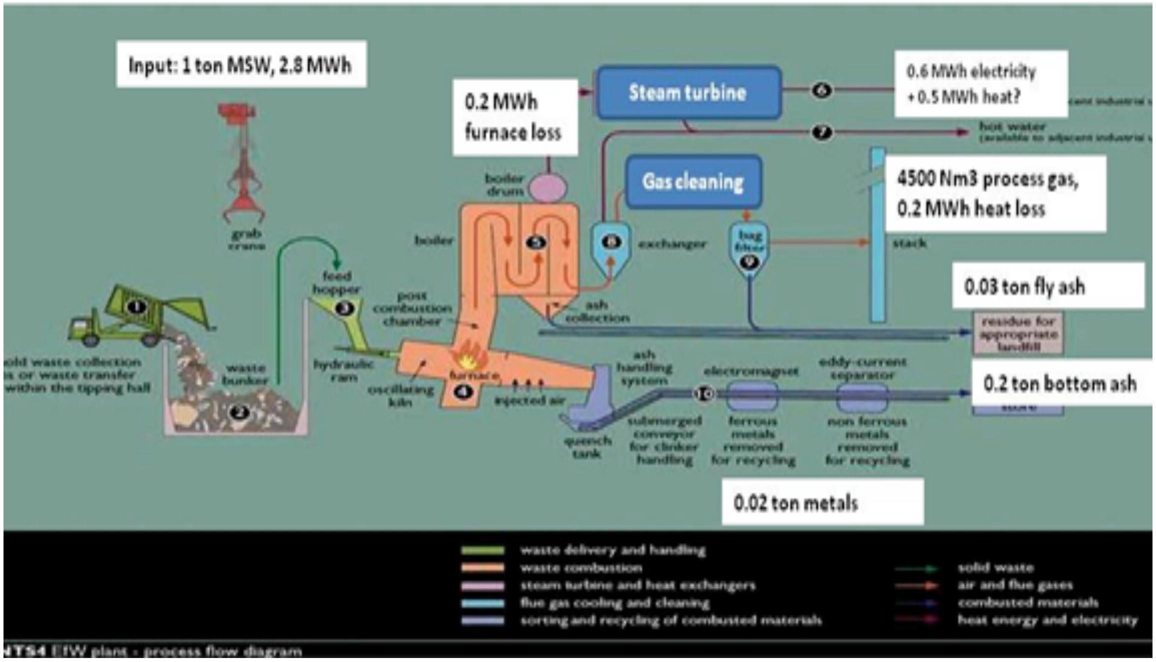

Figure 7 Material and energy inputs and outputs in a WTE plant (EEC schematic drawing)

The heat contained in the combustion gases is transferred, through the water-cooled furnace water wall and superheater tubes, to the high-pressure steam that drives the turbine generator. The low-pressure steam from the generator exhaust can be used for district heating. The most efficient WTE facilities are co-generators of electricity (> 0.6 MWh) and district heating (> 0.5 MWh) per ton of MSW processed. As an example, 28 WTE plants provide about 35% of the district heating needs of Denmark.

Most WTE plants built in the last decade are of the grate combustion type. A 2007 survey of three dominant technologies (Martin, Von Roll, Keppel-Seghers)[13] showed consistent growth of about three million tons of mass burn capacity per year in the period 2000-2006.

2.4 Combustion of refuse-derived-fuel (RDF)

The Refuse-Derived-Fuel (RDF) technology represents the simplest possible advance over the grate combustion of as-received MSW. The original RDF concept was to allow separation of marketable materials from the MSW feed before it enters the combustion chamber. Basically, this process consists of single shredding of the MSW, sorting out some of the recyclable materials, and then combusting the resulting RDF. In the U.S., there are 12 RDF WTE facilities, ranging in capacity from 360 to 2,700 tons per day and in total process about six million metric tons of MSW annually (i.e., 20% of the U.S. WTE capacity). A variation of the RDF process is also used in Europe where the Mechanical Biological Treatment (MBT) process treats mixed MSW and produces an

RDF product that is co-combusted with coal in power and cement plants that must be equipped with Air Pollution Control (APC) systems of the same performance as WTE plants.

The SEMASS WTE facility at Rochester, Mass., is one of the best examples of successful application of the RDF technology. It consists of three units of 900 metric tons/day each and pre-shreds the MSW to less than 15 cm size in a hammer-mill, removes about 50% of its ferrous metal content by passing the shredded material through a magnetic separator, and then stores it in a building adjacent to the WTE. From there, a belt feeder conveys it to the feeding chutes of the boilers; a second conveyer belt returns the unused material back to the RDF storage building. This feeding system is similar to a gas engine where only part of the fuel flows into the carburetor while the rest returns to the fuel pump.

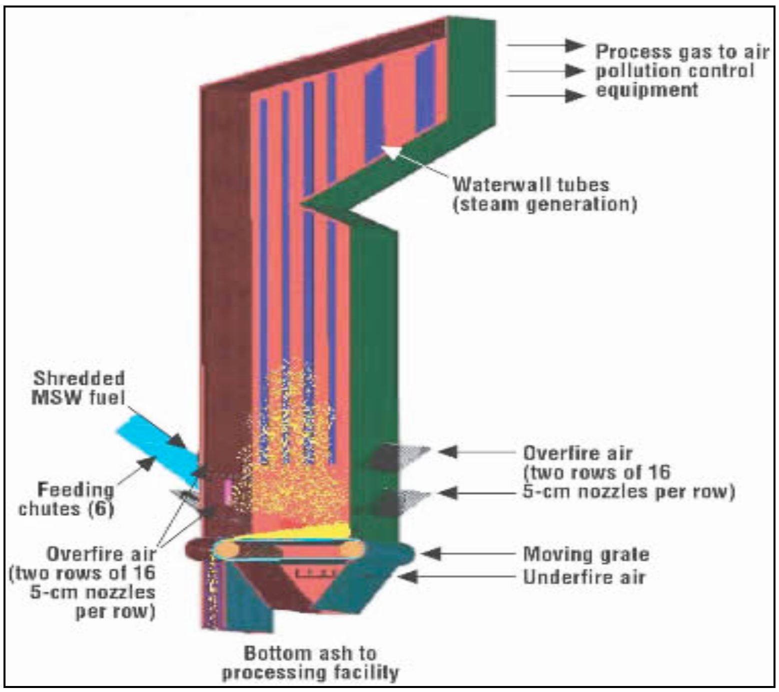

Figure 8 Schematic diagram of the SEMASS combustion unit (EEC figure)

In grate combustion plants, the crane operator always keeps the feeding hopper full. In contrast, the SEMASS boiler (Figure 8) is fed through a chute fed by a conveyer at such rate that the feed does not pack up in the chute but is carried in an air stream so that it enters the furnace in a quasi-fluidized state; therefore, a fraction of the feed is combusted in suspension while the rest settles on the far end of the horizontal grate and is slowly moved towards the feed end.

Since not all of the ferrous content is recovered prior to combustion, SEMASS conveys the bottom ash through magnetic separators, to recover ferrous metals, and then eddy-current separators, to recover non-ferrous metals. It is interesting to note that the post-combustion ferrous metal, recovered from the bottom ash, commands a higher market value than that collected from the pre-combustion stream. From a reaction engineering perspective, shredding of the highly heterogeneous MSW to a more uniform particle size and composition should be beneficial: Heat and mass transfer rates increase with smaller particle size and a certain degree of homogenization should facilitate combustion control in the furnace. Since the drying, volatilization, and combustion rates would be higher, the specific productivity (e.g., tons per unit volume of combustion chamber) of shredded WTE should also be higher than for grate combustion WTE. However, for wider adoption of the RDF technology, these advantages must translate into lower capital and operating costs than grate combustion technology.

Nearly all of the large-size RDF WTE plants are in the U.S. One of them, of 1,800 tons/day capacity was built near Palm Beach, Florida when the county was generating 2,900 tons/day of MSW. In the intervening twenty years, waste generation increased to 5,900 tons/day and the county decided to build a second WTE plant of 3,000 tons/day capacity. It is interesting that the new plant will be a mass-burn facility because it will be less costly to build and operate. The same thing happened in Honolulu, Hawaii where mass-burn grate combustion was chosen for a 700 tons/day expansion of a WTE plant that is of the RDF type.

2.5 Fluidized bed combustion

The fluidization process converts a bed of solids into a fluid by introducing a gas flow through the bottom of the bed. This phenomenon can be illustrated in Figure 9 that shows a bed of solid particles placed on a perforated plate in a vertical cylinder. As a gas is injected through the plate at a constantly increasing flow rate, at the beginning the particles remain at rest. However, as the gas flow increases the particles are lifted and the bed of solids starts behaving as a boiling liquid. At this stage, the bed motion is described as “bubbling fluid bed” (BFB); if there is an opening through the wall, some of the material from the bubbling bed will flow out through this opening (“overflow stream”). If the gas flow rate is increased further, the particles are lifted from the fluid bed and can be carried out of the reactor by the gas flow (“carryover stream”). For example, this is what happens to the small MSW particles in the SEAMASS reactor that was discussed in the previous section (Figure 8).

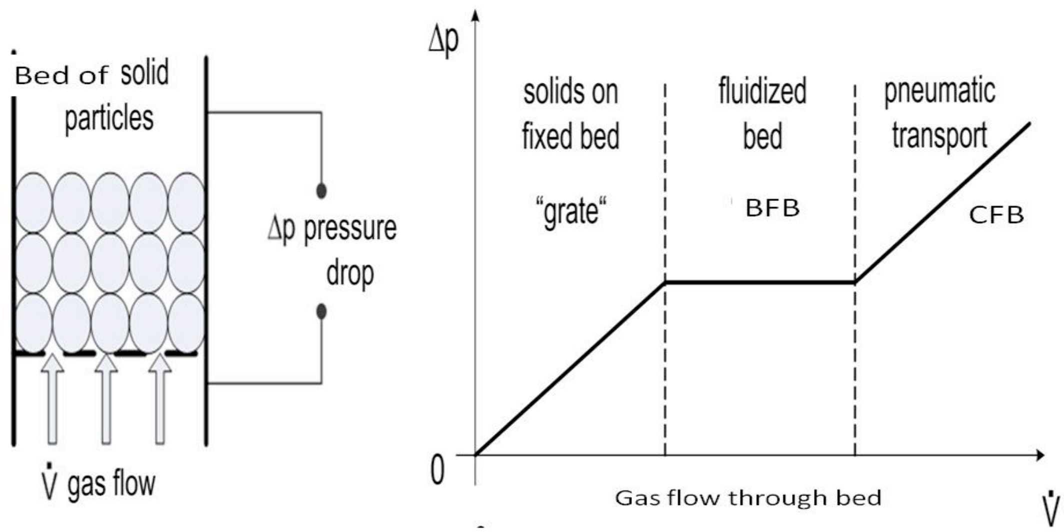

Figure 9 Change in behavior of bed of solids with increasing gas flow and pressure drop through the bed (F. Neubacher, WTE Fluidized bed technology, ESST (Springer) p.11853)

The fluidization process is used extensively in zinc roasting and other minerals processing, in wood and biomass boilers, and numerous other applications. It has also been applied to the combustion of solid fuels derived from the processing of MSW, most frequently by means of "circulating fluid bed. The most frequent application is called circulating fluid bed (CFB) where the carryover stream from the fluid bed reactor passes through a cyclone that separates most of the solids from the gas stream and returns them to the fluid bed reactor for further processing. A heat transfer medium, such as sand, is added to the fluid bed and recirculated.

Figure 10 shows the configuration of a circulating fluid bed reactor that is used to combust RDF in Neumuenster, Germany. The MSW (210,000 tons/year, 9 MJ/kg) is shredded, and separated into metals and inorganic materials; the remainder is subjected to bioreaction and drying and the resulting 103,000 tons of RDF (14.1 MJ/kg) are combusted in a circulating fluid bed. The combustion heat is used to co-generate electricity and heat. There are a few RDF fluid bed reactors in Europe and several in China (Figure 11).

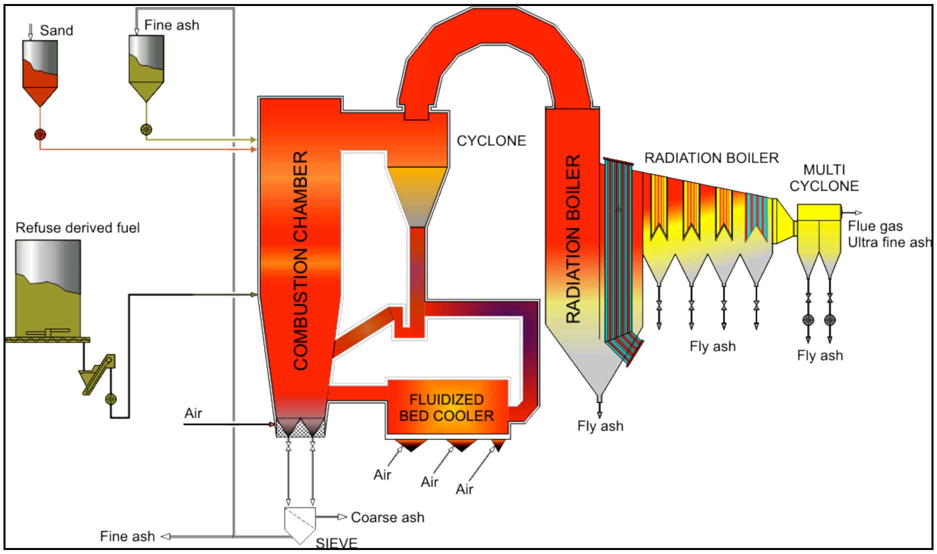

Figure 10 The Neumuenster fluid bed reactor combusting RDF[14]

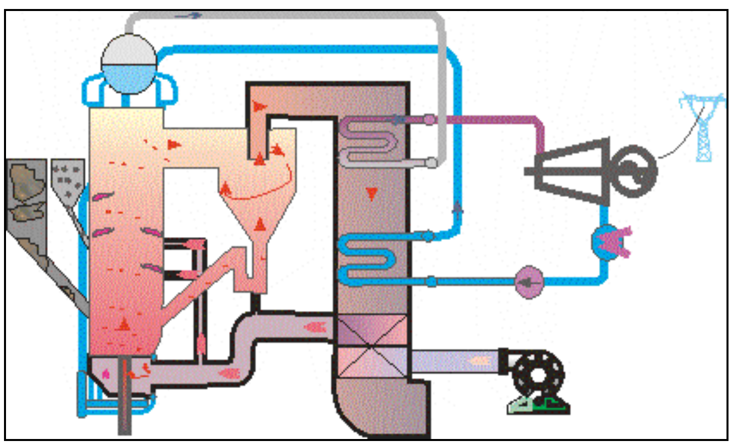

Figure 11 The Zhejiang University circulating fluid bed (CFB) WTE[15]

It has recently come to the attention of the Earth Engineering Center (EEC) that a 500-ton per day WTE plant is planned in Arizona, which will be based on the bubbling fluid bed (BFB) principle (Figure 12). The developers of this project (Reclamation Power Group) advised EEC that the projected cost of this plant is $50 million. This corresponds to about one half of the capital cost, per ton of capacity, of a conventional grate combustion plant, as discussed in a later section of the Guidebook. The provider of this technology in North America (Energy Products of Idaho) is included in the List of WTE Providers. The WTE fluid bed technology, like all technologies, is constantly advancing and requests for proposals for thermal treatment of MSW in the LAC region should not exclude either conventional or novel technologies, provided they can meet the performance criteria described in a later section of this Guidebook.

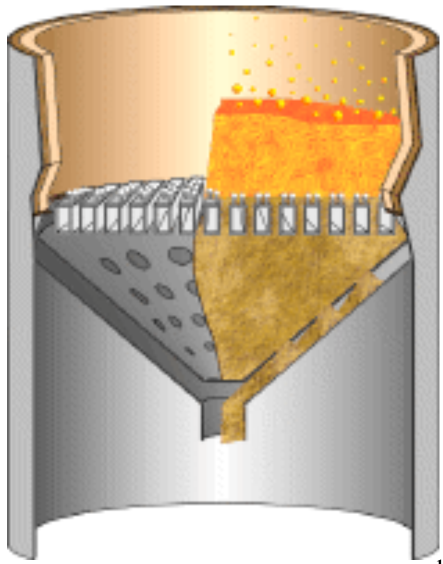

Figure 12 Illustration of bubbling fluid bed[16]

2.6 The production of secondary fuels via Mechanical Biological Treatment (MBT) technology

The Mechanical Biological Treatment (MBT) is a variation of the RDF process developed in Europe. As discussed earlier, MSW contains food and yard wastes that range from about 25% in developed nations to 50-55%, and higher, in the developing world. These natural organic materials contain a lot of moisture and removing some of it increases the calorific value of the partly dried solid wastes. MBT processes have been developed since 1995 with the objective of separating mixed MSW into three solid fractions: Recyclable materials, natural organics that are composted aerobically or anaerobically, and a combustible residue that is called "solids recovered fuel" (SRF).

Figure 13 shows the process sequence and products of the MBT process in which the shredded MSW is separated in a rotating cylindrical vessel ("trommel") into a fine, organic fraction that is composted and an oversize fraction that is mechanically sorted to recyclable materials (metals, some paper, some plastics, etc.) and to SRF fuel.

Figure 13 also shows the "BMT" variant of the MBT process, where mechanical separation takes place after the shredded MSW is subjected to "biodrying" by means of airflow through the bed of the shredded solids. During the various unit operations of the MBT process, a large part of the moisture is driven out and some of the organics are reacted to carbon dioxide (composting or biodrying) or methane (anaerobic digestion).

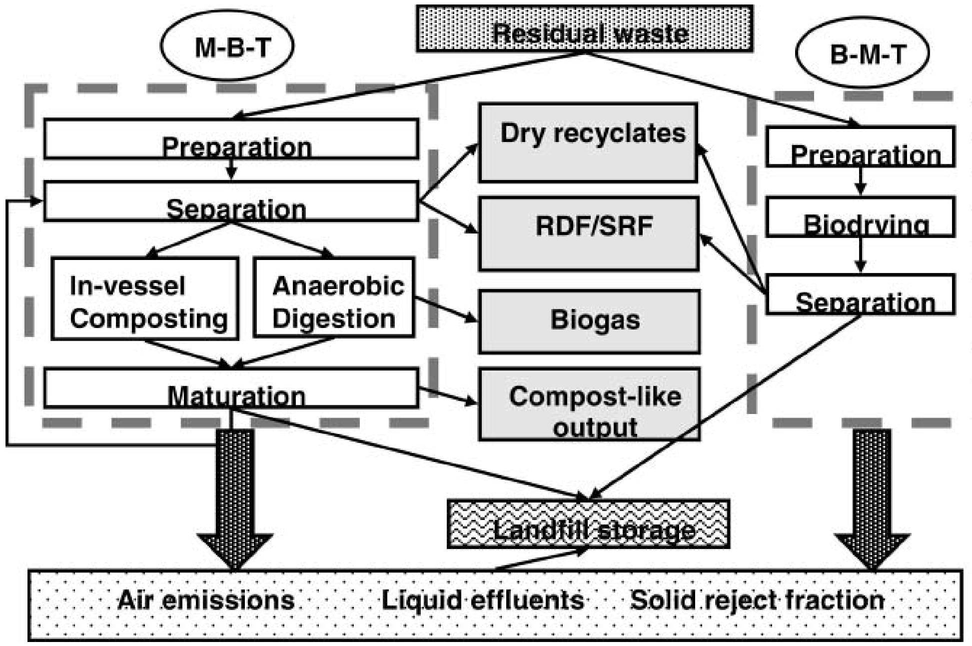

Figure 13 Process diagram of the MBT process[17].

By 2006, the MBT capacity had increased to about five million tons of SRF, mostly in Germany and some other European nations (Figure 14). There are various types of such processes and some have been more successful than others. The recyclables stream can be as good as source-separated recyclables and is marketable. However, the quality and visual appearance of the compost product may not be good enough to be used, even when it is given away for free. Also, the "SRF" fuel product contains a relatively high amount of chlorine and volatile metals so the receiving co-combustion plants must provide for this in their boilers and Air Pollution Control systems. Therefore, there are cases where both of these products are not acceptable in the market and end up in landfills; in such cases, the MBT serves to sort out recyclables and decrease the amount of MSW to be landfilled.

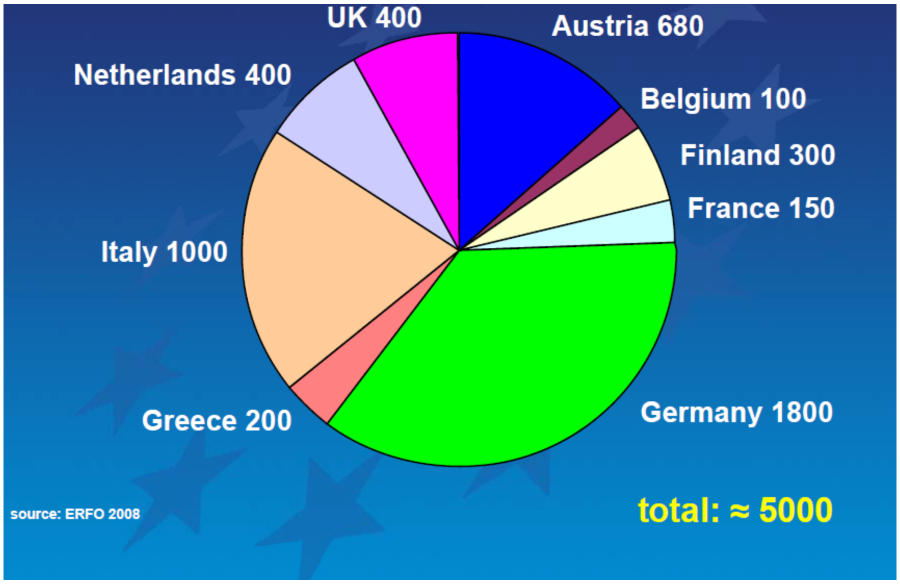

Figure 14 2008 production of SRF by the MBT process in Europe (in thousands of tons)[18]

When the SRF is used for co-combustion in power plants or cement kilns, the users demand a "gate fee", i.e., it has a negative value. However, this gate fee is much lower than the gate fee required by WTE plants in the same area and this difference provides the economic incentive to produce SRF. Figure 15 shows the various cost components of SRF production, including the negative prices ("gate fees") paid to various co-combustion plants in Germany. It can be seen that the gate fee paid to such plants ranges from 10-18 euro ($14-15) for high heating value SRF to 34-60 euro ($48-84) per ton of low heating value SRF.

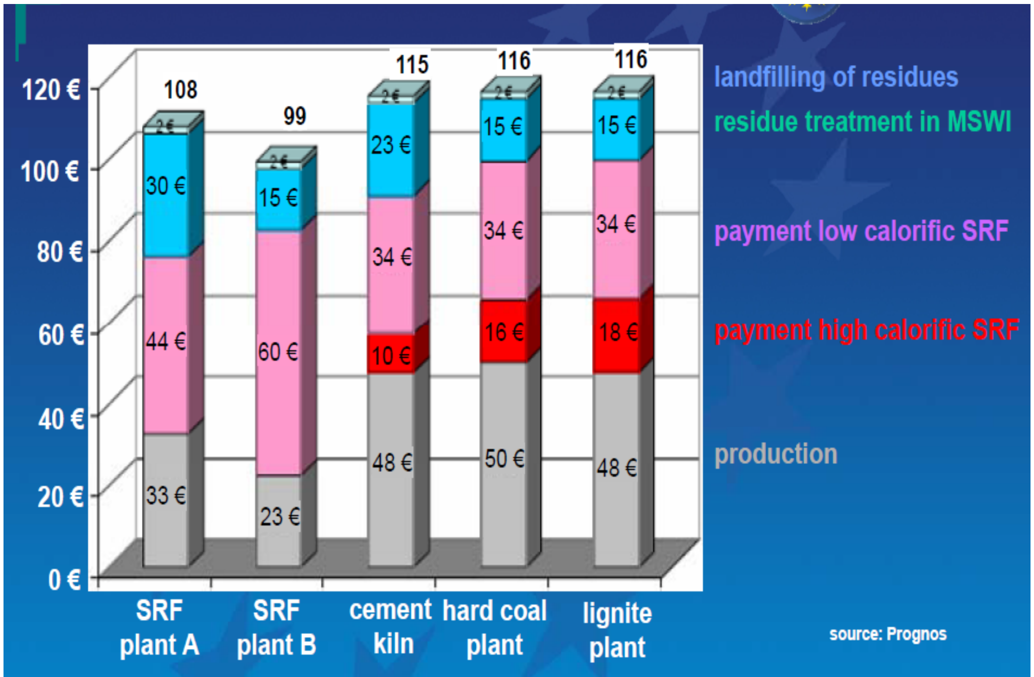

Figure 15 2006 costs of production and utilization of one ton of SRF[18].

MBT was developed in Europe principally in response to the EU Landfill Directive (LFD, 99/31/EC) that requires phasing out of landfilling because of its potential to produce landfill gas and leachate. Its objective is to produce a fuel that can be co-combusted in coal-fired and also in cement plants, thus avoiding the need for building a WTE plant. However, since this fuel has a negative value in the co-combustion market, it is necessary to consider whether it is worthwhile for a region to build several small-size MBT plants that serve a number of municipalities, and then transport the produced SRF to a regional WTE for combustion with energy recovery.

A municipality that wants to implement WTE may consider the simplest possible MBT process, whereby the MSW is shredded and subjected to biodrying by means of airflow through the bed of solids. After biodrying, non-combustible materials (metals, glass, inert) would be separated; the resulting SRF may be assumed to have a mass equal to 60% of the original MSW and a calorific value 66% (i.e., 100/60=1.66) higher than the original MSW. For the hypothetical case of processing one million tons of MSW, the economics of an MBT plant followed by a WTE plant that combusts the SRF product of the MBT can be compared to building a conventional grate combustion plant that combusts raw MSW as follows:

Capital cost of 1-million ton MBT + 0.6 x capital cost of 1-mllion ton WTE < capital cost of 1-million ton “as received” WTE

In the above case, the MBT+WTE combination will be attractive when the capital cost of the one million ton MBT plant is substantially less than 40% the capital cost of the one million ton WTE. For example, let us assume that the capital cost of a one million ton WTE built in Latin America is $500 per annual ton of capacity. Therefore, according to the above reasoning, for the MBT+WTE combination to be attractive, the MBT plant should cost less than $200 per ton of annual capacity. Of course, there should be additional comparisons of operating costs and energy production of the two alternatives but repayment of the capital cost is the major cost component in WTE plants.

The above discussion indicates that the MBT operation for the LAC region should be as simple as possible and not as complex as the flow sheet of the 70,000-ton/year biodrying MBT plant of Figure 16. However, like all technologies, the BMT process is constantly advancing; therefore, requests for proposals for thermal treatment of MSW in the LAC region should solicit submissions from all proven technologies and then compare the respective capital and operating costs.

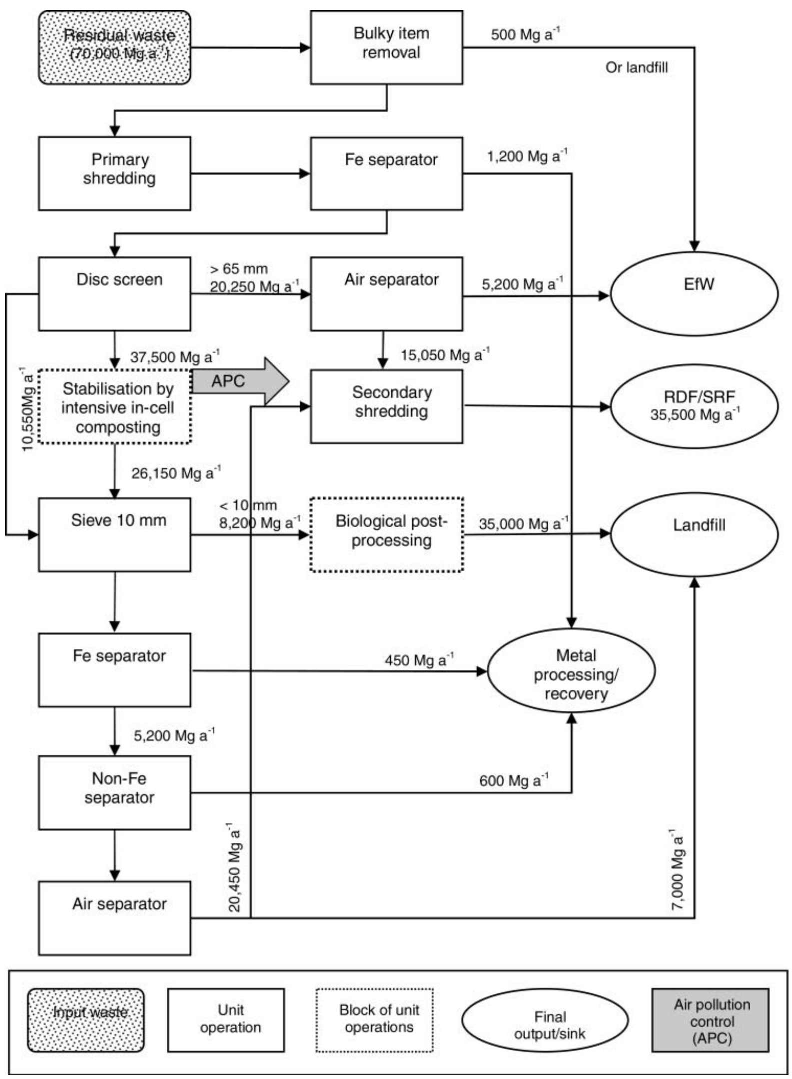

Figure 16 Simplified flow sheet and mass balance of the Nehlsen biodrying MBT plant in Stralsund, Germany[17]

3 Gasification technologies

The WTE processes called "gasification" are in fact a combination of partial oxidation and volatilization of the contained organic compounds. Gasification in the first furnace is followed by combustion of the volatile gases and steam generation in a second furnace, or by use of the syngas in a gas engine or turbine. Japan is the largest user of MSW gasification in the world. As discussed later, the principal technology used is grate combustion of "as received MSW" but there are over one hundred thermal treatment plants based on relatively novel processes such as direct smelting (JFE, Nippon Steel), the Ebara fluidization process, and the Thermoselect gasification and melting process. These processes have emissions as low as the conventional WTE combustion process and produce a vitrified ash that can be used beneficially outside landfills.

Transportation of "as collected" MSW from one municipality to another is not allowed in Japan. As a result, the grate combustion facilities are relatively small. Also, the MSW of several communities is processed to a refuse-derived-fuel in local RDF facilities and is then transported to a central WTE that serves several communities. Also, all WTE plants are required to vitrify their ash after combustion, by means of electric furnace, or thermal plasma melting, or other means. These regulations allow for the introduction of thermal treatment processes that would be considered uneconomic in other developed nations.

3.1 The JFE direct melting process

The JFE Direct Smelting reactor resembles a small iron blast furnace where the feed particles are fed through the top of a vertical shaft (Figure 17). Several Direct Smelting WTE plants have been built by JFE and also, in a similar version, by Nippon Steel. MSW is shredded and converted to RDF, drying the organic fraction in a rotary kiln and then extruding the product under pressure into 20-mm long by 15-mm diameter cylindrical particles. The material produced in several RDF facilities is then transported to a regional Direct Smelting facility, where it is combusted and energy is recovered. For example, the Fukuyama Direct Smelting plant is supplied by seven RDF facilities located at municipalities served by the DS facility.

The RDF is fed by means of a corkscrew feeder on top of the shaft furnace. As the feed descends through the furnace, it is gasified and its inorganic components are smelted to slag and metal, which are tapped at the bottom of the shaft. The gas product is combusted in an adjoining boiler to generate steam that is used to generate electricity in a steam turbine, same as in conventional WTE.

Air is introduced into the furnace through primary, secondary and tertiary tuyeres located along the height of the shaft. The primary air, near the bottom of the shaft, is enriched to about 30% oxygen in order to generate the high temperatures required to melt slag and metal at the bottom of the furnace.

The RDF-DS combination can handle up to 65% water in the MSW (the usual allowable range is 40-50%), which in the drying kiln is reduced to 5-6%. The process requires the addition of coke (about 5% of RDF), which is added along with the RDF at the top of the shaft as well as sufficient lime to form a fluid slag at the bottom of the furnace. The JFE process produces slag and metal globules (10% of RDF), that are used beneficially, and fly ash (2% of RDF) that contains volatile metals and is landfilled. The slag and metal overflow from the furnace are quenched in a water tank to form small spherical particles of metal and slag. The copper content of the metal fraction is apparently too high to be used in steelmaking and too low to be suitable for copper smelting; its main use is as a counterweight in cranes and other ballast applications.

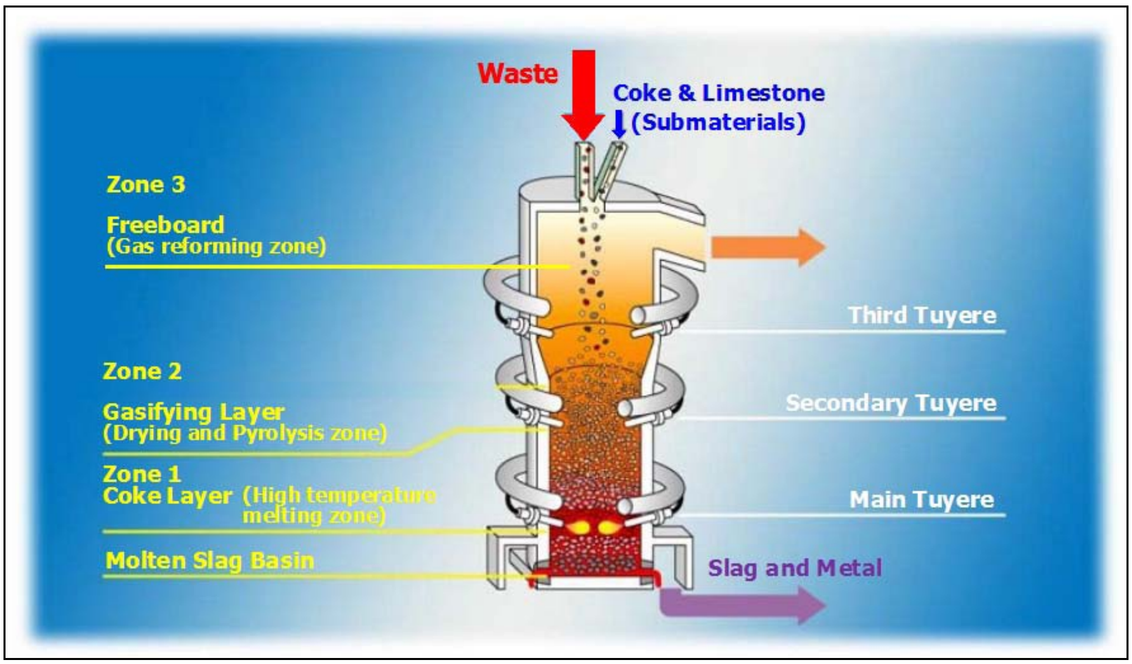

Figure 17 The JFE Direct Smelting process[19]

3.2 The Energos Grate Combustion and Gasification Process

The Energos grate combustion and gasification technology is currently in operation at six plants in Norway, one in Germany, and one in the U.K. Energos is part of the ENER-G group, headquartered near Manchester, UK. This technology was developed in Norway in the 1990s in order to provide an economic alternative to grate combustion WTE with equally low emissions to the atmosphere and flexibility in feedstock. All operating plants treat MSW plus additional streams of commercial or industrial waste[20,21]. The current operating plants range in capacity from 10,000 to 78,000 tons per year[22].

The feedstock to an Energos plant is post-recycling MSW mixed with a smaller amount of other waste streams. These include industrial wastes and residues from materials recovery facilities (MRF). Prior to thermal treatment, the materials are shredded in a high-torque, low-rpm shredder and then ferrous metals are removed magnetically[20,23]. In the first chamber of the Energos process, the feedstock is partially oxidized and gasified on a moving grate at sub-stoichiometric oxygen conditions (air to fuel ratio, λ=0.5-0.8); combustion of the fixed carbon on the grate results in total organic carbon (TOC) of <3% in the WTE ash[20,21]. The volatile gases generated in the gasification chamber are then combusted fully in an adjoining chamber and the heat in the combustion gases is transferred to steam in a heat recovery system. Temperatures reach up to 900°C in the gasification chamber and up to 1,000°C in the oxidation chamber[20]. Formation of NOx is kept relatively low (at about 25 % of the EU limit)[24], any dioxins in the feed are destroyed in the combustion chamber, and the rapid cooling achieved in heat recovery steam generator minimizes formation of dioxins. A schematic diagram of the gasifier and combustion chamber is shown in Figure 18.

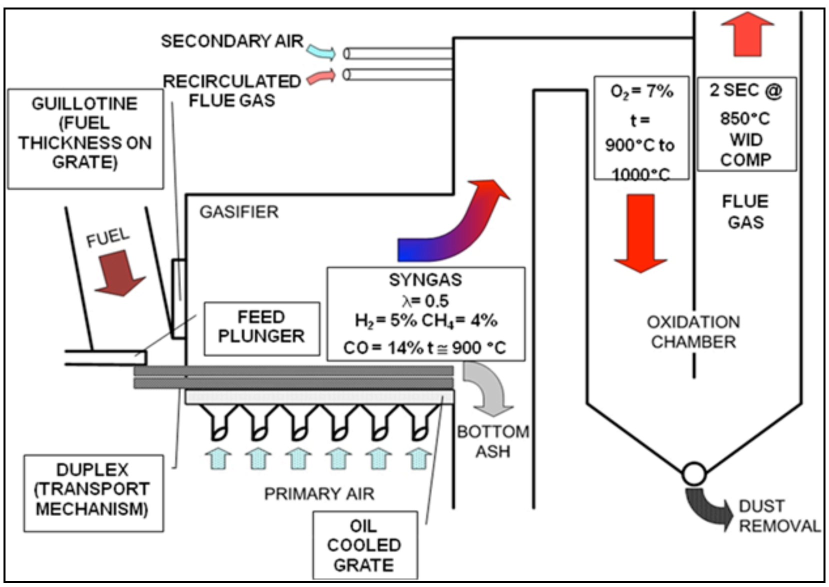

Figure 18 The Energos gasifier and combustion units[20,21]

After the heat recovery steam generator (Figure 19), the flue gas enters the dry flue gas cleaning system that consists of dry scrubbing with lime, activated carbon injection, a bag filter, and a filter dust silo[24]. The lime absorbs acidic compounds in the flue-gas and the activated carbon adsorbs dioxins and heavy metal molecules[25]. Emissions are monitored continuously. Table 1 shows typical emission measurements at the Averoy plant of Energos in Norway. These measurements were taken by an independent agency (TUV

NORD Umweltschtz) for the Norwegian Environmental Agency and are reported at 11% oxygen[21].

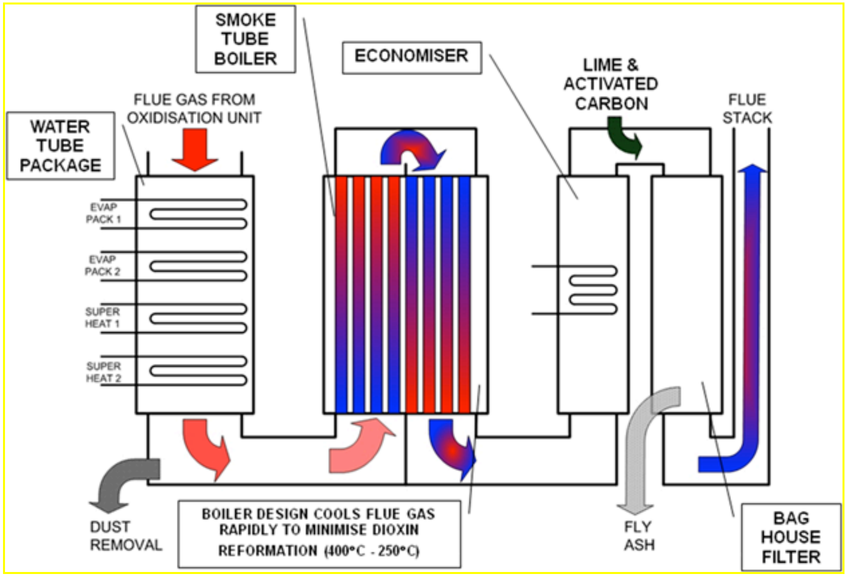

Figure 19 The Energos heat recovery and Air Pollution Control units[20,21]

Table 1 Averoy plant emissions (at 11% oxygen)[21]

Parameter	EU limits, mg/Nm^3	Energos, Averoy
Particulate matter	10	0.24
Hg	0.05	0.00327
Cd + Ti	0.05	0.00002
Metals	0.5	0.00256
CO	50	2
HF	1	0.02
HCl	10	3.6
TOC	10	0.2
NOx	200	42
NH_3	10	0.3
SO_2	50	19.8
Dioxins, ng/Nm^3 TEQ	0.1	0.001

The reported availability of the Energos plants is about 90% (8,000 hours per year)[21]. The feedstock, annual capacity and other information on the seven operating plants is shown in Table 2.

Table 2 Operating parameters of Energos plants[20,22,25]

Plant location (start up year)	Feedstock	Annual capacity, tons (number of lines)	Approximate site area*, m²	Thermal energy produced (MWh/yr.)	MWh,th per ton	Capital investment, million US$[2]	Investment per ton of annual capacity[2]
Ranheim, Norway (1997)	Paper mill rejects + various commercial wastes	10,000 (1)	N.A.	25,000	2.5	14	$1,350
Averoy, Norway-Nordmore Region (2000)	MSW + commercial wastes	30000 (1)	6,000	69,000	2.3	31	$1,033
Hurum, Norway (2001)	MSW + commercial waste from airport + paper rejects	39000 (1)	6,000	105,000	2.7	26	$657
Minden, Germany (2001)	MSW + RDF (paper and plastic waste)	39000 (1)	6,000	105,000	2.7	26	$673
Forus, Norway-Stavanger Region (2002)	Post-recycling MSW (18,000 tons) + industrial wastes (21,000 tons)	39000 (1)	6,000	105,000	2.7	$32	$825
Sarpsborg #1, Norway (2002)	MSW + commercial wastes	78000 (2)	9,000	210,000	2.7	$41	$525
Sarpsborg #2, Norway (2010)	MSW + commercial wastes	78000 (2)	9,000	256,000	3.3	$41**	$525

**Site area has been estimated by use of the following data provided by Energos: Single Line site area is 6,000 sq meters and double line site area is 9,000 sq meters.*
***Capital investment for Sarpsborg #2 Plant was assumed to be same as for Sarpsborg #1.*

Over the years, the Energos plants are reported to have treated over 1.8 million tons of post-recycling wastes and produced 3,800 GWh of mostly thermal energy. These plants provide district heating to the host communities as well as steam to local industries, including chemical, pharmaceutical, paper, and food processing plants[26]. For example, the Forus plant that serves Stavanger, Norway, is a combined heat and power (CHP) system; during periods of low heat demand, steam is used to produce electricity that is sold to the grid.

As shown in Table 2, these plants range in annual capacity from 10,000 to 78,000 tons. As would be expected, the smaller plants were the costlier to build, per ton of annual capacity. The Sarpsborg plant, with capacity of 78,000 tons per year, was reported by Energos to cost $525 per annual ton of capacity, which is at the low end of the capital cost of much larger grate combustion plants (about $600 per annual ton of capacity). At the low capacity end, the Averoy plant cost about $1,000 per annual ton of capacity.

3.3 The Ebara fluidized bed process

The Ebara process (Figure 20) consists of partial combustion of debagged and shredded MSW in a fluidized bed reactor followed by a second furnace where the gas produced in the fluidized bed reactor is combusted to generate temperatures up to 1,350ºC such that the ash is vitrified to slag. There is no oxygen enrichment. The largest application of the Ebara process is a three-line 900 tons per day plant in Spain.

The ash overflow from the fluidized bed is separated from the sand used in the reactor for fluidization. Separation is by means of an inclined vibrating screen with 3-4 mm openings through which sand particles can pass through, while glass and metal particles cannot. Bottom ash in Japan cannot be used for applications such as road construction and therefore has to be melted into slag, which is the final solid product and can be used in construction. The Spanish plant of the Ebara process produces a net of about 560 kWh per ton of RDF.

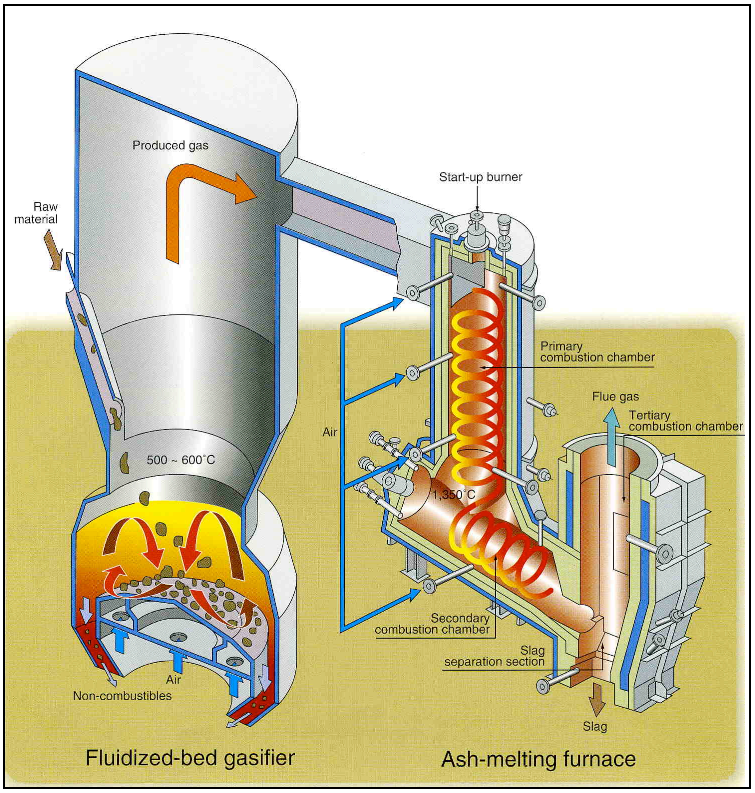

Figure 20 The Ebara fluid bed gasification process[27]

3.4 The Thermoselect gasification and melting process

The JFE steel company of Japan operates many plants ranging from grate combustion to the JFE Direct Smelting process described above, and also seven JFE Thermoselect plants of total capacity of 2,000 tons per day. The syngas produced in the Thermoselect furnace (Figure 21) is quenched and cleaned before it is used in gas turbines or engines to generate electricity. The amount of process gas per ton of MSW is much lower than in conventional grate combustion. However, cleaning a reducing gas is more complex than for combustion process gas. Also, the Thermoselect process uses some of the electricity it generates to produce the industrial oxygen used for partial oxidation and gasification of the MSW. The expectation is that the syngas product can be combusted in a gas turbine to generate electricity at a much higher thermal efficiency than is possible in a conventional WTE plant using a steam turbine.

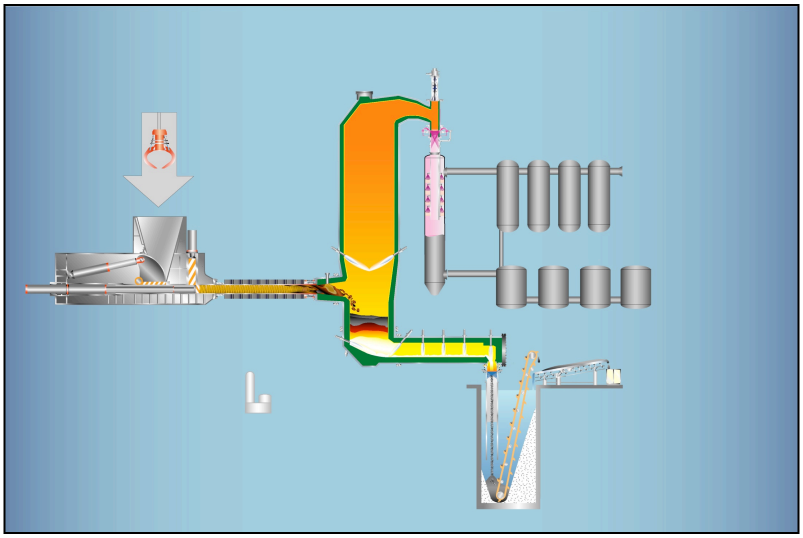

Figure 21 The Thermoselect gasification process[28]

3.5 Plasma-assisted WTE processes

In recent years, there has been a lot of interest in plasma-assisted gasification of MSW. A plasma torch is a device for transforming electricity to heat by passing current through a gas flow (Figure 22).

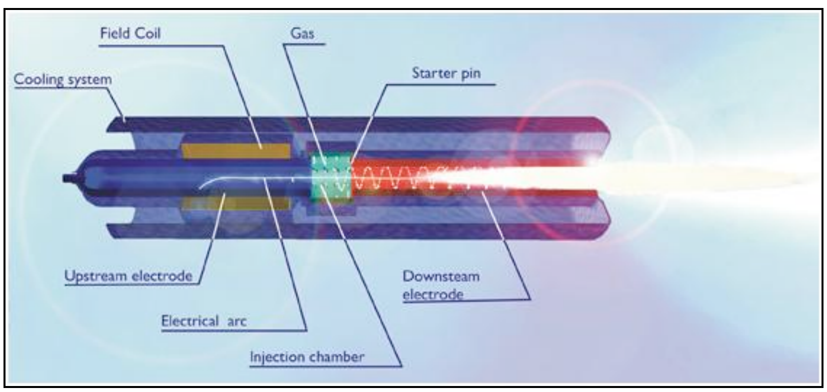

Figure 22 The Europlasma plasma torch[29]

A study of this technology was conducted by the Earth Engineering Center and is available on the web[29]. Plasma technology has been used for a long time for surface coating and also for the destruction of hazardous materials, such as asbestos (Figure 23).

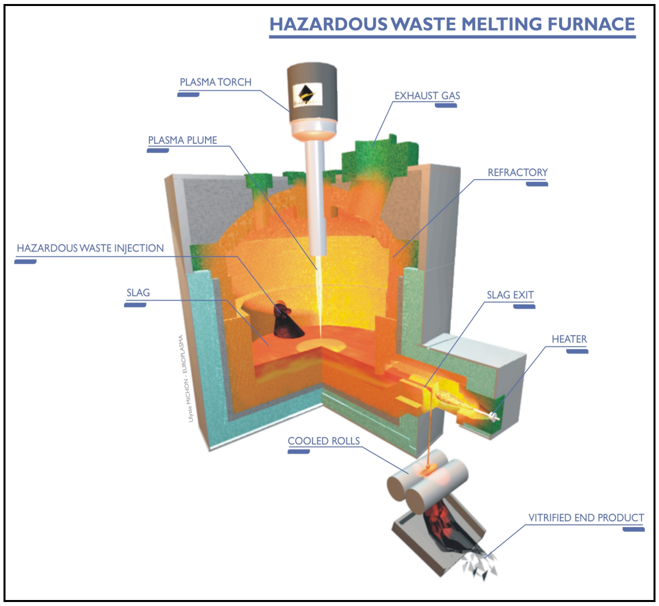

Figure 23 The Europlasma reactor for destruction of asbestos containing materials[29]

In the case of MSW processing, plasma torches are used to gasify the solids, to crack the volatile gases, and to vitrify the ash to slag and metal globules. The syngas product is combusted in a gas engine or turbine generator to produce electricity or it can be used to produce synthetic fuels. The technologies investigated in the EEC study were Westinghouse Plasma, owned by Alter NRG, Plasco Energy Group, Europlasma, and the InEnTec process of Waste Management Inc. The main advantage over grate combustion is the dramatic decrease in process gas flow, up to 75%. Also, the reducing atmosphere in the gasification process should result in lower NO_X emissions than in the grate combustion process. However, this study showed that the capital cost per ton of capacity were of the same magnitude as in grate combustion. Because of the use of electricity for high temperature gasification, it is expected that the energy production per ton of feedstock will not be higher than in the case of grate combustion. For example, the Alter NRG gasification process (Figure 24) is expected to generate about 0.6 MWh/ton of MSW.

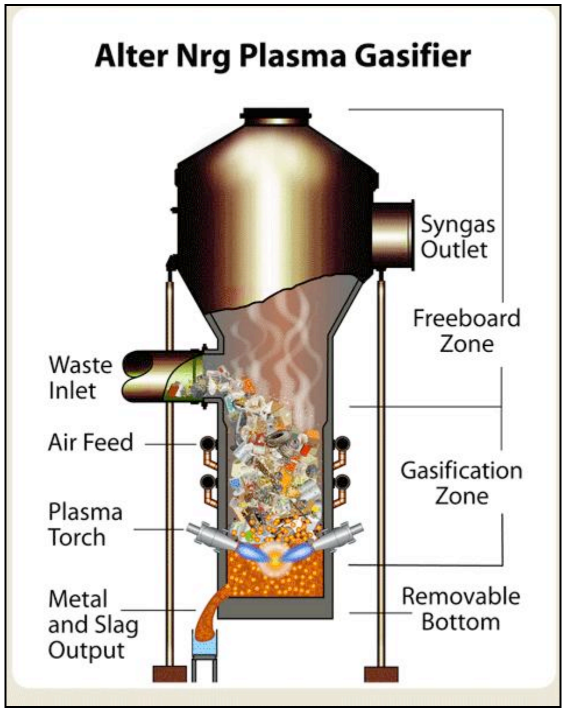

Figure 24 The Alter NRG plasma gasifier[29]

3.6 Pyrolysis

Pyrolysis is the thermal treatment of wastes using only external energy, that is, without any significant combustion of the wastes. Therefore, it requires a much higher initial investment of electricity than gasification, where part of the heat needed for gasification is provided by partial combustion of the wastes. Because of this factor, pyrolysis is not suitable, and has not been applied on an industrial scale, to the processing of MSW that, as noted before in this report, contains about 2.8 MWh of chemical energy per ton of MSW. However, pyrolysis can be applied to source-separated plastic wastes that contain about 8 MWh of chemical energy per ton; therefore, some of that energy can be expended for pyrolysis of the wastes. At this time, most plastic wastes (90% in the U.S.) are not recycled for practical reasons; instead of being landfilled, they could be combusted or subjected to pyrolysis.

Several processes for the pyrolysis of plastic wastes have been investigated by the Earth Engineering Center for the Flexible Packaging Association of America (FPA[7]) and some were found to be technically and economically viable. However, these processes are not suitable for mixed MSW and will not be discussed further in this report.

3.7 Application of various WTE processes in Japan

It can be seen from the above discussion, that Japan has been a leader in developing and implementing traditional and novel thermal treatment technologies. This nation generates about 65 million tons of MSW, treats thermally 40 million tons, and recycles the rest. Table 3 was prepared for the IDB Guidebook and lists all the types of WTE technologies used in Japan. It can be seen that despite the abundance of other technologies, 84% of the 37.8 million tons of MSW listed in Table 3 are processed in grate combustion plants.

Table 3 Thermal treatment technologies used in Japan

	Number of plants	All plants, tons/day	Average tons/day per plant	Percentage of WTE capacity of Japan
Martin reverse acting grate (66 plants)*	66	71,500	1083	62%
JFE Volund grate (stoker; 54 plants)*	54	10,100	187	9%
Martin horizontal grate (14 plants)*	14	7,454	532	7%
Nippon Steel Direct melting (28 plants)	28	6,200	221	5%
JFE Hyper Grate (stoker; 17 plants)*	17	4,700	276	4%
Rotary kiln (15 plants)	15	2,500	167	2%
JFE Thermoselect (gasification; 7 plants)	7	1,980	283	2%
All other fluid bed (15 plants)	15	1,800	120	2%
Ebara fluid bed (8 plants)	8	1,700	213	1%
JFE Direct Melting (shaft furnace, 14 plants)	14	1,700	121	1%
Hitachi Zosen fluid bed (8 plants)	8	1,380	173	1%
JFE fluid bed (sludge & MSW; 9 plants)	9	1,300	144	1%
All other Direct Melting (9 plants)	9	900	100	1%
Fisia Babcock (2 forward, 1 roller grate)*	3	710	237	1%
Babcock & Wilcox air cooled grate (43)*	43	690	16	1%
Total	**310**	**114,614**		**100%**
Total tons/year (at 330 days-24h/year)		37,822,620		
% of total MSW to grate combustion plants*				84%

***Grate combustion plants**

In closing the gasification section, it should be noted that it is often assumed that gasification processes will encounter less resistance by environmental groups who are opposed to “incineration”, i.e. grate combustion with energy recovery. In fact, in the recent past, the same groups have opposed gasification, which they call “disguised incineration”.

3.8 Preliminary comparison of alternative WTE Options

The selection of the optimum waste management option and in specifically for our case, the optimum WTE option depends heavily on the specific characteristics of the area of interest, in terms of waste quantities and properties, energy needs and prices, availability of funds, etc.

In any case a preliminary, qualitative assessment of the alternative WTE technologies is presented below in order to be used as a general "rule of thumb" when examining the possibilities to implemented WTE technologies.

For this purpose, the methodology of SWOT (Strengths – Weaknesses – Opportunities – Threats) analysis is used for the comparative evaluation of the alternative WTE technologies using the following criteria:

- Technical criteria
    - Ability to treat various waste streams – specifications for waste to be treated – pre-treatment requirements – requirements in relation to upstream waste management
    - Quantity of energy to be recovered
    - References at international level
    - Implementation risks
- Environmental criteria
    - Expected air emissions
    - Contribution to reduction of global warming
    - Generation of wastewater
    - Generation of solid and hazardous residues
- Social criteria
    - Acceptability by citizens / authorities
- Financial criteria
    - Investment cost
    - Operation cost
    - Revenues
    - Expected gate fee

It is noted that the list of aforementioned criteria is not exhaustive and refer explicitly to the comparison of alternative WTE plants. The list of criteria should in any case be adapted (e.g. additional criteria should be used), when comparing alternative waste management systems, or technologies aiming at different secondary products (e.g. MBT or recycling facilities).

Based on the criteria, the basic WTE technologies are assessed, namely:

- Conventional waste incineration
- Gasification
- Pyrolysis
- Plasma

The basic results of this assessment for each group of criteria are presented in the following table.

Table 4 SWOT Analysis of Alternative WTE Technologies

	Strengths	Weaknesses	Opportunities	Threats
		TECHNICAL CRITERIA		
Incineration	May treat multiple waste streams, without great demands in terms of input properties, except the reduction of humidity Generates significant quantities of energy Fully referenced and implemented technology, with well-developed know-how for construction and operation	Low calorific value waste streams reduce the efficiency of the plant Smaller energy quantities produced compared to other technologies	May be used for the treatment of hazardous/infectious waste Increased energy efficiency in case the produced heat may be also utilized	Possible significant reduction in waste input quantities may generate technical problems Energy intensive industrial units (e.g. cement plants or power plants) are competitors for waste utilizations
Gasification	May treat multiple waste streams Generates significant quantities of energy, higher than other technologies More references than other non-conventional technologies Relatively increased know how	There is no full scale experience with mixed municipal waste Problematic when treating waste with high humidity (sludge)	Further development is expected in the future – has been developing with high rate in recent years	Significant change in calorific value / waste composition affects the efficiency Appearance of technical limitation not initially considered Energy intensive industrial units (e.g. cement plants or power plants) are competitors for waste utilizations
Pyrolysis	May treat multiple waste streams Generates significant quantities of energy Well developed for special waste streams (e.g. tires)	Emerging technology especially in relation to mixed Municipal Solid Waste for which there are no full scale experiences Requires pretreatment activities (e.g. shredding,	More easily implemented for smaller waste quantities It is expected to be further developed in the future	Appearance of technical limitation not initially considered Energy intensive industrial units (e.g. cement plants or power plants) are competitors for waste

	Strengths	Weaknesses	Opportunities	Threats
		sieving) Problematic when treating waste with high humidity (sludge) Smaller energy quantities produced compared to other technologies Relatively small experience on the operation and results of such facilities Uncertainty in relation to efficiency rates and technical limitations		utilizations
Plasma	It has the least pre-treatment requirements in relation to input waste Generates significant quantities of energy, higher than other technologies	The least developed and implemented technology, especially in relation to MSW Low level of experience internationally Uncertainty in relation to efficiency rates and technical limitations Significant energy needs	May possibly treat multiple waste streams	The high cost may restrict its further development Appearance of technical limitation not initially considered Energy intensive industrial units (e.g. cement plants or power plants) are competitors for waste utilizations
ENVIRONMENTAL CRITERIA				
Incineration	Fully modernized air abatement and wastewater treatment systems exist. Significant contribution to reduction of greenhouse effect via the energy production from non-fossil fuel	Significant air emissions, which need to be abated Significant waste water quantities, which need to be treated Generation of solid and hazardous residue that needs to be managed	The environmental performance is substantially enhanced when the thermal energy is also utilized	The management of the hazardous residue is problematic and increases the operating cost Even the bottom ash may be proved to be hazardous
Gasification	Smaller emissions (air emissions and wastewater) compared to incineration Significant contribution to reduction of greenhouse effect via the energy production from non-fossil fuel	Generation of solid and hazardous residue that needs to be managed		The management of the hazardous residue is problematic and increases the operating cost Even the initially considered non-hazardous residue may be proved to be in fact hazardous
Pyrolysis	Smaller emissions (air emissions and wastewater) compared to incineration Significant contribution to reduction of greenhouse effect via the energy production from non-fossil fuel	Generation of solid and hazardous residue that needs to be managed		The management of the hazardous residue is problematic and increases the operating cost Even the initially considered non-hazardous residue may be proved to be in fact hazardous
Plasma	Smaller emissions (air emissions and wastewater) compared to incineration Significant contribution to reduction of greenhouse effect via the energy production from non-fossil fuel Generation of inert residue	Since this technology is has not been implemented in large scale, there may be environmental effects which are not known		The reduced air emissions are not fully proven and referenced
SOCIAL CRITERIA				
Incineration	Authorities are starting to consider WTE as an alternative	Relatively negative perception of WTE from	The negative social perception on WTE seems to be changing	Other waste management stakeholders, including

	Strengths	Weaknesses	Opportunities	Threats
	waste treatment solution, especially for highly urbanized areas and megacities	the citizens Problematic attitude by the informal sector recyclers	internationally especially when linked with climate change benefits	industries using waste may react to WTE implementation The development of new WTE technologies communicated as being "clean technologies" may affect the level of acceptance of incineration
Gasification	Authorities are starting to consider WTE as an alternative waste treatment solution - however its lack of commercial references is still a problem	Reluctance in acceptance due to the fact that this is a relatively new technology	The negative social perception on WTE seems to be changing internationally	In the citizens mind this technology is similar with waste incineration
Pyrolysis	Authorities are starting to consider WTE as an alternative waste treatment solution - however its lack of commercial references is still a problem	Reluctance in acceptance due to the fact that this is a relatively new technology	The negative social perception on WTE seems to be changing internationally	In the citizens mind this technology is similar with waste incineration
Plasma		Reluctance in acceptance due to the fact that this is a relatively new technology	Is communicated as being the "cleanest" WTE technology The negative social perception on WTE seems to be changing internationally	In the citizens mind this technology is similar with waste incineration
FINANCIAL CRITERIA*				
Incineration	Smaller unitary investment and operation cost compared to other WTE technologies Revenues from energy trade are expected	Investment cost seems always high comparing to other alternatives like landfills and MBT	Benefits are maximized if site allocation provides reduced collection costs Utilization of thermal energy increases revenues and viability Increased revenues are expected in case part of the Waste treated is considered renewable The high level of competition between WTE technologies may decrease the investment cost	Very sensitive to significant reduction in waste quantities
Gasification	Revenues from energy trade are expected	Very high operating and investment cost resulting in increased gate fees	Increased revenues are expected in case part of the Waste treated is considered renewable source	
Pyrolysis	Revenues from energy trade are expected	Very high operating and investment cost resulting in increased gate fees	Since there are no large scale units for MSW, the actual investment cost may be lower. Increased revenues are expected in case part of the Waste treated is considered renewable source of energy and policy instruments promoting production of renewable energy are in place	
Plasma	High revenues from energy trade are expected	The highest operating and investment cost resulting in increased gate fees	Increased revenues are expected in case part of the Waste treated is considered renewable source of energy and policy instruments promoting production of renewable energy are in place	

* *The financing elements of WTE plants are further analyzed in section 5.1 and 5.13*

Based on the above assessment the decision makers may have a preliminary idea of the pros and cons of each technology and based on the specific characteristics of the area of interest to select the optimum solution.

For example:

- Waste incineration advantages include:
  - The possibility to treat several waste streams
  - The huge experience and know how existing international from the large number of plants already operating
  - The smaller cost compared to other WTE technologies
  - The significant amount of energy produced
  - The low level of uncertainty following its implementation

  The main weak points of the technology are the generation of hazardous residues as well as the negative public perception towards waste incineration
- Waste gasification advantages include:
  - The increased amount of energy produced
  - The relatively low level of uncertainty following its implementation
  - The relatively acceptable experience and know how existing international from the several plants already operating
  - The great development it presents in recent years

  The main weak points of the technology are the relatively higher cost as well as the generation of hazardous residues
- Waste pyrolysis advantages include:
  - The higher amount of energy produced
  - The development it presents in recent years being and emerging technology

  The main weak point of the technology are the significant pre-treatment requirements, the low level of international experience from the operation of this technology especially in high capacities, which result in a lot of uncertainties following its implementation, the relatively higher cost as well as the generation of hazardous residues

- Plasma technology is a very new technology only recently developed, in low scale in waste treatment. Its low level of implementation increases the uncertainty for its implementation and especially in relation to its performance (e.g. on energy produced and air emissions). If, following its implementation in larger scale, its performance proves to be similar to the one presented by its providers, then this technology may become interesting for the future, despite the fact that each costs are relatively high

4 The current state of WTE technology

Table 5 summarizes the waste-to-energy technologies presented in the previous sections along with their estimated capacities and locations over the globe. Appendix 3 on the web (www.WTErt.org. Master List of WTE Plants) lists over 800 WTE plants operating globally; their total annual capacity is estimated at about 195 million tons. This list shows that 230 new WTE plants started operations in the years 2000-2011.

Table 6 shows 105 plants that were built since 2000 or are under construction in twenty-two nations, based on one of the available grate combustion technologies.

Table 5 Feedstock, energy product, and total capacity of existing WTE technologies

WTE process	Feedstock	Energy product	Estimated* annual capacity, tons	Continents/countries where applied
Combustion on moving grate	As received MSW	High pressure steam	<168 million	Asia, Europe, America
Rotary kiln combustion	As received MSW	High pressure steam	>2 million	Japan, U.S.A., E.U.
Energy Answers Process (SEMASS)	Shredded MSW	High pressure steam	>1 million	U.S.A.
RDF to grate combustion	Shredded and sorted MSW	High pressure steam	>5 million	U.S.A., E.U.
Circulating fluidized bed	Shredded MSW or RDF	High pressure steam	>11 million	China, Europe
Ebara fluidized bed	Shredded MSW or RDF	High pressure steam	>0.8 million	Japan, Portugal
Bubbling fluidized bed	Shredded MSW or RDF	High pressure steam	>0.2 million	U.S.A.
Mechanical biological treatment (MBT or BMT)	Shredded and bioreacted MSW	RDF to cement kilns and coal power plants	>5 million	E.U.
Direct smelting process	RDF	High pressure steam	>0.9 million	Japan
Thermoselect gasification	As received MSW	Syngas (CO, H_2,CO_2)	>0.8 million	Japan
Plasma-assisted gasification	Shredded MSW	Syngas (CO, H_2,CO_2)	>0.2 million	Canada, Japan, France
Global WTE capacity			**<195 million**	

**Based on data compiled by the Earth Engineering Center of Columbia University (earth@columbia.edu)*

Table 6 WTE furnaces built since 2000 using the Martin grate combustion technologies

Start-up year	Country	Plant name	Number of lines	Throughput (tons/day)	Thermal capacity (MWh/h)
2000	Italy	Busto Arsizio	2	504	61
2000	Japan	Iwaki-Nambu	3	390	53
2002	Japan	Tsushima-Yatomi	3	330	48
2000	France	Toulouse	2	547	61
2001	France	Metz	2	384	41
2001	France	Lille	3	1044	111
2004	Japan	Nagoya-Gojougawa	2	560	81
2002	Japan	Koochi	3	600	79
2001	China	Shanghai-Pudong	3	1094	77
2001	Japan	Ryuusen-En	3	317	43
2001	France	Melun	2	384	44
2001	Belgium	Thumaide	2	768	76
2001	S. Korea	Kang Nam	3	900	87
2001	S. Korea	Jang-Yu	1	199	16
2001	Switzerland	Fribourg	1	384	40
2001	Sweden	Göteborg	1	396	45
2003	Japan	Hiroshima-Naka	3	600	78
2002	Japan	Otokuni	1	75	11
2003	Germany	Mainz 1-2	2	734	89
2002	France	Belfort	2	296	31
2001	S. Korea	Incheon	2	500	56
2001	S. Korea	Guri	2	200	21
2002	Italy	Piacenza	2	360	45
2002	Japan	Tokyo-Itabashi	2	600	84
2002	Slovakia	Bratislava	2	524	50
2003	Sweden	Malmö	1	600	87
2002	Japan	Hitoyoshi	2	91	10
2004	Austria	Arnoldstein	1	260	30
2002	Japan	Niihama	3	202	28
2002	France	Villefranche sur Saône	1	156	17
2002	France	Villefranche sur Saône	1	108	12
2002	U.K.	Chineham	1	288	31
2004	France	Villers Saint Paul	2	480	53
2003	France	Nîmes	1	336	36
2004	France	Le Havre	2	576	61
2003	Switzerland	Monthey	1	291	38

2003	Japan	Tochigi	2	237	34
2005	Japan	Sendai	3	600	86
2004	Taiwan	Taichung-Wujih	2	900	100
2003	France	Toulouse	2	480	54
2004	Spain	Bilbao	1	720	71
2004	U.K.	Marchwood	2	576	61
2004	Russia	Moscow	1	200	15
2004	Italy	Brescia	1	552	100
2004	Italy	Trieste III	1	204	22
2004	China	Bing Jiang	3	450	39
2005	Taiwan	Lihtser	2	600	67
2005	Austria	Wels	1	576	80
2004	France	Est Anjou	1	360	35
2005	Japan	Miyazaki	3	579	73
2006	Japan	Kagoshima	2	530	61
2005	China	Tongxing	2	1320	97
2005	U.K.	Portsmouth	2	576	61
2005	China	Guangzhou Likeng	2	900	78
2007	Germany	Zella-Mehlis	1	518	60
2006	S. Korea	Jeon Ju	2	400	54
2005	U.K.	Sheffield	1	672	72
2007	Netherlands	Amsterdam	2	1612	187
2006	Taiwan	Miaoli	2	500	56
2005	France	Châlons en Champagne	1	360	35
2007	France	Toulouse	1	240	31
2006	China	Zhongshan	2	700	65
2009	Switzerland	Zürich-Hagenholz, 2K1/2K3	2	920	96
2009	Switzerland	Giubiasco	2	644	67
2007	U.S.A.	Lee County, FL	1	635	69
2006	China	Zhongshan	1	350	32
2007	France	Avignon	1	211	21
2007	France	Bourgoin Jallieu	2	528	64
2007	China	Fuzhou	2	1320	97
2008	Sweden	Malmö	1	696	90
2008	Macao	Macao	3	864	71
2008	France	Marseille	2	960	126
2007	Italy	Pozzilli (ENERGONUT	1	322	50
2008	Netherlands	Twente-Hengelo	1	792	92
2008	Italy	Padova	1	375	44

2008	Germany	Mainz 3	1	427	48
2009	Belgium	Thumaide	1	317	39
2009	U.S.A.	Hillsborough County, FL	1	544	65
2010	Czech Rep.	Brno	2	672	86
2010	Netherlands	Dordrecht	1	720	75
2010	Sweden	Göteborg	1	377	44
2009	U.K.	Nottingham	2	562	54
2010	China	Baoding	2	1200	97
2010	U.K. (Jersey)	Jersey	2	360	38
2012	Switzerland	Winterthur	1	324	38
2011	China	Chengdu, Phase II	3	1800	146
2011	China	Foshan Nanhai	3	1500	122
2011	U.S.A.	Honolulu	1	997	106
2011	Belgium	Thumaide	1	317	39
2012	Switzerland	Bern	1	480	57
2011	S. Korea	Asan	1	200	29
2011	Azerbaidjan	Baku	2	1584	156
2011	China	Dongguan	3	1800	146
2011	France	Arques	1	300	33
2012	China	Langfang	2	1000	78
2012	China	Taizhou City	2	1000	75
2012	Italy	Torino	3	1855	206
2012	China	Yuxi	2	400	32
2012	China	Taixing	1	300	24
2012	Italy	Bozen	1	509	59
2012	China	Cangzhou	2	800	65
2013	Sweden	Brista 2	1	864	80
2013	China	Shijiazhuang	2	1000	81
2013	China	Fengsheng	3	1800	146
2013	Denmark	Roskilde KN6	1	720	81
2013	Estonia	Tallinn	1	660	80

Grate combustion is used not only in large-scale applications, but also in small WTE plants that serve communities as small as 10,000 inhabitants. Figure 25 is based on an analysis of 2004 data compiled by the International Solid Wastes Association (ISWA)[30] for 332 WTE facilities in Europe. The plant capacities of these plants were divided in segments of 0-50000, 50000-100000 tons, etc. and the results are plotted in Figure 24 in the form of number of plants vs capacity range. Figure 24 shows that 85 plants (26% of the total number surveyed) have an annual capacity of less than 50,000 tons (roughly less than 100,000 people) and an equal number have annual capacity between 50,000 and 100,000 tons. The cumulative capacity of these 332 plants was about 50 million tons of feedstock combusted (solid line in Figure 24).

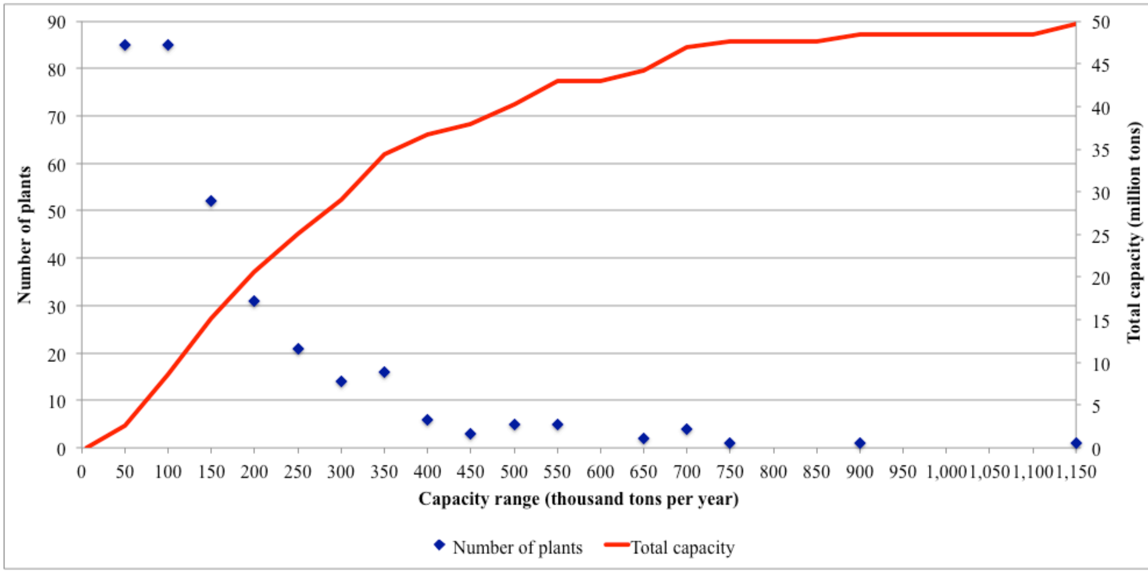

Figure 25 Number of plants vs plant capacity in Europe (ISWA, 2004 data) (EEC)

It is obvious from the above discussion and also from Appendix 3 that most of the existing and under construction WTE plants have adopted the grate combustion technology. The reasons for the global dominance of the grate combustion technology are as follows:

Simplicity of operation: Grate combustion is a fully automated process, with the exception of the two crane operators that feed the hoppers of the combustion furnace; even this part has been automated in some very recent WTE plants.

High plant availability: Grate combustion has been developed over half a century and the cumulated industrial experience has led to continuous improvement of equipment and operating methods. This, plus its simplicity of operation, has resulted in relatively low maintenance and downtime of grate combustion plants. Several providers of grate combustion furnaces will guarantee over 8,000 hours of operation in a year, that is, over 90% plant availability. Since repayment of the capital cost is the major cost item per ton of MSW processed, this is a very important factor and one that should be verified by prospective clients by examining the operating record of existing installations of the proposed technology.

Personnel requirements and training: The above two factors have resulted in the fact that a grate combustion plant consisting of three parallel furnaces (lines) and combusting 960 tons per day each (40 tons/hour per line) requires a full-time personnel of about 60 people. Also, the existence of operations of the same type elsewhere in other nations allows for fairly easy training of personnel in nations that introduce WTE for the first time.

The above factors explain the difficulty of introducing novel WTE technologies, especially for large-scale plants where the capital investment and financial risk are very high. However, the high availability of grate combustion plants is partly due to their very generous sizing and the corresponding high capital cost of WTE plants, in comparison to coal-fired power plants, per ton of material combusted or per MWh of electricity generated. Therefore, lower capital cost per ton of MSW processed is the one area where gasification and other novel thermal treatment technologies have a chance of competing successfully with grate combustion, the workhorse of the global WTE industry.

Emerging WTE technologies claim lower emissions than grate combustion but there is a need for actual operating data from such plants to back up these claims. The Earth Engineering Center has examined operating data of over two hundred grate combustion plants and they were in the order of 0.02 nanograms TEQ per standard cubic meter, which corresponds to only 0.1 grams of toxic equivalent dioxins emitted per million tons of MSW processed. Gasification plants can achieve very low nitrogen oxide emissions but very low NOx emissions can also be obtained by grate combustion facilities that use selective catalytic reduction (SCR) or the Very Low NOx (VLN) process developed by Covanta Energy and Martin GmbH.

A definite advantage of gasification processes is their ability to vitrify the ash and this explains the large number of such plants in Japan (Table 3). However, even in Japan, plants of capacity over 500 ton/day capacity utilize grate combustion furnaces backed up by a second furnace for vitrifying ash. Also, the Syncom grate combustion process, applied at Sendai, Japan, and Arnoldstein, Austria uses oxygen enriched air to produce a semi-vitrified ash.

Although grate combustion is the dominant WTE technology at this time, novel WTE processes are constantly advancing and an alternative that is less capital intensive than grate combustion may emerge. Therefore, it is recommended that municipal requests for proposals for thermal treatment of MSW include both older and new technologies, provided they meet the required performance criteria described later in this Guidebook.

5 Planning for and building a WTE plant

This Guidebook was prepared specifically for developing nations where WTE plants have not been widely implemented. WTE plants require a large investment and should be as low-risk as possible. Therefore, the following sections of this Guidebook are based on the application of a widely proven technology: Combustion of as-received MSW on a moving grate with energy recovery.

5.1 Applicability of WTE plants

Taking into account that the incineration investment costs are between 500 – 1.000 $/ton of waste (or even up to 2.000 $/ton as indicated by World bank), and the operating cost between 50-200 €/tn and hence it is clear that both investment and operational costs are a big barrier for the implementation.

It is interesting to analyze the implementation of WTE plants taking into account the GDP of each country. In order to avoid strong data limitations and gaps for the sample countries, 34 countries were taken as a more representative sample and a graph that correlates GDP/capita of 2010 and incineration was constructed and is presented below (GDP data derive from World bank, waste incineration data from Eurostat for EU Countries, USEPA for USA, and www.waste-management-world.org).

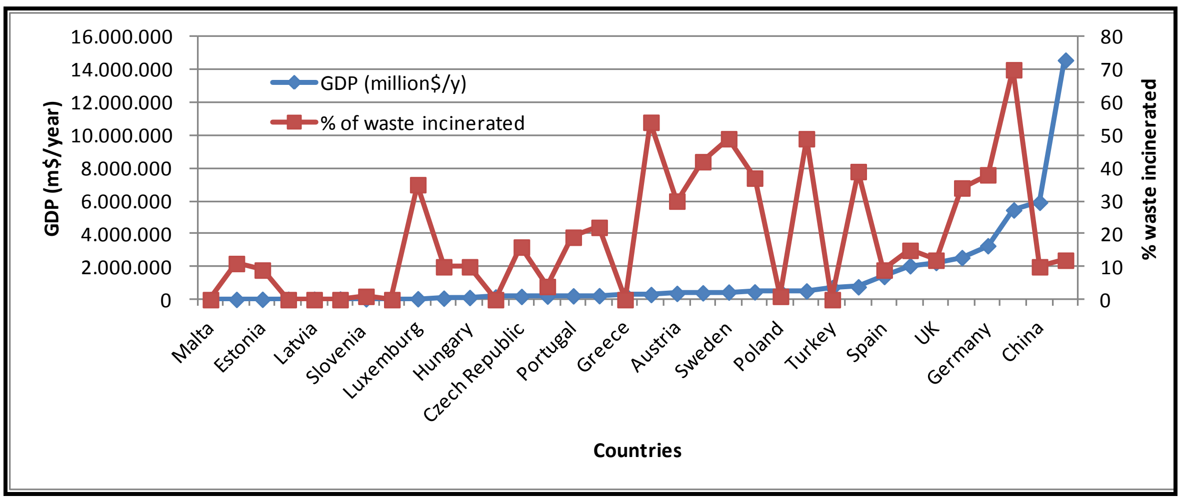

Figure 26 Correlation between GDP/year and implementation of waste incineration (EEC)

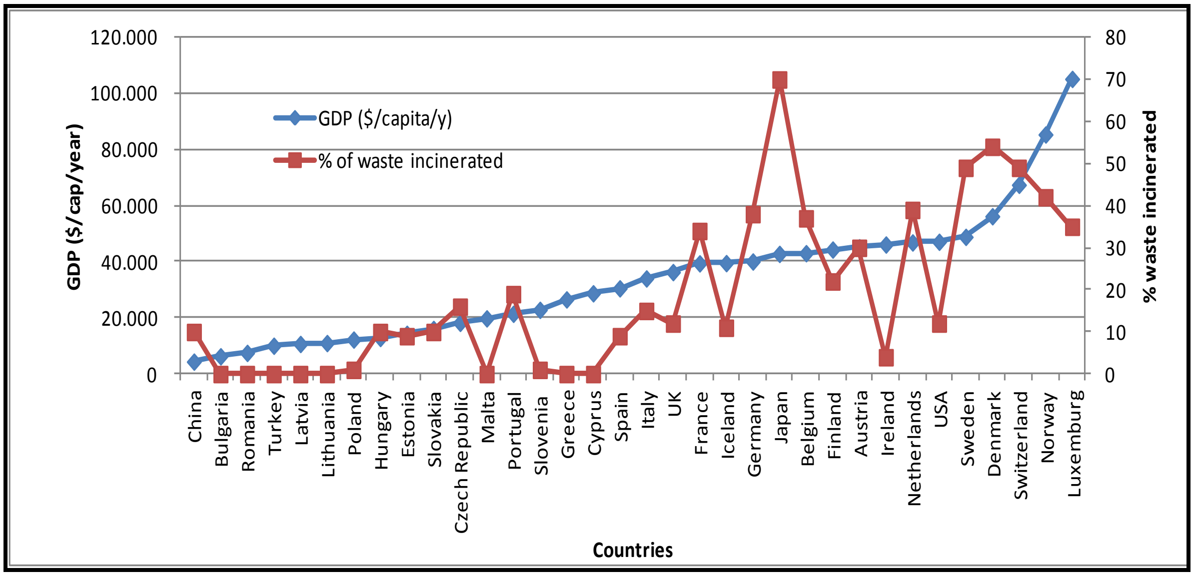

Figure 27 Correlation between GDP/capita and implementation of waste incineration (EEC)

It is clear from the figure above, that there is a positive correlation between GDP growth and incineration: the more the GDP the more the incineration. In principle there is a limit of 100 b$/year or 15.000$/capita/year of GDP where waste incineration has been implemented by a percentage exceeding 10% of waste generated. This rate increases in countries presenting higher GDP (e.g. USA, Germany, Denmark, etc.).

The role of GDP, as outlined with the previous graphs, is more than crucial for the development of WTE systems. Most of the current problems of WTE in low-income countries are directly related with the lack of substantial resources, both for the construction and operation of WTE facilities. A substantial growth of GDP will result in a different social context of those countries and thus to a different waste management system.

Having described the correlation between the implementation of WTE and GDP as it appears in the countries where WTE facilities have been developed, additional applicability pre-conditions should be considered when deciding whether a WTE plant is suitable for a specific region. These pre-conditions include:

- **Waste quantity to enter the WTE plant**: International experience has shown that economies of scale dictate that in order for a WTE plant to be viable its capacity should have a high capacity. The following graph (DEFRA, 2007) presents the costs of the WTE plans for various capacities in the form of gate fees (the fees include both financing and operating costs).

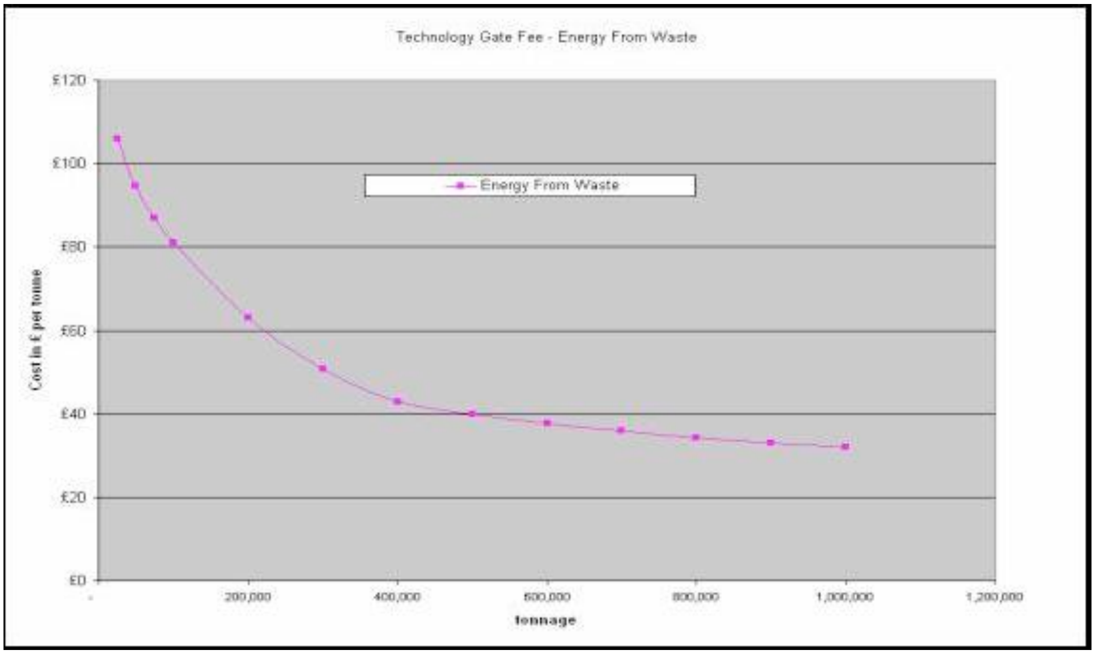

Figure 28 Economies of scale for waste incineration (EEC)

As it is apparent from this figure the cost of WTE is extremely high for capacities lower than 300.000 tn/y, while the cost benefits of increasing facility scale begin to reduce above 400.000 tn/y. Based on the above it is concluded that the WTE plants capacities should not be below 150.000 – 200.000 tn/y in order to be financially feasible.

- **Upstream activities**: waste collection should be well organized and waste pretreatment would increase the calorific value of the waste that will enter the WTE plants. In this way the financial performance of the WTE plant may be significantly improved
- **Waste composition**: Certainly the energy production from a WTE plants depends on the input composition and properties (e.g. moisture) which affects the calorific value of the final blend. The high organic content that usually appears in medium- and low-income areas generally means very dense waste, high moisture content and reduced heating values, as opposed to relatively light waste with low organic content in the higher income countries. This aspect should also be taken into account when deciding on the possibility to develop WTE plants as it has a negative impacts on the WTE plant economics
- **Energy absorption**: a well maintained electricity grid able to absorb the energy from the WTE plant should be in place, otherwise the implementation of a very expensive WTE plant cannot be justified

- The viability of a WTE plant is very sensitive on the **prices** it may sell the energy produced, which has to be high enough in order for the WTE gate fee to remain in comparable levels against the landfilling. A price of not lower than 80$/MWh should be in place in order for the revenue from the energy produced in WTE plants to be enough in order to decrease the respective gate fees. In this respect the fact that part of the energy produced in WTE plants is deriving from the biodegradable fraction of waste, thus being renewable energy, should be considered when developing the price policy for the energy produced in WTE. The need to produce energy from renewable sources has been internationally recognized and motives (e.g. subsidies, green certificates) should be put in place in order to promote the utilization of renewable energy sources. According to the Confederation of European WTE plants (www.cewep.eu), on average 50% of the energy produced in WTE plants is considered to be renewable, while in some Countries (e.g. in Denmark) this rate reaches 80%.
- **Affordability**: the willingness to pay is usually correlated with the average income of the citizens or at least with the GDP / capita. The average affordability thresholds used internationally lie between 0,2 – 0,5% of average GDP/capita. Assuming an average gate fee for WTE plant of 60-100$/tn, corresponding to 40% of the overall waste management cost (including collection, transportation, recycling and disposal), waste generation per person of 350 kg/year, WTE plants would be more affordable in areas, where the average GDP is at least 10.500$/capita.
- The viability of WTE plants is more probable if the utilization of electricity is combined with the **utilization of the thermal energy produced**. Considering the fact that district heating networks are not common in Latin America and Caribbean countries, the only end users of the heat may be heat consuming industries. Therefore it is preferable for the WTE plants to be close to industrial areas in order to increase the opportunity of absorption of the heat produced.
- The viability of a waste management system that includes WTE facilities is related with the fact that WTE plants may be located very close or even inside the metropolitan areas (such examples exist internationally) and therefore the respective collection and transportation costs are decreased, the waste quantities generated are high and the GDP/capita is always higher than the average of the respective country. In this case the overall costs of the system with WTE may be comparable to the systems that do not include WTE

5.2 Selecting the size of the WTE furnace and plant

Deciding on the required capacity of a WTE plant is critical. The municipality must consider the amount of waste that can be consistently delivered to the plant, day by day, throughout the year, taking into account:

- Current rate of waste generation and projected rate for next thirty years; projections should be based on population growth with time and also on further economic development.
- Current and projected rates of recycling and composting. International experience has shown that rigorous recycling and composting programs can increase the sum of recycling and composting rates to as much as 40% - 60% of the MSW generated in developed nations through long-term coordinated efforts including regulation, incentives, and public education. The Guidebook recommends that plans for a new WTE be accompanied by planning for single stream collection of designated recyclables (paper fiber, metals, and certain types of plastic and glass). Preferably, the collected recyclables should be brought to a Materials Recycling Facility built adjacent to the WTE plant where they are sorted out to marketable materials and the residue is combusted in the WTE. Collection of the recyclables can be done either formally, by the community, or informally by individuals who follow rules established by the community.

5.3 Materials that can be processed by grate combustion

The feedstock to the WTE can include all non-radioactive and non-explosive materials:

- Residential and commercial wastes remaining after the projected recycling and composting.
- Combustible industrial wastes that are currently disposed in regulated or non-regulated landfills and are mixed with the MSW in the storage bunker.
- Post-recycling combustible construction and demolition wastes.
- Sludge cake generated by the wastewater treatment plant of the municipality.
- Shredded rubber tires, mattresses and post-recycling furniture.
- Hospital wastes that are contained in sealed thick plastic bags, such as are used in medical incinerators.

In the case of medical wastes, our analysis of a tabulation of all European WTE plants by the International Solid Wastes showed that forty-one plants reported co-combusting medical wastes (Table 7); on the average, the medical wastes co-combusted by these plants amounted to 1.8% of their total feedstock.

Table 7 Co-combustion of medical wastes in Europe (ISWA, 2004)

Country	Plant Name/Location	Total combusted (tons/yr.)	Medical wastes (tons/yr.)	Medical wastes as % of total
Norway	Lenvik	5,050	120	2.38%
Italy	Rufina/Pontassieve	9,878	31	0.31%
Italy	Ferrara	20,500	613	2.99%
Great Britain	Shetland Islands	21,511	16	0.07%
Italy	Terni	27,000	1,200	4.44%
Norway	Spjelkavik	34,658	210	0.61%
France	Douchy les Mines	39,295	3,530	8.98%
Sweden	Karlskoga	42,600	200	0.47%
Italy	Melfi PZ)	47,000	2,000	4.26%
Italy	Desio (MI)	49,019	3,152	6.43%
Denmark	Svendborg	54,000	400	0.74%
Italy	Schio (VI)	57,470	4,700	8.18%
Italy	Ospedaletto (PI)	57,944	3,525	6.08%
Italy	Vercelli	58,890	2,600	4.42%
Germany	Neustadt	59,449	668	1.12%
Italy	Padova	60,376	2,992	4.96%
Denmark	Hjørring	61,270	479	0.78%
Italy	Valmedrara (LC)	62,300	5,600	8.99%
Italy	Cremona	64,996	529	0.81%
Belgium	Houthalen	69,195	1,700	2.46%
Germany	Kempten	76,661	514	0.67%
France	Villefranche sur Saône	78,301	287	0.37%
Norway	Frederikstad	80,381	760	0.95%
Belgium	Gent	94,383	475	0.50%
Norway	Bergen	105,000	1,300	1.24%
Czech Republic	Brno	106,740	254	0.24%
Italy	Piacenza	111,409	750	0.67%
Switzerland	Lausanne	120,000	6,000	5.00%
Italy	Modena	122,042	5,000	4.10%
Norway	Oslo (Klemetsrud)	148,161	1,677	1.13%
Italy	Ravenna	169,954	9	0.01%
Belgium	Brugge	174,733	3,523	2.02%
Italy	Granarolo Emilia (BO)	179,676	2,418	1.35%
Denmark	Århus	183,047	361	0.20%
Germany	Völklingen	210,488	2,270	1.08%
Belgium	Thurmaide	259,614	22,157	8.53%
Austria	Zwentendorf	323,000	800	0.25%

Germany	Krefeld	346,231	1,263	0.36%
Sweden	Malmö	385,879	1,700	0.44%
Denmark	København	401,823	1,942	0.48%
Netherlands	Amsterdam	877,351	9,733	1.11%
Total (41 plants reporting)		**5,457,275**	**97,458**	**1.8%**

Analysis of the same data, showed that twenty-three plants reported co-combustion of sludge from wastewater treatment plants (Table 8). On the average, the sludge combusted by these plants amounted to 2% of the total feedstock.

Table 8 Co-combustion of wastewater sludge in Europe (ISWA, 2004)

Country	Plant Name/Location	Total (tons/yr.)	Tons wastewater sludge	Sludge as % of total combusted
France	Besançon	50,000	6,000	12.00%
France	Arrabloy	53,707	3,091	5.76%
Netherlands	Roosendaal	55,166	99	0.18%
Denmark	Hjørring	61,270	2,735	4.46%
France	Villefranche sur Saône	78,301	1,004	1.28%
Italy	Macomer (NU)	79,000	500	0.63%
France	Taden	103,200	9,525	9.23%
Denmark	Hørsholm	109,493	137	0.13%
Switzerland	Lausanne	120,000	6,000	5.00%
Italy	Verona	131,300	700	0.53%
France	Cenon	134,242	11,104	8.27%
Sweden	Halmstad	146,804	1,224	0.83%
France	Thiverval-Grignon	191,000	5,600	2.93%
Germany	Völklingen	210,488	452	0.21%
Italy	Macchiareddu (CA)	212,600	9,000	4.23%
Germany	Kamp-Lintfort	221,145	4,700	2.13%
Belgium	Thurmaide	259,614	7,352	2.83%
Spain	Palma De Mallorca	328,747	2,056	0.63%
Germany	Krefeld	346,231	16,873	4.87%
France	Issy-Les-Moulineaux	537,094	532	0.10%
France	Saint Ouen	622,653	463	0.07%
France	Paris	690,123	990	0.14%
Netherlands	Amsterdam	877,351	23,981	2.73%
Total (23 plants reporting)		**5,619,529**	**114,118**	**2.03%**

It should be noted that only some WTE plants reported to ISWA materials that were co-combusted. Therefore, there could be other co-combusting WTE plants that are not included in Tables 8 and 9.

5.4 WTE Plant Configuration

In the case of communities where there is large seasonal variation of MSW due to tourism, it may be necessary to provide for temporary storage of MSW during the tourist season.

Grate combustion WTE plants can be guaranteed to have 90% availability, i.e., to be in full operation 8,000 hours per year. A WTE line consists of the furnace (Figure 31), boiler, and Air Pollution Control (APC) system. For example, a 40 ton/hour line will process 40 x 8000 tons per year = 320,000 tons of MSW; however, smaller and larger capacity grates have been designed and are in operation.

Table 6 shows several single-line plants that have capacity of only 5 tons per hour per line, i.e. annual capacity of 40,000 tons.

Most WTE plants consist of one to three lines in parallel. However, there are some larger plants, such as TUAS Singapore South with six combustion lines and Singapore Senoko with five combustion lines. Each line is provided with its own furnace, boiler and APC system. However, a common steam turbine can use the superheated steam generated in two or more lines. Also, the cleaned gas from all lines is led to a common stack.

At earlier times, it was preferred to divide the required plant capacity to two or three lines. However, as the grate combustion technology matured and became fully reliable, several recent plants (Appendix 3) consist of only one line since they are less costly to build and operate.

The number of lines and their capacity will depend on the requirements of each community. The reader will find additional information in the three Case Studies for Argentina, Chile and Mexico that are presented in Part 2 of this Guidebook.

Considering the above factors, a community can plan the capacity of the plant according to its needs. It is important to mention that if the community cannot afford to build a plant as large as it would like to, it can always start by building fewer lines and expand the plant later. In such cases, the building housing the initial plant should be designed so as to allow for future expansion at minimum cost.

5.5 Selecting the site for the WTE plant

The perception that WTE facilities are undesirable neighbors from an esthetic viewpoint has also been an obstacle to the development of WTE. However, modern WTE facilities operating in the U.S., Europe, Japan, and other nations have been designed with this concern in mind. WTE plants located in the center of architecturally sensitive cities, such as Vienna, Osaka, and Paris, have shown that designs can be made compatible with local esthetic requirements. One of the most recent plants is the Isseane WTE on the Seine, five kilometers from Eiffel Tower. A gallery of hundreds of WTE facility photos showing their modern design features is available on the web[31].

As a rule, WTE plants should be sited at locations that esthetically and functionally will be improved by such a facility. This is in definite contrast to landfills that are usually located at greenfields far away from inhabited areas. Examples of locations that can be improved by the addition of a modern WTE are old and operating landfills, abandoned mining sites and quarries, and past industrial sites. However, it should be noted that many WTE plants around the world are built in the middle of residential or industrial sites so as to minimize travel distance from the point of generation to the WTE; and also to facilitate the use of the by-product low-pressure steam of the turbine generator for district or industrial heating or cooling. An example of this practice is Denmark where a population of 5.5 million is served by 28 WTE plants, most of them in urban areas.

In contrast to landfills, the architecture and landscaping of modern WTE plants can be esthetically pleasing and attract visitors. Some cities, such as Vienna, Paris, Osaka, and Brescia have built WTE plants that have become landmarks and tourist attractions. The most recent addition will be the new WTE of Copenhagen that is planned to have a roof to be used as a ski slope.

The factors that should be considered for the selection of the WTE plant site are:

- Proximity to waste generation center
- Proximity to electricity connection lines
- Proximity to district heating or cooling
- Proximity to water
- Proximity to industrial steam consumers
- Proximity to landfill (for ash disposal)
- Access roads
- Traffic
- Utilities

Table 9 shows approximate land requirements of various plants configurations, Figure 29 shows the plant dimensions for a two-line 400,000 ton capacity WTE, and Figure 30 shows the site plan for a two-line 640,000 ton capacity plant. When there are land constraints, the plot plan of a WTE can be considerably smaller.

Table 9 Land area requirements examples

Capacity (tons)	160,000 (-line)	336,000 (2–line)	640,000 (2-line)	960,000 (3-line)
Plant length (m)	150	240	360	360
Plant width (m)	70	100	130	150
Total plant area (m^2)	10,500	24,000	46,800	54,000
Land length (m)	250	360	460	460
Land width (m)	170	230	230	250
Total land area (m^2)	42,500	82,800	105,800	115,000
Land occupied by plant	25%	29%	44%	47%

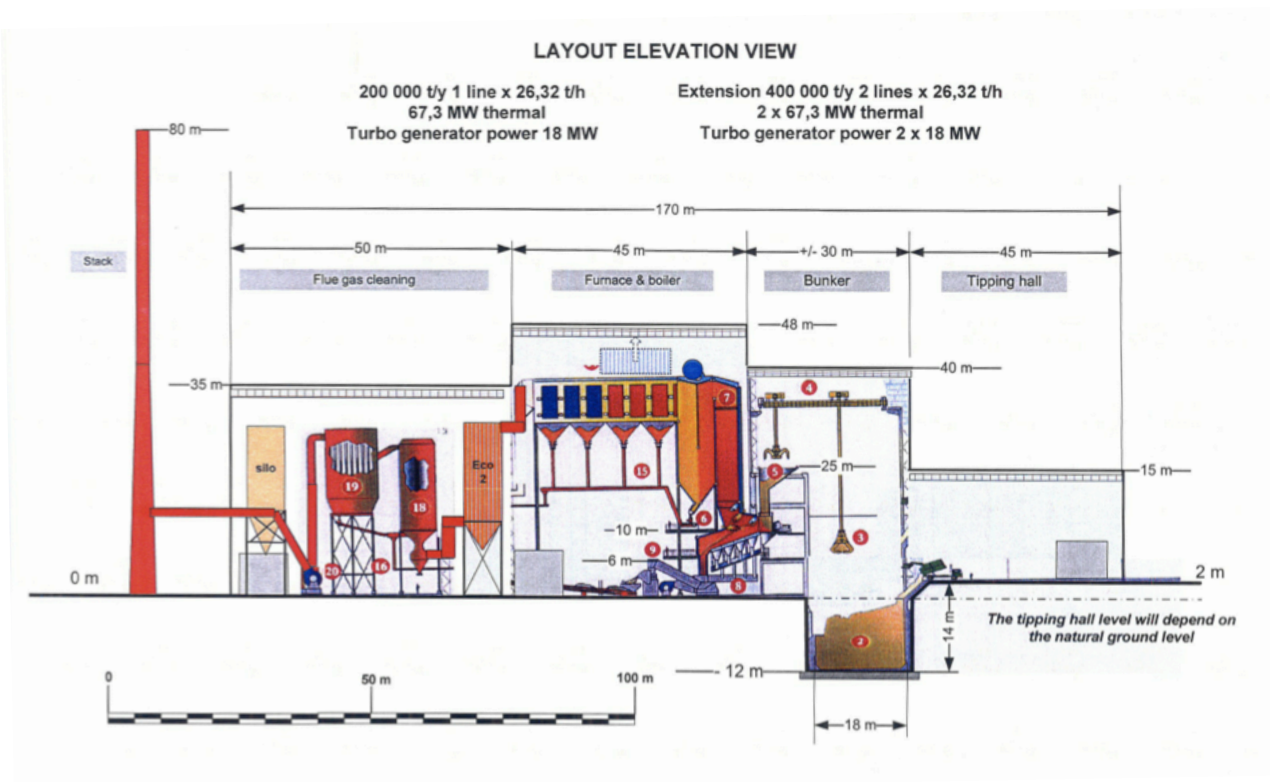

Figure 29 Layout elevation view of a grate combustion WTE (EEC)

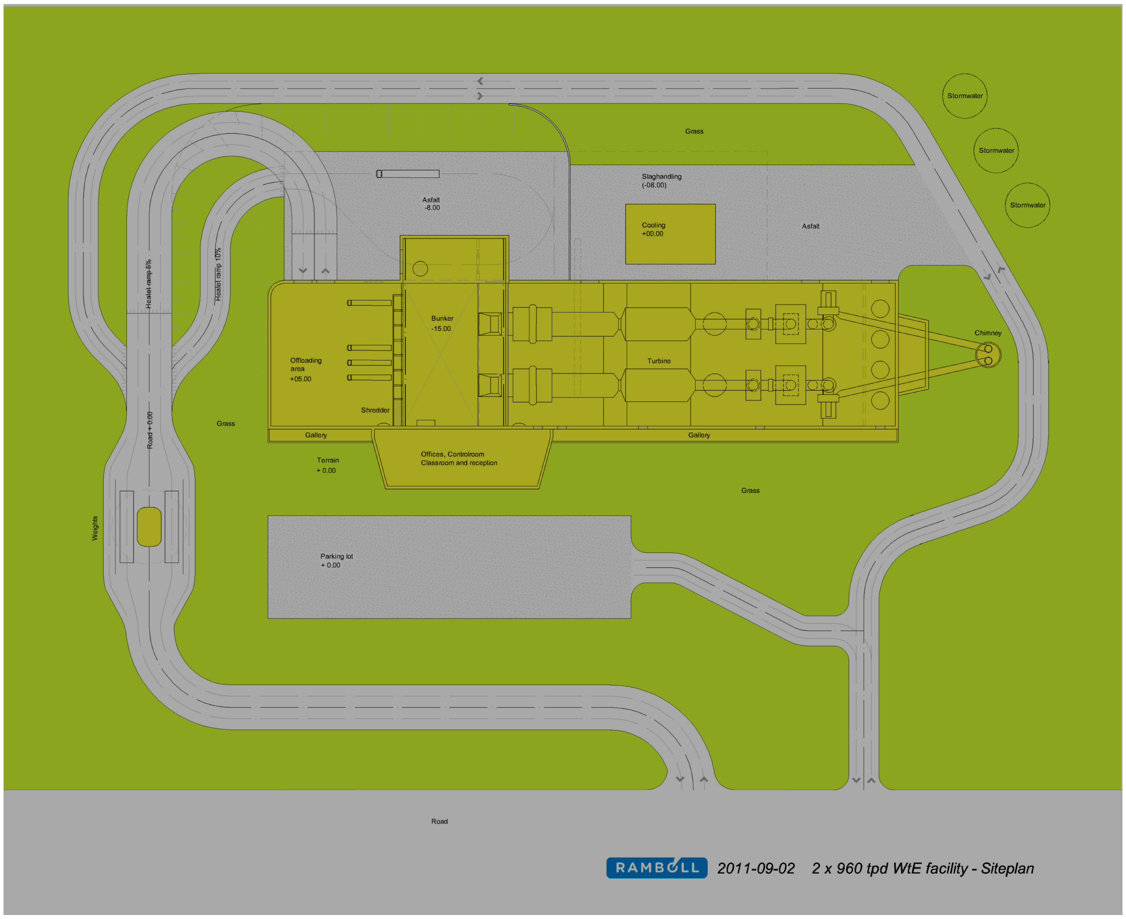

Figure 30 Site plan for two-line x 960 tons/day plant (EEC)

5.6 Receiving building and waste bunker

The collection trucks are weighed at the plant entrance and then enter the receiving area of the plant. This building is under negative pressure so that no odors are emitted to the surroundings when the building doors are open. The building air is used for combustion in the WTE furnaces.

The concrete bunker of a typical two-line 300,000-ton plant is about 16 meters wide by 60 meters long and 15 meters deep. Therefore, it has a volume capacity of about 15,000 cubic meters.

5.7 The combustion chamber

The combustion chamber (Figure 31) is the heart of the WTE plant. The grate width ranges from 3-12 meters, depending on the furnace capacity, and its length is about 8 meters, thus providing for a residence time of the solids in the furnace of about one hour. The high temperature oxidation in the combustion chamber reduces objects as large as a big stuffed suitcase to ash that is discharged at the other end of the grate. The furnace height above the grate is about 20 meters so that the combustion gases have a travel time of 4-8 seconds within the combustion chamber ("first pass"). The enormous size of these furnaces explains their ability to combust all sizes of MSW.

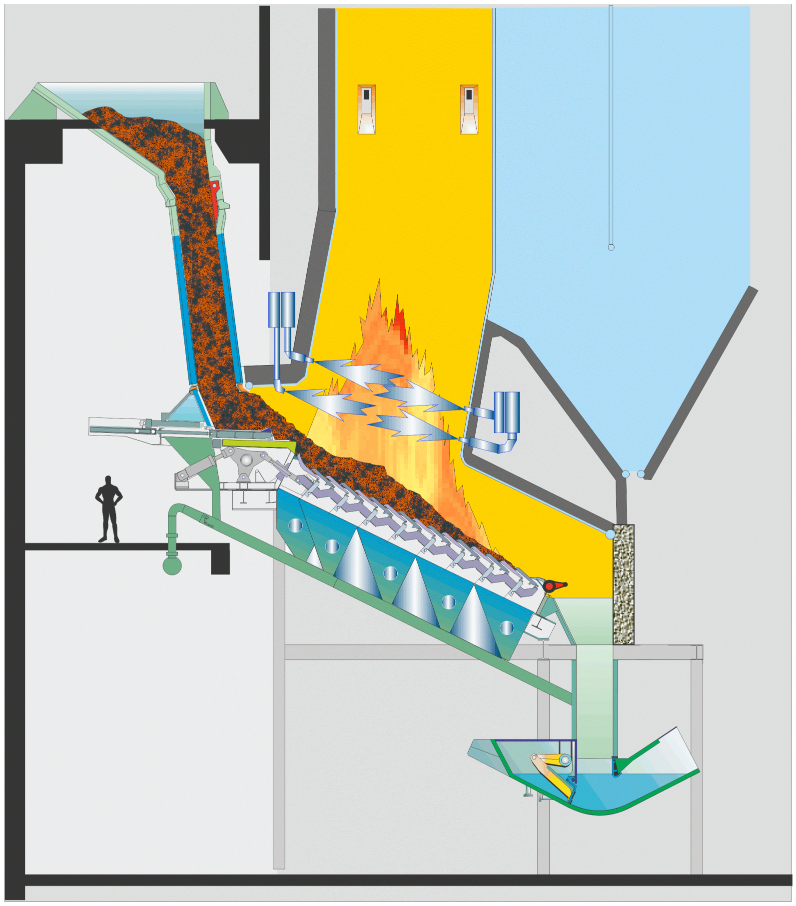

Figure 31 WTE combustion chamber with inclined moving grate (Koralewska, R., .Martin GmbH, presentation at WTERT Bi-annual meeting, October 2006)

The average heat generation over the entire surface of the grate is about one megawatt per square meter and combustion temperatures range from 950-1100^{o}C. The furnace height above the grate is about 20 meters so that the combustion gases have a travel time of over four seconds within the combustion chamber ("first pass"). The enormous size of these furnaces explains their ability to combust all sizes of MSW.

The heart of the WTE furnace is the moving grate that transports the waste from the feed end. Proven great technologies range from inclined grates, either forward or reverse-acting to the direction of solids flow, to roller grates, to horizontal grates; also, grates are either air-cooled, by means of the primary air flow, or water-cooled by water flowing through tubes installed within the grate bars. The Earth Engineering Center of Columbia has investigated the flow of solids on different grates and has also discussed this subject with WTE experts in different parts of the world. As of this time, there is no clear answer as to which type of moving grate is the optimum one to use because this issue goes way beyond transport and chemical rate phenomena; it also involves capital and operating costs, maintenance, and plant availability; for example, one of the major providers of WTE, Martin GmbH, installs both inclined and horizontal grates, depending on the customer's preference. Therefore, the choice of grate technology is made on the basis of proven performance and plant availability and the overall proposal and guarantees submitted by various providers of grate combustion technology. The master list of grate combustion plants provided in Appendix 3 shows the grates used in over 800 WTE plants around the world.

An important criterion for grate performance is the amount of carbon that is left in the ash leaving the furnace. The desirable concentration is less than 1% carbon.

5.8 Energy recovery

As explained earlier, the energy content of MSW depends on its composition and moisture content. Energy recovery per ton will depend on the net calorific value (or lower heating value) of waste, the efficiency of the furnace, and whether the energy is used to generate electricity and / or steam (for district heating, industrial plants in the vicinity of the WTE, need for desalination of water on islands, etc.).

The heating value of MSW varies from country to country and also among cities in the same nation. Therefore, characterization of the composition of MSW to be combusted in the WTE is the second important task, after determining the amount of solid wastes to be combusted annually. If the energy content of waste is less than 6 MJ/kg, it may not be worth building a WTE facility.

Considering a typical MSW in the LAC region of 9 MJ/kg, i.e. 2.5 MWh per ton, it can be assumed that the heat losses of the furnace, in the ash, and the stack gas of a 200,000 ton WTE are 10% of this amount. Therefore, the heat in the superheated steam entering the turbine generator will be 2.25 MWh per ton of MSW combusted.

For thermodynamic reasons, the thermal efficiency of the steam turbine depends on the pressure of the entering superheated steam and the pressure at the exit of the turbine where the steam is either condensed by air or water flow or is used for district heating or other purpose. Since the WTE combustion gases contain much more chlorine than coal-fired power plants, the temperature and pressure of the superheated steam are lower, typically in the range of 400-450^{o}C. Therefore, the thermal efficiency of the WTE steam turbine is about 28% and the gross power generated by the turbine 2.25 x 28% = 0.6 MWh of electricity per ton of MSW. However, an estimated 15% of this electrical energy will be used within the plant so that the energy delivered to the grid from this plant will be 0.5 MWh per ton of MSW combusted.

For larger size plants, the furnace loss is lower and the thermal efficiency of the turbine higher. Thus, a 1,000,000 ton plant is expected to produce a net of 0.65 MWh/ton of electricity. The most recent WTE in Amsterdam is actually delivering to the grid over 0.7 MWh per ton of MSW in addition to exporting steam and hot water for district heating.

5.9 The R1 thermal efficiency factor of the European Union

Co-generation of electricity and heat can result in much higher recovery of energy. To encourage WTE plants to aim for high thermal efficiencies, the European Union has instituted the R1 rule. According to this rule, a WTE is considered as a recovery facility when the R1 factor, calculated as follows:

$$R1 = (2.6\ MWh_{elec} + 1.1\ MWh_{heat})\ /\ 0.97\ MWh\ \text{stored in the MSW}$$

Where the factors *2.6* and *1.1* express the energy required to produce electricity and heat, respectively, and the factor 0.97 the 3% expected heat loss in transforming chemical to thermal energy is greater than 0.6 (> 0.65 for recently built WTE plants). For example, in the case of an existing WTE plant producing for the grid 0.6 MWh of electricity per ton MSW, the R1 factor would be:

$$R1 = (2.6 \times 0.6)/(0.97 \times 2.8) = 0.63$$

Obviously, the WTE revenues from energy recovery will be higher in the case of co-generation of electricity and heat. There are WTE plants in Europe that generate as much as 0.5 MWh of electricity plus 1 MWh of heat. The corresponding R1 factor is:

$$R1 = (2.6 \times 0.5 + 1.1 \times 1)/(0.97 \times 2.8) = 0.88$$

In all recent WTE projects in Europe, the R1 criteria are mandatory and must be guaranteed by the companies bidding for such projects.

The challenge for LAC region cities that want to build WTE plants is to find, or locate, companies near the WTE who can use the low pressure steam, e.g. paper recycling or food processing plants. The problem is that some LAC countries do not have the necessary laws and regulations in place for co-generation and, in some cases, they prohibit it.

5.10 Emission control of WTE plants

The negative public perception of WTE plants is based on emissions of incinerators that stopped operating two decades ago. In the U.S. the MACT (Maximum Achievable Control Technology) standards for Large Municipal Waste Combustors (MWC), issued by the U.S. EPA[32] under the requirements of the Clean Air Act, established mandatory emissions limitations that are protective of human health and the environment. The existing 87 U.S. WTE facilities that process about 26 million tons of MSW are in full compliance with these requirements that are more stringent than for any other high temperature source, such as coal-fired power plants, metal smelters and cement plants. The same is true in E.U., Japan and all other developed nations that use WTE.

Opponents of WTE picture modern WTE plants as major polluters but there are no credible data to back up these claims. To illustrate this point, there are two ways to consider the relative impacts of modern WTE plants. First, Table 10 shows the impact of MACT on the U.S. WTE industry by comparing pre-MACT to post-MACT national emissions rates. Except for NO_x that was reduced by 24%, WTE emissions were reduced by 90% and in the case of dioxins and furan exceeded 99.9% reduction from 1990 emission levels. It should be noted that since 2005, the average dioxin emissions of the U.S. WTE plants have been reduced further to 0.045 nanograms TEQ, corresponding to an annual 6 grams TEQ for the entire industry. In comparison, the dioxins emitted from uncontrolled burning of residential and garden/field waste ("backyard barrel burning") have been estimated at over 500 grams TEQ per year.

Table 10 Effect of implementation of MACT by the U.S. WTE industry33

Pollutant	1990 Emissions	2005 Emissions	Percent Reduction
Dioxins and furans	4,400 g TEQ/yr	15.0 g TEQ/yr	99+%
Mercury	57 tons/yr	2.3 tons/yr	96%
Cadmium	9.6 tons/yr	0.4 tons/yr	96%
Lead	170 tons/yr	5.5 tons/yr	97%
Particulate Matter	18,600 tons/yr	780 tons/yr	96%
HCI	57,400 tons/yr	3,200 tons/yr	94%
SO_2	38,300 tons/yr	4,600 tons/yr	88%
NO_x	64,900 tons/yr	49,500 tons/yr	24%

The potential impact of WTE emissions per MWh of electricity produced can be compared with other sources of electrical energy. Figure 32 shows that only natural gas and nuclear power plants have lower stack carbon emissions per MWh. Furthermore, when the avoided landfill emissions of methane are taken into account, WTE actually results in net reductions in GHG emissions for every MWh generated or ton of PRW processed. As a consequence, the World Economic Forum, the U.S. EPA, the European Union, and the IPCC all view WTE as a mechanism to reduce GHG emissions. Figure 33 and Figure 34 show that SO_x and NO_x emissions per MWh of electricity generated are also comparatively low.

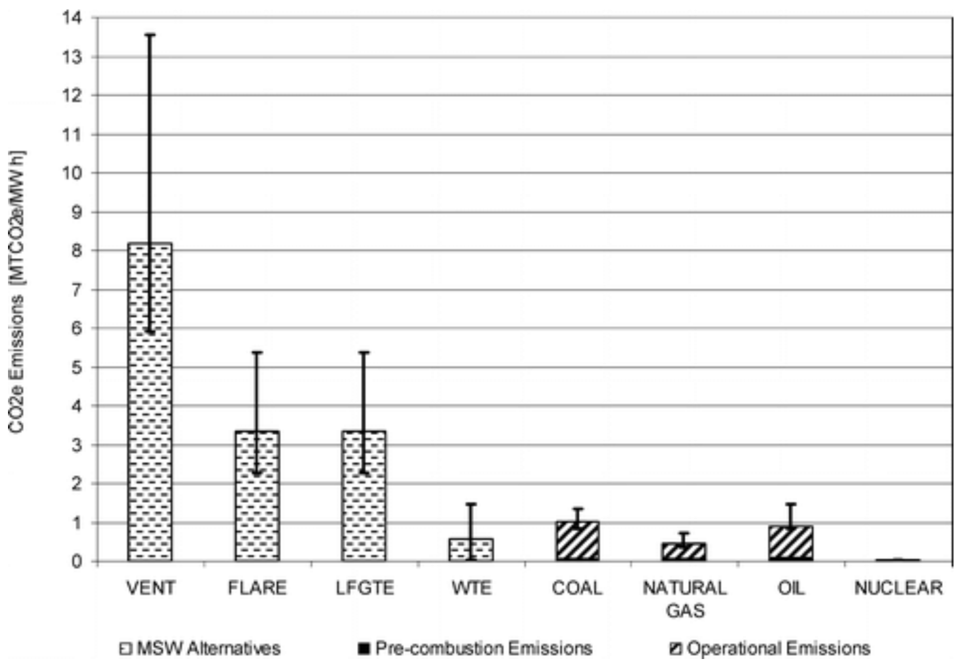

Figure 32 Carbon dioxide emissions (metric tons CO_2/MWh) of various energy sources[34]

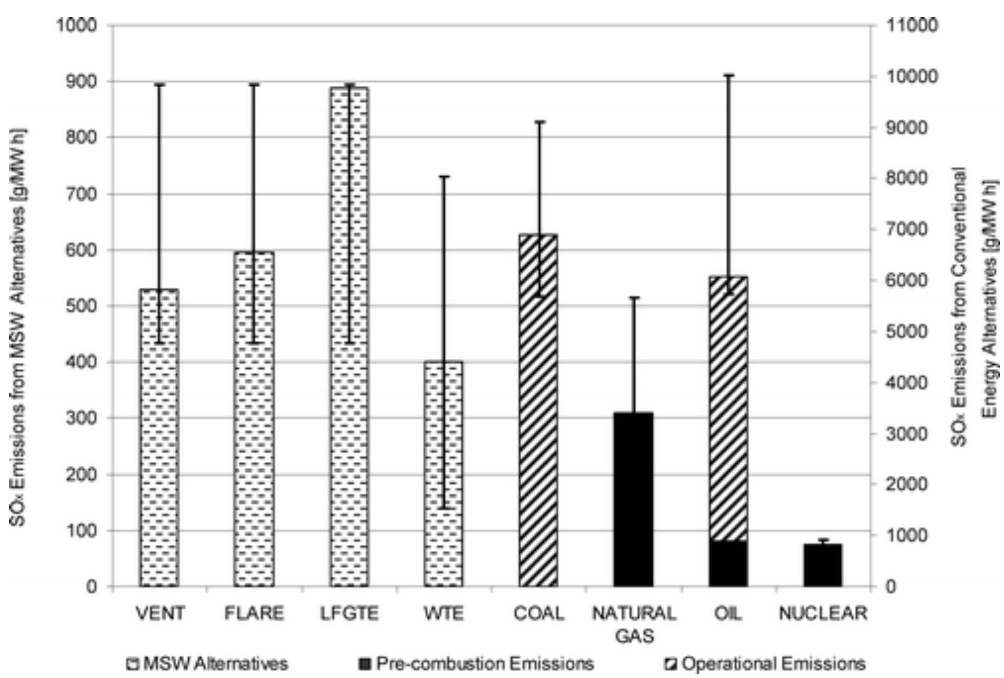

Figure 33 Sulfur dioxide emissions (g/MWh) of various energy sources[34]

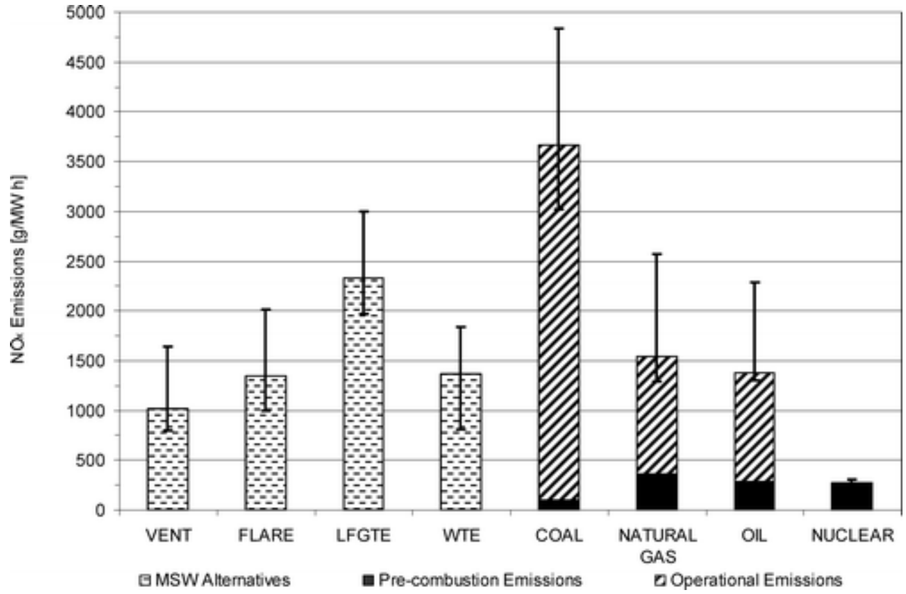

Figure 34 Nitrogen oxide emissions (g/MWh) of various energy sources[34]

5.10.1 APC Systems

In summary, the APC systems of modern WTE facilities are amongst the most advanced of all high temperature industrial processes, including coal-fired power plants, metal smelters and cement plants.

The following table gives an indication of the technologies used for the treatment of the waste incineration flue gases.

Table 11 Main APC systems in WTE plants

Parameter	Used abatement technology
Suspended solids	Cyclones
	Electrostatic precipitator (wet – dry)
	Bag filters
Acid gases	Dry sorption
	Semi dry sorption
	Wet scrubbers
Nitrogen oxides	Selective non catalytic reduction
	Selective catalytic reduction

A typical air emissions control system may include:

<u>Semi - dry scrubber</u>

Dry and semi-dry scrubbing processes are simple and hence cheap concerning their investment and are in use in many plants all over the world. In most cases the adsorbent is either injected directly into the gas duct or into a spray dryer downstream of the boiler in dry form (dry process) or as a slurry (semi-dry process). The scrubbing products are in most cases removed from the flue gas by a fabric filter.

As flue gases enter the dry scrubber lime milk is sprayed to cool them down and to react with acids like HCl and SO2, while partially capturing mercury.

Liquids evaporise in the vertical scrubber and after evaporation the reaction products have the form of dry dust in the flue gases. Larger particles fall at the bottom of the scrubber and are removed.

The reactant used is proposed to be lime milk (suspension of fine Ca(OH)2 in water). The actual reaction are quite complex but in a simplified version, the main chemical reactions are:

$$Ca(OH)_2 + SO_2 \rightarrow CaSO_3 + H_2O$$

$$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O$$

$$Ca(OH)_2 + 2HgCl_2 \rightarrow CaHgCl_2 + 2H_2O.$$

Semi-dry scrubbers offer several advantages, such as:

- In combination with other materials such as activated carbon at least 50% of mercury and cadmium is removed
- No wastewater is produced

These advantages balance the disadvantage of slightly larger quantities of fly ash.

Depending on the composition and temperature of flue gases the lime slurry solution will be sprayed in a concentration range of 3 to 20% w/w. [usually 15%w/w]

The lime slurry will be created with the use of CaO (quick lime).

- Entrained Suspension Reactor

The use of this reactor optimizes mass transfer between the calcium hydroxide and the flue gases and offers high removal rates of the polluters in the flue gases. Such reactors are vertical with a cone-shaped floor. Depending of the entrance point of the flue gases spraying may be done at the flow direction, or „contra" flow. The spraying system itself has two types: rotary atomizers and dual fluid nozzles».

Main design parameters are enough space to ensure good contact of acid gases with the reactant. Besides, the suspension of Ca(OH)2 in water should be dried enough to ensure no wastewater is produced. Usually Computation Flow Dynamics is utilized to optimize flow and mass transfer operations. Also, the flue gas residence time is rather important and should be at least 15 seconds.

- Recirculation of Fly Ash

A high proportion of dust from the bag filters is recirculated back in the entrained suspension reactor so that calcium is completely consumed.

Initially, this dust is collected by feeder screws or drag conveyors. The amount of recirculation is controlled by a frequency converter of the feeder screw, while material not recirculated is moved to the residues silo.

Fly ash enters the reactor and gets carried away by the flow of gases and therefore a fluidized bed is flowing between the reactor and the bag filter that ends up in the entrained suspension reactor.

Powdered Activated Carbon (PAC) Injection

Powdered Activated Carbon (PAC), is used to remove heavy metals and organic compounds. The system includes a PAC silo, a feeder, an injection blower and an in-pipe reactor with injection nozzle and injection valve.

PAC is transferred pneumatically from the silo to the exit pipe of the scrubber and is injected in the entrained reactor between the semi-dry scrubber and the bag filter.

- PAC Silo

The silo consists of a cylinder and two feeding funnels (con-shaped) made of special steel. In order to allow inspection two sliding doors will be situated at the lower part.

- PAC Feeder

The feeder should continuously supply PAC to the injection system. The amount of PAC is determined according to the flue gases flow after the bag filters (i.e. through a dosing screw)

- Injection Blower

For good system operation three injection blowers will be installed (one spare). At the exit of the blowers pressure gauges should be installed for measuring pressure. Pressure transmitters should be located at the main injection lines for monitoring air input pressure.

- Removal of Heavy Metals

Mercury, cadmium, thallium and partially arsenic are removed by the activated carbon while molecules of these metals become adjacent to the small dust particles captured at the bag filters. Other heavy metals also cling onto dust particles and are removed.

- Removal of Volatile Organic Compounds (VOC's), Dioxins/Furans and PolyAromatic Hydrocarbons (PAH)

Activated carbon „captures" such compounds and then the PAC dust is removed in the bag filters. Residues from the bag filters are stored in the fly ash silo and are transferred outside the plant for proper management.

Bag filters

Bag filters ensure very efficient collection of dust, while at the same time they absorb further the acidic residues. In order to achieve this further absorption it is important that a layer of dust is maintained on the fabric. The layer of dust will efficiently collect particles with diameter of smaller than mikrons (μm). This ensures high removal efficiency of heavy metals and dioxins, since those of are usually smaller particles.

The automatic system of control and cleaning of filters (that it is caused - begins from the detected pressure difference of filters) ensures, that continuously a layer of dust will remain on the bags/filters. The cleaning of filters owes to take place when these are in operation (it is not necessary is isolated the part of filters under cleaning) and not to influence the process of cleaning.

- Dust/particles removal

Gases flow through bag filters from the outside of the bag towards the inside and dust is collected on the outside.

Gases reach the bag filters through a pipe and are distributed via openings to various filter sections. A special pipe ensures smooth flow of the gases and this way removal is optimized and the lifetime of the filters is extended.

Fly ash is captured on the dust layer that is formed on the bags, and the filter itself. Clean gases flow the upper-part openings to the compartment outlet damper and via the outlet pipe through the I.D. fan they reach the chimney and finally the atmosphere.

The dust layer increases the bag filter efficiency while remaining quantities of lime react with acidic compounds. Dioxins and rest of VOCs are absorbed by the activated carbon and the PAC particles are captured by the dust layer. When pressure of the filter increases up to a level, this means that the dust layer has become too thick and the cleaning process is activated.

- Bag filter cleaning

The fly ash that stays at the outer surface of the filter bags is periodically removed by an air pulse blown into the bag from the inner side. This cleaning releases the particles, which fall into the discharge hopper.

Under each filter station an air tank is positioned equipped with plunger valves. Compressed air is blown at the lower inner part of the bags and the pulse is very short, no more than 0,1 s. The entire process, which takes place while the bag filter is in operation, should require minimum amounts of energy.

The frequency of the pulses may be continuous or controlled.

- Bag filter precoat

Precoating of the filters is achieved with slaked lime as soon as new bag filters are installed. This precoating protects the filter material from sticky substances like tar but also helps in creating the proper dust layer:

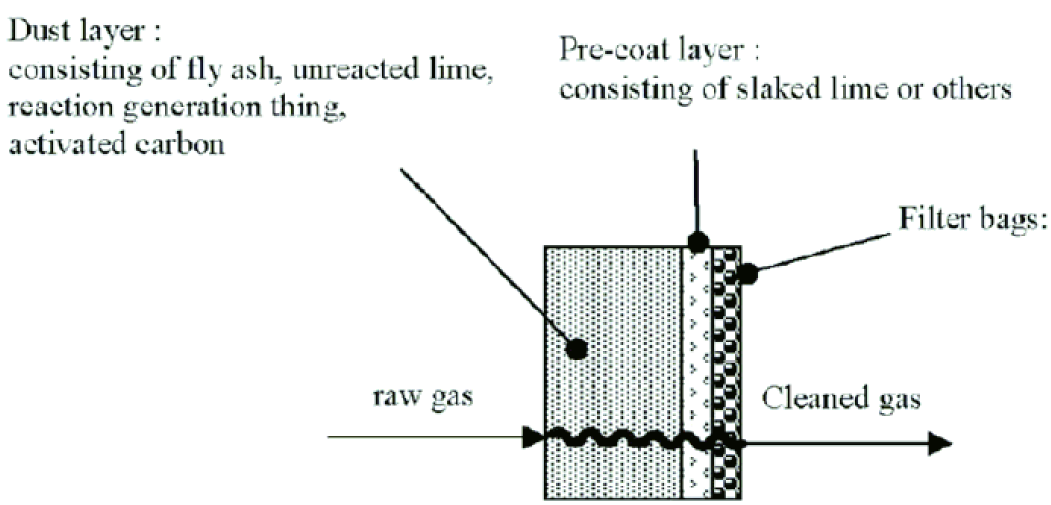

Figure 35: Cross section of a bag filter

NOx Removal

The production of NOx may be prevented with the following measures:

- Continuous mixing of wastes in the bunker to ensure a better fuel mixture
- Good mixing of secondary air through ideal position of the secondary air nozzels , so as to create turbulence in the combustion chamber that subsequently causes good mixing of combustion gases and smooth flow
- Use of low NOx burners
- Use of natural gas

As an end-of-pipe measure for NOx removal, the Selective Non Catalytic Reaction is proposed. In SNCR, ammonia (NH3) or urea (CO(NH2)2) is injected into the furnace to reduce NOX emissions. The NH3 reacts most effectively with NOX between 850 and 950 °C, although temperatures of up to 1050 °C are effective when urea is used. If the temperature is too high, a competing oxidation reaction generates unwanted NOX. If the temperature is too low, or the residence time for the reaction between NH3 and NOX is insufficient, the efficiency of NOX reduction decreases, and the emission of residual ammonia can increase. This is known as NH3 slip. Some ammonia slip will always occur because of reaction chemistry. Additional NH3 slip can be caused by excess or poorly optimized reagent injection.

The chemical reactions are:

$$2NO + 4NH_3 + 2O_2 \rightarrow 3N_2 + 6H_2O$$

$$2NO_2 + 8NH_3 + 4O_2 \rightarrow 5N_2 + 12H_2O$$

Enough nozzles are placed in order to ensure ammonia spraying through the radiation zone, thus ensure good contact and less residual ammonia. Advanced Computational Fluid Dynamics (CFD) should be used to determine the exact number and location of the nozzles, thus resulting in optimized efficiency and ammonia emissions below limit values.

The number and position of the operating nozzles should be controlled depending the furnace temperature, which should be measured with advanced devices like infra-red pyrometers or acoustic systems.

The volume of injected ammonia solution is determined by the NOx concentrations measured at the chimney. The ammonia solution will be diluted with water coming from the boiler (blow down water) before it turns into droplets with the use of compressed air.

The system should ensure:

- Safe storage of ammonia solution (25% w/w)
- Transfer of ammonia
- Ammonia dilution and injection through compressed air into the flue gases via injection nozzles
- Cleaning of the injection nozzles from ammonia remains when the boiler is not in operation

ID fan and chimney

Clean gas will reach the atmosphere with the use of a induced draught (ID) fan and a chimney.

The fan will be centrifugal with a changing speed control. The fan wings will be made of material resistant to friction and the impeller will be placed among two bearings with grease lubrication and direct clutch with differentiating speed. The moving part will be placed in a cell with outer insulation to reduce thermal losses and noise.

The control of the fan will be possible from the control room.

A chimney will be also constructed made of an outer part of steel and an inner part of steel plates resistant to corrosion. The outer part should be insulated too. Also a layer of paint will be used.

The chimney will have:

- A metallic door at the lower part
- Lightning rod
- Proper beam for airplanes and appropriate lighting for warning of aviation
- Points for manual sampling
- Connection points for on-line measurement of emissions

It should have also access platforms to the sampling points and a ladder with a platform at its top.

Local conditions such as wind parameters and landscape as well as the expected amount of flue gases determine the chimney height for efficient dispersion. Usually the height is not less than 65m in flat areas.

5.10.2 Emissions monitoring

For the monitoring of operating parameters and emissions from WTE plants there are several approaches that may be used (in line with the Best Available Techniques Reference Documents for monitoring and waste incineration based on the EC Integrated Pollution Prevention and Control Directive):

- Direct measurement
- Calculation of surrogate parameters
- Mass balances
- Calculations
- Emission factors

Direct measurement

Direct measurements refer to the direct quantitative determination of the respective parameter at source and me be continuous or discontinuous:

- **Continuous measurement:**
    - Use of in situ or in-line measurement unit
    - Use of on-line measurement unit for continuous sampling and measurement
- **Discontinuous measurement:**
    - Mobile measurement units
    - Lab measurement of samples collected in-situ or on-line
    - Lab measurement of spot samples

Surrogate parameters

Surrogate parameters are those, which when measured may be correlated with conventional parameters, when these cannot be measured directly.

The surrogate parameters are used for monitoring when:

- They are closely and consistently connected to a required direct parameter
- They are cheaper and easier to be monitored than the direct parameter
- They allow more measurements and from more point sources.

Surrogate parameters categories

Quantitative: provide quantitative information such as:

- Assessment of total volatile compounds instead of individual compounds, when the gas flow is stable
- Calculation of waste gas concentration via the fuel composition, the raw material etc.
- Estimation of total organic carbon and chemical oxygen demand instead of individual compounds

Qualitative: provide qualitative information such as:

- Temperature, retention time and flow is combustion chamber
- CO measurement or total VOC of the flue gas
- Temperature of gas from the cooling unit
- Conductivity instead of metal components
- Turbidity instead of suspended solids

Indicative: provide information on the unit operation or process and give an indication of the emissions:

- Temperature of gas flow from condenser
- Pressure drop, flow rate and humidity
- pH

For example:

- Furnaces: CO_2 measurement (direct)
- Incinerator: temperature of combustion chamber (qualitative) - retention time or flow rate (indicative)

Mass balances

Mass balances are used for the estimation of emissions from a certain unit or process. The simplified mass balance equation is as follows:

Inputs = products + residues + emissions

Where:

Inputs: all incoming materials used in the process

Products: materials exported from the process

Residues: materials in waste

Emissions: materials emitted to the air or included in the wastewater

Calculations

They are based on theoretical equations and models. Following an indicative equation is provided for the estimation of specific materials emitted through the fuel consumption, e.g. CO_2 or metals:

$$E = Q * C/100 * (MW/EW) * T$$

Where:

E: annual load of the material emitted (Kg/y)

Q: Fuel flow rate (Kg/h)

C: Concentration of the material in the fuel (% w/w)

MW: molecular weight of the chemical species included in the material (Kg/ Kg -mole)

EW: elemental weight pollutant in the fuel (Kg/ Kg -mole)

T: operation time (h/y)

Emission factors

The general equation for the use of emission factors is

Emission rate (mass/time) = emission factor (mass/µunit of throughput or mass/energy production or mass/water consumption) * Activity data (e.g throughput or energy produced or water consumed per time)

Emission factors have been developed at international level (EPA 42, CORINAIR, UNICE, OECD) and usually are expressed as the weight of a substance emitted divided the unit weight or volume.

WTE plants monitoring requirements

Via the permitting procedures, strict conditions need to be imposed for the monitoring of emissions to air, water and soil such as:

- Continuous measurement of emissions of NOx, CO, dust, TOC, HCl, HF, SO_2 hydrocarbons to the atmosphere
- Continuous measurement of temperature in the chamber, oxygen concentration, pressure, as well as temperature in the flue gas
- At least 2 measurements per year for metals and dioxins/furans

For wastewater regular measurement should be made for the following parameters

- Flow
- pH
- Temperature
- TSS
- Mercury
- Thallium
- Arsenic
- Lead
- Chromium
- Copper
- Nickel
- Zinc
- Dioxins / furans

5.11 The WTE ash

Grate combustion reduces the volume of MSW by about 90%. The residues of waste-to-energy facilities are bottom ash (20-25% of the MSW weight) and "fly" ash collected in the APC system (2-3% of the MSW weight). The bottom ash contains ferrous and non-ferrous metal particles that can be recovered by means of magnetic and eddy-current separators, respectively.

The bottom ash of grate combustion plants can fulfill different requirements. In the case where high metal recovery rates from the bottom ash are preferred, this can be achieved via a standard combustion process on the grate with dry ash discharge; for example, the KEZO plant at Hinwil, Switzerland and the SATOM plant at Monthey, France have demonstrated that grate combustion plants equipped with dry ash discharge systems allow very high ferrous and non-ferrous metal recovery. When it is desirable to produce a semi-fused ash, enriching the primary air with oxygen, as has been done at Arnoldstein, Austria, and Sendai Japan (Martin SYNCOM process), the ash is sintered on the grate allowing leachate values similar to molten ash. Metals are then chemically/physically fixed in the ash-matrix.

As the APC systems of WTE facilities have improved greatly, the captured heavy metals, dioxins, and other undesirable contaminants are sequestered in the fly ash. At the present time, most of the U.S. WTE facilities mix bottom and fly ash to form a "combined" ash that is chemically inert and is used for landfill maintenance and daily cover, in place of the 15-cm soil cover required by USEPA. Since the U.S. is the world's largest landfiller, there is a big need for use of WTE ash in landfills. However, since there are currently no commercial alternatives for beneficial uses of WTE ash outside landfills, the WTE companies do not get much benefit from supplying it to landfills. In fact, its disposal for landfill maintenance represents a substantial operating cost. In Bermuda, the WTE combined ash is mixed with cement to form one cubic meter concrete blocks that are used for shore protection, and land reclamation.

Figure 36 Concrete blocks made from WTE ash used for shore protection and land reclamation[35]

Bottom ash does not contain dioxins and volatile metals and its chlorine and sulfur concentrations are very low. It can be used beneficially in road construction, remediation of extinct mines, among other uses, as is done in several nations. Numerous demonstration programs, in the U.S. and abroad, have proven that bottom ash can be processed to generate an engineered and environmentally sound aggregate for diverse construction applications. In fact, the WTE facility of AEB Amsterdam (1.5 million tons of MSW annually) processes its ash in a novel way so that only 1% by weight of the MSW combusted has to be landfilled.

In the U.S., a perceived obstacle in developing bottom ash uses outside landfills is that if bottom ash is not mixed with fly ash, the latter is a hazardous waste and thus very costly to dispose. In 2007, EEC tested the phosphating treatment of fly ash (the Wheelabrator Technologies WES-Phix process), by using the USEPA Toxic Contaminant Leaching Procedure (TCLP). The results showed that the fly ash was fully stabilized and could be disposed in a sanitary landfill. Indeed, this procedure has been used successfully for years at the Burnaby, British Columbia WTE of Covanta Energy that treats part of the MSW of metropolitan Vancouver. In a separate study, EEC tested successfully the removal of chloride from APC residue by a simple wash with water.

The Earth Engineering Center is currently examining the Alkemy process that transforms mixed WTE ash (bottom ash plus fly ash) to a light aggregate that commands a price of US$40-80 per ton of aggregate. However, this process requires payment of a gate fee of about $30/ton of mixed ash.

5.12 Energy and mass balances

The energy balance, assuming a calorific value of waste of 9 MJ/kg, is presented in Table 12 below.

Table 12 Energy balance

Energy input (MWh/ton of waste)		Energy lost or consumed (MWh/ton of waste)		Remaining energy (MWh/ton of waste)	
Energy in waste	2.50	Heat losses in furnace, ash, and stack gases	0.25	Energy exported to the grid	0.54
		Turbine losses	1.62		
		Plant consumption	0.09		
Total	2.50	Total	1.96	Total	0.54

The mass balance is presented in Table 13

Table 13 Mass balance

Mass input (tons)		Mass consumed during combustion (tons)		Remaining mass (tons)	
Waste	1	Mass consumed during combustion	0.75	Bottom ash	0.225
				Fly ash	0.025
Total	1	Total	0.75	Total	0.25

5.13 Economics of WTE

The expenditures and revenues of a waste-to-energy plant vary from location to location. For this reason, Chapters 7-9 of this Guidebook examine three Case Studies of the hypothetical application of the WTE technology in Valparaiso region of Chile, the Toluca municipality of Mexico, and Buenos Aires of Argentina. These three case studies involved extensive visits and interaction of the Project team with specialists in these three countries. Readers of the Guidebook are encouraged to examine these three studies and consider similarities and differences as they may apply to their own city. This section discusses the cost and revenue components of a WTE plant, in general.

<u>Capital cost</u>: Modern WTE facilities are equipped with highly advanced combustion and air pollution control systems. Also, they are required to operate at full capacity over eight thousand hours per year (<90% availability) and must be esthetically pleasing in appearance. Therefore, they are more costly to build than a sanitary landfill; for example, a mid-range plant of 160,000 tons annual capacity may cost over US$80 million ($500 per ton of annual capacity). The investment costs as a function of the annual (and daily) capacity for a typical new waste incineration plant are estimated in the following figure (World Bank 2000).

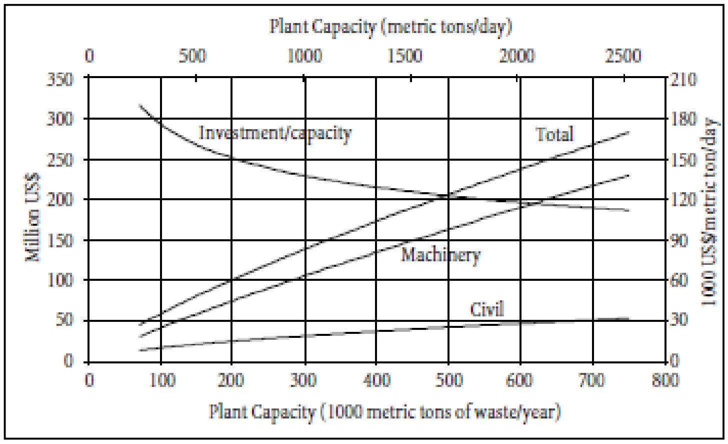

Figure 37 WTE capital investment costs (EEC)

In the case of a privately financed investment, repayment of this investment may entail a capital charge of $60 per ton of MSW processed, over a period of twenty years.

However, the investment in a WTE plant provides significant economic benefits to the host community, during the construction phase, in operation, and long after the initial investment has been paid off.

<u>Operating costs:</u> The three case studies showed clearly that on a per ton basis, the operating costs increased with decreasing size of the WTE plant: They ranged from US$32/ton MSW for the one million tons plant of Buenos Aires to US$47/ ton for the 160,000-ton plant for Toluca.

The operating costs as a function of the annual (and daily) capacity for a typical new waste incineration plant are estimated in the following figure (World Bank 2000).

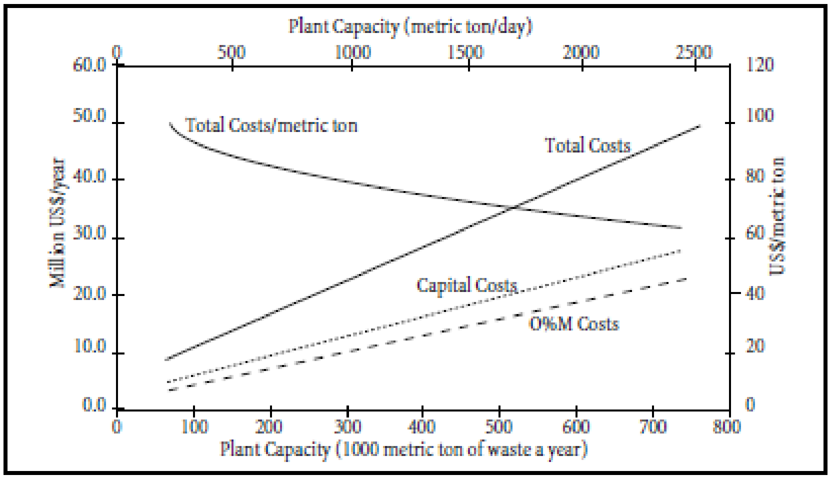

Figure 38 WTE operating costs (EEC)

<u>Co-generation of electricity and heat</u>: An equally important source of revenues for the WTE is the sale of electricity and steam. At this time, most U.S. WTE facilities sell only electricity, amounting to about $30 per ton of MSW at an assumed price of only $0.06 per kWh. However, as states continue to pass laws requiring the use of renewable energy on the grid, any source of renewable energy will be increasingly more valuable in the years ahead. A smaller source of WTE revenue is the recovery of metals from WTE ash; at this time nearly 0.8 million tons of ferrous and non-ferrous metals are recovered from the U.S. WTE plants.

The three case studies (Chapters 7-9) showed that a reasonable price for WTE electricity may range from US$80-120 per MWh, i.e. from US$40 to 70 per ton of MSW processed. There can be additional revenues from the sale of low pressure steam if industrial users can be located near the WTE facility. The revenue from metal sales would be in the order of a few dollars per ton MSW

<u>Gate fee per ton of MSW</u>: For a privately financed WTE, the capital and operating costs per ton of MSW, minus the revenues from the sale of electricity and any carbon credits as discussed in the following paragraph, must be matched by the gate fee per ton of MSW processed. Because of the high capital cost of a WTE, the required gate fee is bound to be higher than for landfilling. However, landfills are situated some distance from urban centers and this requires the construction of waste transfer stations, where the load of the collection trucks is transferred to long distance trucks and the transportation costs from transfer stations to landfills. For example, an EEC study showed that implementation of WTE for New York City would result in the shutdown of over fifteen transfer stations and avoid sending nearly 150,000 diesel trucks annually to other states, hundreds of miles away[36].

Carbon credits: The most important greenhouse gas contributing to global warming is carbon dioxide. The Kyoto Protocol (KP) of the United Nations Framework Convention of Climate Change (UNFCCC) called for industrialized countries (listed in Annex 1 of UNFCCC) to reduce their greenhouse gas emissions to below 1990 levels in the period of 2008 and 2012. The Clean Development Mechanism (CDM) enables Annex I countries to achieve their reduction commitments by helping to implement emission reduction projects in non-Annex I countries, i.e., developing nations such as those in the LAC region.

The carbon market includes different types of carbon credits. The most common form of credits for CDM projects are Certified Emissions Reductions (CER). A CER corresponds to the abatement of the emission of one metric ton of CO_2 equivalent.

A CDM project cycle requires registration and verification, by means of a rigorous and public process that the project will indeed result in a reduction of carbon emissions. After verification, the project is officially authorized to generate CERs. Some nations including the U.S. have not yet agreed to the Kyoto Protocol and continuation of the carbon market is uncertain. However, the E.U. has declared its long-term commitment to emission trading systems.

MSW typically contains about 30% carbon, two thirds of which are of biogenic origin (paper, wood, food wastes, etc.); using it as fuel reduces the amount of fossil fuel used (anthropogenic origin). Also, diverting MSW from landfills reduces the amount of methane emitted by landfills and one molecule of methane emitted to the atmosphere is equivalent to 21 molecules of carbon dioxide. Due to these two factors, one ton of MSW combusted rather than landfilled results in decreasing carbon emission by 0.5 to 1 ton of carbon dioxide, depending on the efficiency of landfill gas collection.

WTE plants in Latin America could qualify as CDM projects. For example, Sumitomo Corporation of Japan invested in a WTE project in Huzhou City of Zhejiang Province in China (Huzhou Nantaihu Green Energy Co., Ltd.). This plant is designed to treat 266,000 tons of MSW generated in Huzhou and supplies 59,000 MWh to the grid. In this case, the evaluation of the CDM project resulted in crediting it with 85,000 CER, that is 0.32 tons CO_2 per ton of MSW combusted.

The UNFCCC tabulation in Table 14 shows that the number of all CERs registered in Latin America until 2012 was 378 million or 13.6% of all CERs in the developing world.

Table 14 CDM projects registered and corresponding CER[37]

Region	Population (millions)	All Projects		Number of CER projected for 2012, in thousands		2012 CER per capita
		Number	%	Number	%	
Latin America	449	939	14.6%	378,014	13.8%	0.84
Asia & Pacific	3,418	5,169	80.6%	2,170,758	79.5%	0.64
Europe and Central Asia	149	69	1.1%	42,261	1.5%	0.28
Africa	891	168	2.6%	99,368	3.6%	0.11
Middle-East	186	71	1.1%	40,469	1.5%	0.22
All less developed nations	**5,093**	**6,416**	**100%**	**2,730,870**	**100%**	**0.54**

Life of a WTE plant: The major cost item in the operation of a WTE plant is the repayment of the capital investment that usually extends over a period of 20 years. However, Appendix 3 shows several WTE plants that have been operated over forty years and are still going strong. With proper maintenance, a new WTE in a municipality can be a good thing for the current generation and a patrimony gift to the following generations.

5.14 Combining plans for new WTE with increased recycling

As noted earlier, there is a general misconception that new WTE plants will decrease recycling in a community. Therefore, planning for a new WTE in a community, especially in Latin America and the Caribbean where the current recycling rates are relatively low, should include instituting or enhancing formal recycling by providing collection bins for recyclable materials that are specified by the community. For example, these can include all types of paper and cardboard, metals and specified plastic containers.

One day a week, the same trucks that on other days collect MSW collect the Single-Stream of recyclables and transport it to a Materials Recycling Facility (MRF) that is located next to the WTE facility. The recyclables are then sorted out, either mechanically or manually, to salable materials that are baled and marketed. The non-salable residue of the MRF is conveyed to the bunker of the WTE plant. The flow sheet of this arrangement is shown in Figure 39. Building a Materials Recovery Facility (MRF) adjacent to the WTE plant will also send a clear message to the community that WTE and recycling are complementary. This MRF will include both mechanical and manual sorting and preferably employ people who were engaged in informal recycling and provide them with better wages and working conditions.

The proposed MRF would have the following operating characteristics (Appendix 3): recyclables collected are tipped on floor of MRF and loaded on an inclined conveyer belt that leads them to elevated horizontal belts passing by a series of sorters that pick particular items (e.g. mixed paper, metals, etc.), and dispose them in bins below the horizontal belts. The bins are periodically emptied in baling machines.

RRT Engineering, a U.S. company who specializes in the building of MRF plants, kindly provided to EEC the drawing of Appendix 5 that shows a facility of capacity to sort up to 80,000 tons of Single-Stream recyclables and is estimated to cost about US$7 million to build, including site preparation, truck access, building, and MRF equipment.

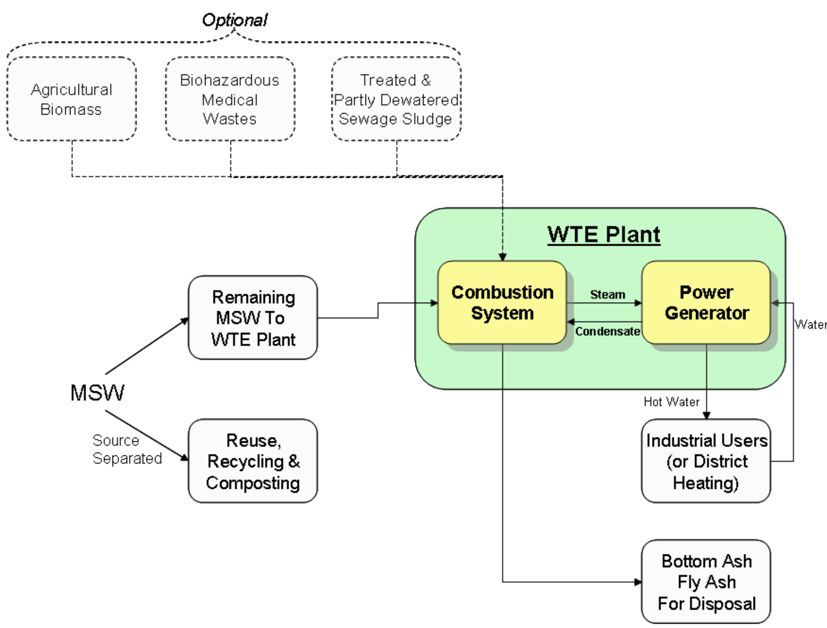

Figure 39 Materials flow in and out of a WTE plant (EEC)

5.15 Emission standards

Modern WTE plants are built to comply with European limits (Table 15), which are similar to the USEPA standards and are the most stringent standards applied to high temperature industrial sources, including coal-fired power plants, cement plants, and metal smelters (table also includes limits from selected Latin America and Caribbean Countries) . Also, as explained in 5.10, WTE emissions are lower than the emissions of landfilling and generally are also lower than the emissions of coal power plants. It is recommended that Requests for Proposals for a new WTE are based on Air Pollution Control equipment that can result in emissions lower than these standards, even if some of the current national standards allow for higher emissions than those shown in Table 15.

Table 15 Emission standards

Pollutant	E.U. Limits	US Limits
	11% O_2 dry basis (mg/Nm^3)	
TOC	10	15
HCL	10	29
HF	1	NA
SO_2	50	61
NOx	200	219
Cd	0.05 total	0.008
Cd, Ti		NA
Hg	0.05	0.04
Pb		0.11
Pb, As, Sb, Cr, Cu, Mn, Ni, V	0.5 total	NA
CO	50	89
Dioxins and furans	0.1 ng/Nm^3 TEQ	9.9 ng total dioxins = 0.1 ngTEQ

5.16 Personnel complement for medium size, three-line WTE plant

The personnel required for the operation of a small to medium one-line WTE facility (10-20 tons per hour or 80,000-160,000 tons per year) consists of:

1 Facility manager
2 Assistant manager
3 Administrative staff (6)
4 Chief engineer
5 Assistant engineer
6 Laboratory (2)
7 Shift supervisors (5)
8 Control room operators (5)
9 Crane operators (10)
10 Security (2)
11 Entrance (2)
12 Other (4)
13 Total: 40

The total number of employees ranges from about 40 people for a one-line plant to 50 people for a million ton plant consisting of three lines. The prospective manager should be involved in the project from the beginning to understand why and how decisions were made. Personnel training should be included in capital cost, as the manufacturer should provide it. Personnel should be hired from 6 to 12 months before plant commissioning and they should be trained in operating facilities before startup. These services are many times included in the vendor's contract. Typically, one shutdown of a furnace line is required once a year.

5.17 Capital and operating costs

The capital and operating costs, and also the revenues, of WTE plants are exemplified in the three Case Studies discussed in the second part of this Guidebook.

Capital costs: Capital costs include land plot, plant construction, services and other infrastructure (e.g. roads). These costs vary according to the specific site, and also, part of the equipment has to be imported. Therefore, local labor and materials data should be collected and foreign exchange risks taken into account. As noted before, because of their size, need for high plant availability and highly advanced APC systems, WTE plants are very costly to build. Depending on its capacity and location, a WTE plant may cost between US$500 and US$1,000 per ton of annual capacity (or even up to 2.000 $/ton as indicated by World bank).

Repayment of the capital investment, including start up costs, is the major cost item of WTE facilities. In some countries, part of the capital cost is provided in form of a grant by local, national, or international government, or multilateral organisms. The prospective owners of the facility, either private or public-private partnership (PPP), provide another part, and the remainder is obtained in the form of a long-term loan from a national or international bank. A project lifetime of twenty years may be assumed although international experience has shown that such plants are constantly maintained and improved; thus, similar to bridges and other infrastructure, they have very long lifetimes. One example in the U.S. is the Saugus, MA facility of Wheelabrator Technologies has completed thirty-four years of service and today is in a better condition than when it was built.

Effect of plant availability on capital charges per ton of MSW: Plant availability is a very important factor in the profitability of a WTE plant. It is calculated by dividing the number of hours that the plant operates at design capacity (e.g. 30 tons/hour) by the total number of hours in a year. The non-operating hours include scheduled maintenance shutdowns plus non-scheduled, short duration interruptions due to temporary problems with some equipment. It is evident that plant availability turns out to be, e.g. 60% instead of the projected 90%, the capital charge per ton of MSW processed will be 50% higher.

Operating costs include:

- Personnel
- Chemicals for APC system: lime, urea, activated carbon, etc.
- Maintenance of equipment
- WTE ash handling and disposal
- Gas cleaning
- Environmental testing
- Insurance

5.18 Revenues

Gate fee: The primary source of revenue for a WTE plant is the payment of a "gate fee" (also called "tipping fee"), per ton of MSW delivered to the processing facility. It should be noted that a gate fee is also required for sanitary landfilling but is usually lower than the WTE gate fee, unless the national government imposes a tax on landfilling. In the U.S., the WTE gate fee ranges from $53/ton in Florida to $85/ton in New Jersey. The landfilling gate fee varies from $28/ton in Texas to $96/ton in New Hampshire. In the three Latin America case studies (second part of Guidebook), the sanitary landfill gate fee ranged from $13-20/ton. In Europe, for example in UK (WRAP, 2011), the gate fees for WTE plants vary between 80-150$/ton, in Denmark and Germany (Country Reports for CEWEP) between 100$/tn-150$/tn.

In some developed countries, citizens pay for waste management services in the same manner as they pay for other services, such as electricity and water. In others, the government subsidizes the gate fee out of various taxes so the citizens have no direct indication of the cost of managing their wastes.

Electricity and steam: The sale of electricity and steam represents the second important source of revenue for a WTE plant. Their calculation will depend on a) proven outputs of a particular technology, b) projected availability of the WTE plant, and c) local agreements, e.g. with utilities or other industries, for long term purchase of the energy of the facility.

Carbon credits: CER prices vary depending on a number of factors. In the current CERs transactions markets the price of a CER is in the range of US$12-20. This is an attractive income that should be considered when developing a WTE facility in the region.

Other revenues: As stated earlier, ferrous and non-ferrous metals can be recovered from the bottom ash of the WTE plant. The portion that could be recovered is approximately 50% of ferrous and 8% of non-ferrous[38].

5.19 Major parts of a WTE plant

The construction of a WTE plant is usually divided into the following major parts:

- Civil engineering works (site preparation, building, services, landscaping)
- Furnace and grate combustion equipment, including ash handling
- Boiler
- Air Pollution Control System
- Steam turbine

The proposal of the General Contractors responding to the Request for Proposals of a municipality will specify the equipment to be used and the subcontractors who will provide the different components. To reduce the capital cost, as much as possible of the construction and equipment should be provided locally.

5.20 Providers of WTE facilities

As noted earlier, the most crucial component of a WTE plant is the furnace and moving gate. There are several European, American, and Chinese providers of such equipment including Martin GmbH, Hitachi Zosen Inova, CNIM, Keppel Seghers, Baumgarte, Fisia Babcock, Babcock & Wilcox, Volund, Covanta Energy, Wheelabrator Technologies, Urbaser, Sanfeng Covanta, and others. Appendix 3 provides a list of providers of WTE technology and equipment.

Some of these companies can also act as the general contractor, with subcontractors providing the civil works, boiler, steam turbine and APC system. It is very important that the contract with the general contractor includes training and start up services.

A list of WTE providers is provided in Appendix 1. A Table of all known WTE combustion facilities in the world can be seen in Appendix 3.

5.21 Business models used regarding ownership of a WTE facility over a term period (usually 20 years):

- Public ownership: Finance, design, tender, build and operate.

- Public ownership: Finance, design, tender, and build; plus separate term contract with private company to operate.

- Public ownership: Term contract with private company to design, build and operate plant (this is the business model selected by Durham County, Ontario for WTE plant starting construction in August 2011).

- Public - private partnership (PPP): Finance, design, build, and operate with private ownership transferred to municipality at end of term.

- Private ownership: Private financing and ownership of 100% of facility, through concession or license agreement; with ownership reverting to municipality at end of term. This is also called a BOT arrangement (Build-Own-Transfer)

- Private ownership: Private company owns 100% of facility through a license agreement during term period. The municipality can purchase plant at end of term at market value.

5.22 Project cycle

A WTE project cycle consists of several stages:

Pre-feasibility study is conducted using available data and provides an order of magnitude estimate of MSW generation and composition, desirable plant capacity, operational characteristics including projected power generation, capital and operating costs, and revenues. On the basis of the pre-feasibility study, a decision is made as to whether to proceed with the next stage of Feasibility and Tendering.

Feasibility and Tendering: The feasibility of the Project is established using detailed engineering data about every aspect of the project so as to obtain reliable accurate estimates. During this stage, the responsibilities of each stakeholder are established and agreements are made with respect to waste supply and energy sales. Also, all the financial issues are resolved, that is, the project-financing model must be decided.

Tendering is divided into two stages: a) Issuing a Request for Qualifications (RFQ) and assessing responses to RFQ; and b) selecting companies to be invited to respond to Request for Proposals (RFP), negotiating regarding respective responsibilities, and selecting the company to build the company to build the WTE. These aspects are discussed in below in the Procurement Process.

5.23 The Procurement Process

Stage 1 - Request for Qualifications (RFQ) from vendors, some of whom will be invited to the next stage of Request for Proposal (RFP).

a) Technical Criteria

- Complete technical submission
- WTE technology proposed
- Proposed core project team
- Reference facility where technology is being used
- Record of plant availability and energy generation
- Other

b) Financial Criteria

- Ability to provide bonding
- Sufficient capability to construct
- Other

Stage 2 - Request for Proposal (RFP): Receipt, review and evaluation of proposals, identification of preferred vendor and negotiation of commercial contract

-Identify a company with whom a design, build, operate, or other type, contract for a term of 20 years will be executed. There may also be an "early works" agreement with this company to obtain proprietary information that may be needed to conclude the Environmental Assessment of the project

- Negotiation of long-term commercial contract as per business model chosen

5.24 Use of independent Consultant and Monitor of the procurement process

On the basis of the Pre-feasibility study of a WTE project, the municipality may decide to proceed with implementation of the project and issuing the RFQ for the project. It is recommended that at this point, the authority responsible for the project retains the services of an engineering firm who will act as the Consultant to the municipality during the execution of this project. This firm must have a record of acting in the same capacity on previous WTE projects. The Consultant will also serve as independent monitor of the procurement process:

- Review the fairness of the design of the criteria for the RFQ and RFP solicitations

- Review a Participation Agreement that all companies responding to RFQ will be required to sign in order to gain access to the Pre-Feasibility Study and Data
- Participate in the development of the procedure and principles for evaluation of RFP submissions
- Monitor the conduct of ‘commercially confidential’ meetings with each pre-qualified proponent

5.25 Contractual obligations of General Contractor and of Municipality

- The Project Proposal will incorporate state of the art emission control technology that meets or exceeds European Union emissions and monitoring standards as well as the Maximum Achievable Control Technology (MACT) of USEPA.

- Agreed upon daily and annual capacity of facility.

- Provide for complete flow control of MSW by the municipal owners.

- Contractual emission guarantees, entailing significant contractual remedies, to meet EU and USEPA limits.

- Plant capacity to provide for increase of recycling rate in municipality.

- Aesthetic appearance of plant (architectural treatment; landscaping; visitors' facilities).

- Electricity generation, in MW and MWh/year; connection to grid; guaranteed price for electricity.

- Provision for commercial/industrial heating/cooling.

Financial obligations:

- Penalties for actual processing rate being less than design capacity, after agreed upon start up period.

- Penalties for lower delivery of MSW by municipality than design capacity of WTE.

- Agreed upon gate fees per ton of MSW processed and method for cost of living adjustment with time.

5.26 Typical timetable for completion of project

Prefeasibility study including the siting of the WTE plant: 12 months

Feasibility and Cost benefit analysis, including the WTE design: 4 months

Preparation and launching of the tender documents: 6 months

Contract award: 15 months

Month 1: Request for Qualifications (RFQ)

Month 3: Submission of responses to RFQ

Month 5: Request for Proposals (RFP) from qualified companies

Month 8: Submission of RFP

Month 10: Selection of company to build plant;

Environmental permitting of the facility: 10 months

Completion of design according to the environmental permit: 1 month

Construction phase: 24 months

Total: 72 months

5.27 Regulatory, social, and other issues

National and local regulations affecting the implementation and operation of WTE facilities vary widely, as illustrated by the three Study Cases presented in this Guidebook.

Waste management system: A basic requirement for introducing WTE is that a well-functioning waste management system exists in the country. Without this, the amount of waste delivered to the plant cannot be warranted, and building the plant may be too risky.

Synergies with other entities and neighbor communities: Synergies with industries (or Eco-industrial parks) interested in purchasing heat (steam), or with industries interested in purchasing recovered materials (e.g. metals), can help the plant secure certain revenues. Also, agreements with neighbor communities may help increase the profitability of the WTE plant by increasing its feedstock.

Public information: Public acceptance is essential for the success of a WTE project. Some WTE projects around the world have failed, or were deferred for several years because of inadequate information to public as to environmental benefits over landfilling. Therefore, it is important to provide complete and detailed information about the project to the community from the very beginning. Community groups should be formed who explain the impacts of the plant in the community. It is important to listen to the people's concerns, to address any misunderstandings, and to dispel misconceptions, such as the one that WTE competes with recycling. Initially a public awareness and communication plan should be developed describing the main targets of the public awareness campaign and the main tools to implement it.

The public information campaign should seek to:

- Underline the energy utilization of waste and ensure the public acceptance via the promotion of the benefits for society. Basic target of the campaign should be the communication of WTE as a reliable waste management practice which is strongly connected with integrated waste management and sustainable development.
- Address the oppositions and divert the negative perception of WTE plants (especially in relation to the citizens living close to the facilities). The negative perception of the citizens for WTE plants is partially based on the misconception or false information that the WTE plants will result in emission of hazardous air emissions – mainly dioxins.

Following the finalization of the communication plan, the proposed measures should be implemented in order for the public to become aware of the benefits from developing WTE plants and in this way the public opposition may be reduced. Such tools include:

- Mass media
    - Spots in national and local television
    - Spots in national and local radio
    - Announcements in national and local press
    - Website
    - Direct distribution of material via email, post etc.
    - Newsletters
- Promoting means
    - Distribution of Leaflets / brochures
    - Distribution of Guides, magazines
    - Development of posters and advertisements on central points
- Means of direct communication
    - Discussions
    - Letters to interested parties
    - Participation / organization of seminars, conferences
    - Development of help phone line

Stakeholders: Various entities will be affected in different ways by the WTE project:

- Public agencies and private companies involved in the collection and disposition of waste: All entities in the waste management system need to be part of the project in order to ensure that there will be enough waste delivered to the plant.
- Energy/electricity agencies and companies: These entities have to be involved from the beginning of the project to ensure that the plant is in line with all the regulations for the sale and distribution of energy, and to secure long term purchasing agreements.
- Community groups: As mentioned above, it is important to involve the community from the beginning, to avoid public opposition.

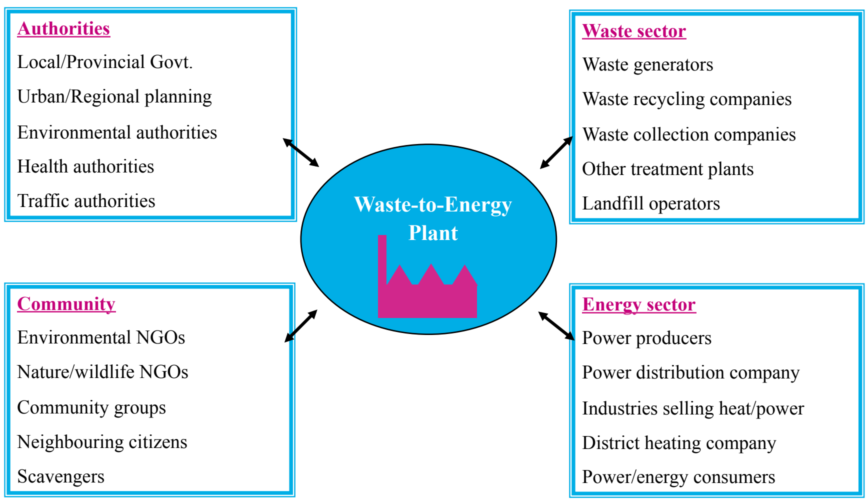

Figure 40 WTE stakeholders[39]

5.28 Risks and positive effects related with WTE implementation

The possible risks and problems that may arise during the development and operation of a WTE facility are basically related with the need to have a continuous waste flow of similar properties as well as with the fact that the overall waste management fees will increase and the citizens may not be in a position to bear this additional cost.

Regarding the waste flow, a big risk is associated with the fact that it is not possible to have a secure waste flow projection for the next 20 or 30 years (in terms of both waste quantity and composition), and significant changes will affect the operation and economic of the facility. The WTE facilities are cost intensive and consequently the waste collectors may select to continue with the cheaper current practice of controlled or uncontrolled disposal instead of leading the waste to the WTE plant. The potential inability of citizens to pay the additional fees may also contribute to this result.

Moreover in case the waste quantities that will end up in the WTE plant is significantly lower than the originally estimated quantities, the plant may not be able to produce enough energy in order for the investment to become viable. Also, the potential increase of recycling will affect the calorific value of the waste input (since big parts of paper and plastics will be diverted from the WTE plant) resulting in reduced energy production and consequently in reduced revenues. This will have a negative impact on the operating costs and gate fee since it may be necessary to use conventional energy sources (e.g. natural gas) to maintain the thermal heat in the incineration chamber.

For addressing these risks motives against or even banning of waste landfilling or subsidies and policies promoting WTE plants should be in place in order to divert waste management practices to more modern solutions. In this respect, specific policies should be develop that will promote the development and operation of the WTE plants, including

- Financial policies
    - i. Grants for construction of WTE plant
    - ii. Loans with good conditions for construction of WTE plant
    - iii. Tax relieves for WTE operators
    - iv. Imposing of landfill tax
    - v. Subsidization of electricity prices
    - vi. Subsidization of WTE gate fees
- Legal policies
    - vii. Restriction of waste disposal
    - viii. Simplification of permitting procedures for WTE plants
- Other policies
    - ix. Promotion of PPP for the development of WTE
    - x. "Green" Certification of the energy from WTE

Moreover it has to be noted that there are also non-technical risks related with the development of WTE plants which derive from the practices followed by WTE sellers in order to promote their product. More specifically, in many cases WTE is promoted as the "magic solution" ignoring the specific financial, social and institutional characteristics of the area under examination as well as the current status waste management (e.g. even in very area poor areas with no organized waste management system and no regulations). In such cases the development of WTE plants is destined to fail and this fact generated a general misconception on the development of WTE (i.e. even justified and well developed proposals for WTE plants fail to be implemented due to such misconceptions). In any case WTE plants may be developed under very specific conditions and all the specific characteristics of the area need to be taken into account in order to make sure that the project will become successful.

The WTE systems also have positive effects for the areas where they are implemented, including the minimization of waste that end up in landfills as well as the generation of energy from non-fossil fuels. The overall positive effects of the WTE systems include:

- Growth:
  - New job opportunities and capacity building in waste and energy sector
  - Transfer of know –how and development of additional industrial infrastructure
- Energy dependence:
  - Reduction on dependence on fossil fuel
  - Fine tuning of the energy prices for the benefit of the citizens
  - Increase of energy production from renewable resources
- Environmental conditions:
  - Preservation of landfill space via the reduction of waste going into landfill
  - Increase of energy production from renewable resources and preservation of natural resources, namely fossil fuels
  - Reduction of air emissions (mainly CO_2) from the fossil fuel consumption

5.29 Waste to Energy Projects in the Latin America and the Caribbean

Application of Waste to Energy technologies requires cautious planning and understanding of the local conditions. Aim of this section is to describe the special characteristics of the Latin America and the Caribbean (LAC) in order to examine if WTE projects are viable in the region. For this reason, the special characteristics of the region are presented firstly, whereas a table at the end provides useful comments about WTE and these characteristics.

To begin with, LAC is the continent with the second highest proportion of urban population after Northern America. According to the latest data, the 79 percent of LAC's population lives in cities, and one in five urban dwellers lives in large urban agglomerations. In addition, LAC now has 51 cities with more than one million inhabitants - 14 of these being in Brazil alone – including the four megacities (Mexico City, Sao Paulo, Rio de Janeiro, Buenos Aires) and Lima, which is close to the population-limit of ten million.

Urbanization brings high growth in population and in income as well as unpredicted spatial growth of cities. More specifically, from 2002 to 2010, the urban population in LAC increased by almost 63 million, whereas the per capita gross domestic product increased by 23%. Urban areas in LAC are becoming a symbiosis of extreme wealth and extreme poverty, while allowing the rise of a new middle class. It is characteristic that 40 percent of the population of Mexico City and a third of São Paulo's population is at or below the poverty line. As trends show, the urban population will keep increasing with high rates making every potential use of land even more valuable. Estimations for 2050 speak for forty percent more urban population than the current one, exceeding 650 million.

A significant, and in many cases the dominant, characteristic of the solid waste management sector in the LAC is the big and potent informal sector. The catadores in Brazil, the pepenadores in Mexico and the cartoneros in Argentina are typical examples of the waste informal sector, contributing the maximum to recycling and reuse, and thus to the minimization of the waste that is led for disposal. IDB estimates that the waste informal sector in LAC ranges from 500,000 to 3.8 million people. However, apart from its great number, another important characteristic of the informal sector is its hostile attitude against any potential change in the current waste management practices, fearing that they may lose their jobs.

Despite the fact that operation of uncontrolled and open-air dumpsites is accused to cause significant health and environmental problems, nearly 50% of the waste generated in the region is not disposed of properly, with the lack of political and legal will to have been identified as the main reasons for this situation.

Economic prosperity is directly connected to the solid waste generation. Empirical evidence for waste generation has shown that a 1% increase in the gross domestic product per capita creates a 0.69% increase in municipal solid waste amount. Despite the fact that economic growth in LAC is understandably slowing down from 6% in 2010 to 4.5% in 2011 and to 4% in 2012, the rates of development are still quite high, with the forecasts to be optimistic regarding the continuing of the development. This economic prosperity is expected to lead to an increased solid waste generation. Typical example is Brazil, which in 2010 examined a 6 percent increase in its municipal solid waste generation, slowing down however to 1.8% in 2011. In that way, finding a reliable and sustainable solution to treat waste is more than necessary. However, it should be mentioned that the increase in the gross domestic product per capita is possible to make viable and affordable more expensive treatment technologies, if not in the whole LAC, at least in specific countries or cities.

An additional issue to the aforementioned ones, those of the urbanization and of the economic development, is to cover the growing energy demand. By 2030, with a modest rate of economic growth, the LAC's demand for electricity would reach nearly 2,500 terawatt-hours (TWh), up from around 1,150 TWh in 2008. Under this lens, solid waste treatment may be used as an alternative source of energy, promoting in these cases technologies that include energy production. However, a factor that affects a lot the success of such technologies is the energy price that public authorities are willing to pay. As investment in new generation capacity is estimated to be about $430 billion between 2008 and 2030, a small part of it could be invested in WTE projects, generating not only electricity but also giving an appropriate solution to the waste generated in urban and metropolitan areas.

The table below summarizes the main characteristics of the LAC and provides useful comments regarding each characteristic.

Table 16 LAC Main characteristics

Characteristic	Info	Comment
Urbanization	• 79 percent of LAC's population lives in cities, and one in five urban dwellers lives in large urban agglomerations • From 2002 to 2010, the urban population in LAC increased by almost 63 million • Estimations for 2050 speak for forty percent more urban population than the current one, exceeding 650 million	• Use of space is valuable for public authorities. WTE technologies not only minimize the volume of waste that should be disposed of but also require much less area compared to landfills • Waste characteristics of urban areas are similar to those required for the proper and sustainable operation of WTE plant • Urban and metropolitan areas can provide a regular waste influx
Informal sector	• The waste informal sector in LAC is estimated from 500,000 to 3.8 million people • Waste informal sector is strongly opposed to any potential change in the current waste management practices, fearing of losing their jobs	• Application of any WTE technology in LAC must seriously take into consideration the waste informal sector • Firstly the planners should assess if they can integrate the informal sector in the new system, providing to them jobs, since collecting waste or scavenging is in most cases the only thing they know to do. Otherwise, planners should assess if both sides can co-exist and to mutually benefit
Inefficient waste treatment	• Nearly 50% of the waste generated in the LAC is not disposed of properly • Lack of political and legal will have been identified as the main reasons for this situation	• Modern WTE technologies guarantee the adequate treatment of municipal solid waste, requiring however an institutional background to avoid phenomena of inappropriate operation

Economic prosperity and waste generation	• 1% increase in the gross domestic product per capita creates a 0.69% increase in municipal solid waste amount • Economic growth in LAC is understandably slowing down from 6% in 2010 to 4.5% in 2011 and to 4% in 2012, with the rates however to remain high • Economic prosperity is expected to lead to an increased solid waste generation, making indispensable the finding of a reliable and sustainable solution	• Economic development may lead WTE technologies to be viable and affordable, if not in the whole LAC, at least in specific countries or cities • Using scale economies, authorities may benefit from the increased waste generation and achieve better financial terms for the construction and the operation of a WTE plant
Energy demand	• By 2030, with a modest rate of economic growth, the LAC's demand for electricity would reach nearly 2,500 terawatt-hours (TWh), up from around 1,150 TWh in 2008. • It is the price of the energy generated that in great extent determines the success and the viability of a project	• WTE may be an alternative source of energy, being the same time a CO_2 net saver • In areas that the energy demand is higher, it can be achieved a better price for the energy generated by the WTE units • From about the $430 billion estimated to be invested between 2008 and 2030 for energy generation, a small part of it could be invested in WTE projects, not only for generating electricity but also to provide an appropriate solution to the waste generated in the region

Another element if LAC, which may affect the development of WTE plants is the significant difference on energy prices from Country to Country. This diversion has a direct impact on the actual sustainability of WTE plants as it has an effect on the actual revenue of the plant.

Moreover it has to be noted that the current waste management practices implemented in LAC are in most cases outdated and there is a lack in technological capacities and know-how and this fact is an important barrier in the development of WTE plants in the area, since the WTE plants require specialized personnel to monitor its construction and operation as well as monitor the contractual elements of the WTE development. It is also worth noting that in many countries there is no legislative framework that governs the development of waste management facilities and especially WTE plants and due to this gap the technical and environmental performance of these facilities are difficult to be regulated and monitored.

6 Conclusions to Guidebook

Over the last two decades, the waste-to-energy industry in Europe, North America, and Asia has developed WTE technologies that by now are one the feasible forms of thermoelectric energy generation. By far, the dominant WTE technology, practiced in over 600 plants in over forty nations, is grate combustion of as-received municipal solid wastes with production of electricity and heat. This technology, offered by several providers in Europe, the U.S. and Asia, is the one recommended for the first WTE plants in Latin America and Caribbean nations. However, alternative processes are constantly under development and it is possible that one of more of them may result in lower capital costs, for a certain capacity, than grate combustion.

Considering the current gate fees for landfilling in Latin America, WTE is not economically feasible without some government support. However, the difference between current gate fees at final disposal sites in Latin America and the gate fee required to sustain a WTE, at present energy prices, is estimated (under some specific assumptions shown in chapters 7 to 10) to be $20-30 per ton of MSW.

Currently the LAC municipalities usually do not receive any revenue from managing solid wastes, and have to cover this cost from other sources of income; therefore they cannot afford a higher gate fee. Only part of the population foots the bill for waste management through the payment of property taxes and, also, this tax does not depend on the amount of waste generated.

In all cases studied, the municipalities of the region allocate a significant fraction of their budget to the management of solid wastes but 70-80% of this goes to collection and transport of MSW and only 20-30% is used for proper disposition of the MSW. Also there is a big variance of collection costs among municipalities in the same region. The plan for a WTE in LAC region should consider a more efficient and less costly means of collecting and transporting MSW to the WTE.

As has been observed in the last twenty years, the WTE revenues from electricity will increase with time, while the cost of transforming greenfields to sanitary landfills will also increase. Moreover, the economics developed in this Report are based on a 20-year life of the proposed WTE plant, while some modern WTE facilities have already reached their fortieth year and will continue operating in the foreseeable future.

This Guidebook recommends that national governments place sustainable waste management high up on their list of essential infrastructure projects, similarly to what they have done in the past with regard to providing potable waste, electricity and wastewater treatment. What may not be economic from the short term viewpoint of private investors, it can be an economic boon viewed from the long term perspective of a nation that includes the creation of jobs in building the WTE, the addition of an indigenous source of renewable energy, the amount of land conserved, and some environmental and greenhouse gas advantages of WTE over landfilling. It may be therefore prudent for the national or regional government to consider participating in a public-private partnership that will allow the nation to move towards more sustainable waste management.

Appendices to Part 1

Appendix 1: List of WTE providers

Table 17 WTE providers

Company	Website	Country
Alstom Corporation	www.alstom.com	France
Babcock Noell	www.babcocknoell.de	Germany
Babcock &Wilcox Volund	www.volund.dk	Denmark
CNIM (Martin GmbH owns 10.25% of CNIM)	www.cnim.com	France
Covanta Energy	www.covantaenergy.com	USA
Fisia Babcock Environment GmbH	www.fisia-babcock.com	Germany
Groupe TIRU	www.groupe-tiru.com	France
Hangzhou New Century Energy and Environmental	www.chinaboilers.com/en/filiale_detail.asp?id=62	China
Hitachi Zosen Inova AG (formerly Von Roll Inova)	www.hz-inova.com	Switzerland
Inova	www.inova-groupe.com	France
JFE Steel Corporation	www.jfe-steel.co.jp/en/	Japan
Jiangsu Kelin Environmental and Equipment	www.kelin-china.com/en/gy01.htm	China
Kawasaki Heavy Industries Ltd.	www.khi.co.jp	Japan
Keppel Seghers	www.keppelseghers.com	Multinational
Martin GmbH	www.martingmbh.de	Germany
Mitsubishi Heavy Industries	www.mhi.co.jp/en/	Japan
Standardkessel Baumgarte Holding GmbH	www.standardkessel-baumgarte.com	Germany
Sanfeng Covanta	www.covantaenergy.com/facilities/asia-pacific.aspx	China
Sinosteel Tiancheng Environmental Protection Science and Technology	http://en.sinosteel.com/qqzg/kjqy/2007-09-13/1743.shtml	China
Takuma Co., LTD	www.takuma.co.jp/english/index.html	Japan
Urbaser S.A.	www.urbaser.es	Spain
Weiming Group	http://www.wmgroup.cn/en	China
Wheelabrator Technologies Inc.	www.wheelabratortechnologies.com	USA
Wuxi Huaguang Boiler	www.wxboiler.cn/en/about.asp	China
Wuxi Xuelang Environmental Science and Technology		China
Zhejiang Feida Environmental Science & Technology	www.feidagroup.cn	China
Zhejiang University	www.zju.edu.cn/english/	China

Appendix 2: Reported capital costs of some WTE plants

Table 18 Reported capital cost of some WTE plants

Location	Startup year	Capacity (tons/yr.)	Capital cost (2011 million US$)	Capital cost (US$/ton)
Ranheim, Norway	1997	10,000	18	1,781
Averoy, Norway	2000	30,000	39	1,285
Isle of Wight, UK	2009	30,000	13	444
Sault Ste. Marie, On, Canada	Expected 2011	35,000	31	874
Hurum, Norway	2001	39,000	31	800
Minden, Germany	2001	39,000	32	819
Forus, Norway	2002	39,000	38	987
St. Lucia	Expected 2011	45,000	50	1,111
Ramboll 1	Not disclosed	48,000	30	625
Ramboll 2	Not disclosed	64,000	66	1,031
Bermuda	1994	68,000	98	1,441
Ramboll 3	Not disclosed	72,000	60	833
Sarpsborg, Norway	2002	78,000	49	628
Ramboll 4	Not disclosed	80,000	73	913
Martinique	2002	112,000	87	780
Ramboll 5	Not disclosed	120,000	91	758
Zhejiang, China	2003	128,000	17	129
Guangdong, China	2003	150,000	42	282
Zhejiang, China	2004	150,000	39	258
Ramboll 6	Not disclosed	160,000	112	700
Ramboll 7	Not disclosed	160,000	139	869
Ramboll 8	Not disclosed	192,000	147	766
Ramboll 9	Not disclosed	200,000	138	690
Ramboll 10	Not disclosed	200,000	185	925
Ramboll 11	Not disclosed	208,000	184	885
Ramboll 13	Planned	220,000	200	909
Guangdong, China	2005	225,000	51	224
Zhejiang, China	2003	225,000	33	145
Spokane, Wa, USA	1991	248,200	253	1,018
Guangdong, China	2005	267,000	76	286
Guangdong, China	2005	267,000	62	232
Ramboll 12	Not disclosed	280,000	176	629
Mauritius	NA	300,000	200	667
Guangdong, China	2005	300,000	111	371
zhejiang, China	2005	300,000	39	131
Fujian, China	2005	333,000	39	117
Jiangsu, China	2005	333,000	88	265

Jiangsu, China	2005	333,000	53	159
Zhejiang, China	2001	350,000	76	218
Moscow, Russia	2007	360,000	288	800
Shanghai, China	2002	365,000	118	323
Chongqing, China	2005	400,000	56	139
Guangdong, China	2005	400,000	111	277
Tianjin, China	2005	400,000	95	238
Shanghai, China	2003	500,000	165	331
Palm Beach, FL, USA	Planned	1,000,000	668	668

Appendix 3: WTE plants operating in the world

This Excel spreadsheet was constructed by the Earth Engineering Center of Columbia EEC on the basis of 2011 data obtained from providers of WTE furnaces around the world. It allows for search by country, size, energy output, supplier, etc. and is available at the WTERT web, www.wtert.org, SOFOS database "WTE plants 2011".

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PART TWO

7 Case Study 1: Valparaiso, Chile

7.1 Country facts

Chile is an emerging economy with a GDP of about US$200 billion, a population of 17 million and a per capita income of about US$12,000 in current dollars and $15,000 at purchasing power parity (PPP) dollars, i.e., about one third of the U.S. GDP per capita. Chile is one of the world's most open economies and its total foreign trade (exports plus imports) accounts for 67% of Chile's GDP.

Chile leads Latin American countries and most other emerging economies in the rankings of different credit ratings agencies, such as Moody's and Standard & Poor's, and of international organizations such as the World Economic Forum and The Economist Intelligence Unit. Chile's performance, validated by these institutions, has helped to position Chile as one of the world's most secure locations for foreign investment in the emerging world.

Despite the current adverse external conditions, the Chilean economy has continued to grow between 4% and 5% per year while maintaining stable external accounts, responsible public sector spending (that has transformed the public sector into a net creditor) and strong international reserves (approximately 1/3 of GDP); the 2011 real GDP growth rate is expected to be 4%.

7.2 Waste management in Chile

Chile has experienced tremendous economic growth in the last 25 years, vastly improving the standard of living of its population. As usual, this growth was coupled to the increase of significant and uncontrolled amounts of waste, creating many environmental and social costs that need to be addressed.

The solid waste management system of most regions of Chile is clearly unsustainable and faces important political, geographical, and environmental challenges. Therefore, there is an urgent need to investigate new solid waste management technologies such as waste-to-energy (WTE). In a "sustainable development" approach, waste should be regarded as a resource for recovery of materials and energy and not simply as a disposal problem.

In Chile, municipalities are responsible for the collection, transport and final disposal of MSW. Most municipalities contract waste management services out to the private sector by bidding openly for the collection and disposal services. The rest have their own collection system and disposal facilities, which in many cases are very inefficient. Each municipality acts independently and negotiates its own price; consequently there is no fixed price for this service, and the municipalities charge citizens for the collection and disposal waste costs through a "property tax."

There is a pressing need to solve sanitary problems related to improper waste disposal across the country. Only the capital city of Santiago, where 100% of collected waste goes to modern sanitary landfills, and a few regional urban centers have modern sanitary landfills.

7.3 Reasons for selecting the Valparaiso region for the Chile Case Study

The project team evaluated several factors in order to decide on the site for the Case Study for Chile. The reasons for choosing the Valparaiso region were:

Population: The Valparaiso Region has the third largest urban population in Chile and is also a tourist destination; therefore it generates a large amount of MSW.

Current status of MSW management: Most of the waste disposal facilities of the Valparaiso Region have reached near full capacity; in contrast, Santiago has three sanitary landfills of an expected lifetime of over two decades.

Decentralized Policies of Chile: The national government is developing policies to decentralize the Metropolitan Region and prioritize the development of infrastructure projects at the Regions.

Geographic location: Valparaiso is the gateway to the sea for metropolitan Santiago and is a historical city, designated as Heritage City of Humanity by the U.N. If the first WTE plant in Chile were to be constructed in the Valparaiso Region, it could influence other Regions of Chile to develop and implement modern solid waste management solutions.

7.4 Valparaiso overview

The Valparaiso Region is located in central Chile (Figure 41), 120 km northwest of the city of Santiago. The capital of the region is the city of Valparaiso that also houses the National Congress and is designated as a UNESCO World Heritage Site. It is one of the country's most important seaports and an increasingly vital cultural center. About fifty international cruise ships call on Valparaiso during the 3-month Chilean summer. The port of Valparaiso is also an important hub for shipping of container freight, including exports of wine, copper, and fresh fruit. The population of Valparaiso, with the neighboring resort city of Viña del Mar and surrounding seaside resorts such as Reñaca, Concon, San Antonio and Quintero, is nearly doubled during the summer and holiday months of December, January and February. The city is popularly known as the garden city and is the tourist capital of Chile, because of its thirteen beaches and proximity to Santiago.

The main economic activities of Valparaiso are tourism, culture, transport, manufacturing industries and food production. The Valparaiso Region is host to agricultural lands, wine producers, as well as industrial activity such as copper mining and cement. Chile's largest oil refinery and also an important copper refinery, the state owned Ventanas, are located in the Region. In the interior valleys, there is a booming export industry, mainly of fresh fruits and flowers. The land surface area of the Valparaiso Region is about 16,400 km^2.

Figure 41 Location of Valparaiso Region within Chile (EEC)

7.5 Waste management in Valparaiso Region

According to the most recent census (2006) the population of Valparaiso Region was 1.9 million[40]. The MSW generated in 2009 was 1,600 tons per day, i.e. about 584,000 tons[41].

There is one sanitary landfill, ten regulated landfills, and four non-regulated open dumps that represent about 10% of the MSW disposed in the region. There are no transfer stations in the region and very little recycling[42].

There are several municipalities in this region but this study concentrated on seven adjoining municipalities, Valparaiso, Viña del Mar, Concon, Quilpue, Villa Alemana, Quillota, and Quintero. The map in Figure 42 shows the geographic boundaries of this area.

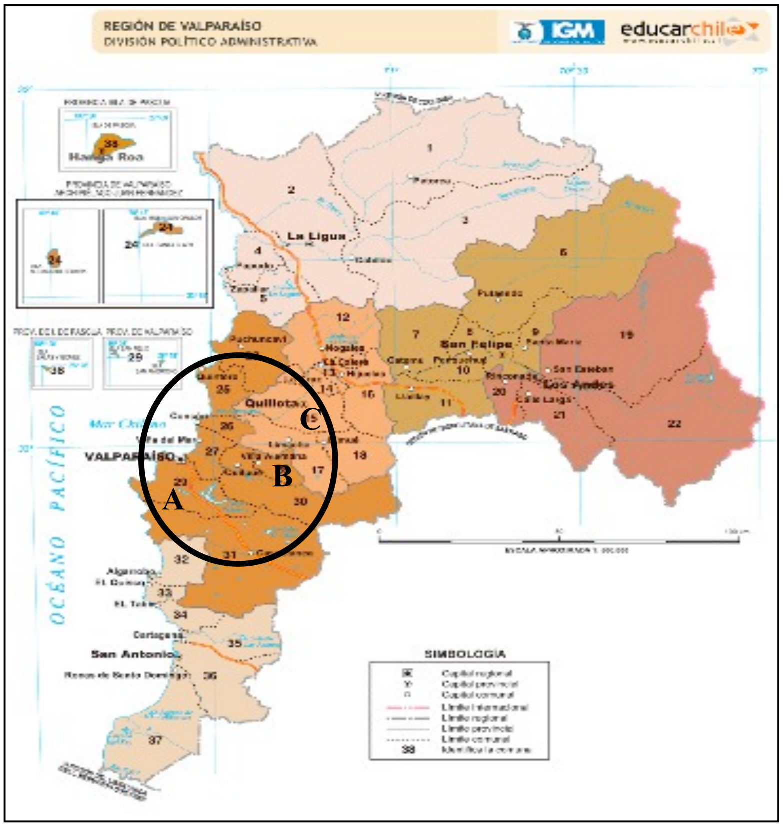

Figure 42 Geographic area of the Valparaiso Case Study (EEC)

The population and waste generation (2009) for the municipalities considered in this study are shown in Table 19

Table 19 Waste Generation by Municipality[43]

MUNICIPALITY	POPULATION	TPY	TPD
Concon	53,944	21,684	59
Viña del Mar	291,760	117,362	322
Valparaiso	275,982	97,580	267
Quilpué	155,318	43,085	118
Villa Alemana	125,275	35,108	96
Quintero	25,054	21,632	154
Quillota	86,160	43,062	118
TOTAL	**1,013,493**	**379,513**	**1,134**

The solid wastes brought into Valparaiso by cruise ships is considered “foreign waste” (by law) and must be transported and disposed in a Santiago landfill.

The Municipality of Valparaiso and Viña del Mar represent 56% of the total population of Valparaiso Region. The MSW generation is growing at 1.8% annually and it is estimated to reach 155,000 tons in Viña del Mar and 121,000 tons per year in the Municipality of Valparaiso[43].

The WTE energy generation and revenue depend on the calorific value of the waste. Several past characterization studies in the literature were reviewed but were found to be old and not reliable. The Valparaiso Government has not developed an up to date characterization.

Table 20 shows the average composition of the Valparaiso and Viña del Mar MSW in 2001, obtained from a 2011 Report provided by Esteban Alvez of Stericycle (Ref. 45). The calorific value of 9.38 MJ/kg, from the 2001 study, is low in relation to those obtained by EEC for Buenos Aires, Toluca and Montevideo. In view of the economic development of Chile in the first decade of the 21st century, it is expected that the current heating value is somewhat higher.

Table 20 Composition of Valparaiso MSW[44] and heating value

MSW component	Characterization of Valparaiso MSW (2001)	MJ/kg material (Tchobanoglous Handbook)	Contribution to heating value of MSW, MJ/kg
Organic Waste	63.6%	4.6	2.9
Paper and cardboard	11.7%	15.6	1.8
Plastics	11.7%	32.4	3.8
Textiles	4.4%	18.4	0.8
Glass	4.1%	0	0
Metal	3.9%	0	0
Other	0.6%	4.0	0.02
Total	100.0%		9.4

7.6 Current disposition of MSW in Valparaiso Region

Recycling

Recycling in the Valparaiso Region is informal and minimal. The local government estimates it to be as little as 2%.

Landfilling

Figure 42 shows the location of the current disposal facilities of the selected municipalities in the Valparaiso Region. Their description follows.

a) El Molle landfill (A in Figure 42)[45]

El Molle is the main landfill in the region, is managed by Stericycle Company, and is located south of the highway La Polvora in the Valparaiso Commune. It has been in operation since 2001 and occupies an area of 943.6 hectares (231 acres). It consists of three cells, the first of which reached full capacity in 2001, the second is operating now and will reach full capacity in 2014, and the third will open as a sanitary landfill in 2013 and is expected to reach full capacity in 2028.

Cell number two receives about 357,000 tons (1,000 tons/day) of solid wastes annually from the municipalities of Valparaiso, Viña del Mar, Quilpue, Concon, La Ligua, Olmue and Limache (total population of 872,000 (2009) inhabitants). Of this amount, 837 tons per day is MSW from the municipalities and 163 tons per day commercial waste from private firms. The facility collects and flares an estimated 15 tons per day of methane and El Molle gets carbon credits for reducing methane emission to the atmosphere. The final density of the landfilled MSW is 0.9 ton/m^3. As discussed in Section 7.12, the average gate fee is US$14 per ton landfilled.

The El Molle landfill has had a history of past environmental problems with several environmental fines. The new administration by Stericycle took over in 2010 and is committed to avoiding the environmental troubles of the past. Stericycle is developing a sanitary landfill in the third cell to be opened in 2013.

b) Villa Alemana municipality controlled, non-sanitary landfill (B in Figure 42)**[42]**

This landfill is owned and operated by the municipality of Villa Alemana and is located in "Sector Sur Poniente Rosenquista, vía 2B-1" in the Commune of Villa Alemana. It is in operation since 1994 and covers an area of 10 hectares (25 acres). It was expected to reach final official capacity in the year 2010, but still receives approximately 23,000 tons of waste per year (63 tons per day) from a population of about 116,000. In the last few years, the landfill received several environmental fines, but still there is no final solution because of a lack of waste disposal site alternatives. It is planned to close this landfill once a planned transfer station is built. The gate fee is only US$6 per ton.

c) San Pedro non-sanitary landfill (C in Figure 42)**[42]**

This Open Dump, owned and managed privately, is located in Fundo Los Hermanos, sector Lo Venecia in the Commune of Quillota. It has been in operation since 1996 and covers an area of 10 hectares (25 acres). It was projected to reach final capacity in the year 2007, but still receives the waste of the municipalities of Quillota, Calera, Hijuelas, La Cruz, and Nogales, i.e., 38,000 tons of waste per year (103 TPD) from a population of about 194,000. The gate fee is US$8 per ton.

7.7 Gate fees

As noted above, the main cities in the Valparaiso Region, Viña del Mar and the city of Valparaiso dispose their MSW at the "El Molle" landfill.

Table 21 shows the collection, transport and disposal cost for the municipalities evaluated in this study.

Table 21 Collection/transport and disposal costs of various municipalities in 2010[43]

Municipality	Disposal site	Contract termination date	Collection cost (US$/ton)	Disposal cost (US$/ton)	Total cost (US$/ton)	Annual cost (US$)	Distance to open dump (km)
Concon	El Molle	29/09/2021	32.8	15.6	48.4	1,049,146	30
Viña del Mar	El Molle	31/10/2021	98.3	13.4	111.7	13,111,765	21
Valparaiso	El Molle	3/10/2021	77.2	12.4	89.6	8,938,332	10
Quilpué	El Molle	1/8/2013	39.4	11.5	50.9	2,193,600	33
Villa Alemana	Villa Alemana	NA	21.9	6.4	28.3	995,143	7
Quintero	Quintero	NA	25.8	3.6	29.4	637,433	3
Quillota	San Pedro	30/06/2011	24.9	7.8	32.7	1,408,629	12

7.8 Proposed capacity and energy generation potential

On the basis of the information collected for the selected municipalities in Valparaiso Region, it is proposed that the first WTE plant in Chile be of nominal capacity of 42 tons per hour i.e., 336,000 tons per year (90% availability, i.e. 8,000 hr./yr.). It is proposed that this plant consists of two lines, each of nominal capacity of 21 tons per hour. The LHV of the Valparaiso MSW is assumed to be 9.4 MJ/kg (

Table 20). Therefore, replicating the calculations in Section 5.8 of the Guidebook (Energy recovery), the net electricity production in a plant of 1,000 tons/day capacity is estimated at 540 kwh/ton, or 182 GWh/yr.

7.9 Site selected for the WTE plant

The Project team evaluated several alternatives for the WTE plant location, in consultation with knowledgeable people in the Valparaiso Region:

- El Molle Landfill
- Concon Industrial Area
- Curauma Industrial Area
- Open Dump Villa Alemana

The El Molle landfill was selected for the following reasons:

- It is the nearest site to Valparaiso and Viña del Mar, the most populous municipalities in Valparaiso Region.
- It is an operating landfill with all environmental and other permits approved.
- Economic reasons.
- Strategic reasons.
- Proximity to main roads and accesses granted.
- El Molle is operated by a private company, which is interested in developing methods that reduce environmental impacts.

The approximate land area required for the proposed plant is estimated at 5 ha accordingly with Section 5.5 of the Guidebook (Selecting a Site for the WTE plant). Figure 43 shows an aerial view of the El Molle site.

Figure 43 Aerial photo of the El Molle landfill (EEC)

7.10 Projected emission limits

A Chilean incineration norm was approved in 2007. Table 22 presents the projected emissions from the WTE plant (measured in the stack) for different pollutants on a daily basis and compares them with Chilean, U.S., and E.U. emission standards.

Table 22 Comparison of WTE limits with international standards[i]

Pollutant	Units	E.U.[a]	US[b] (EPA)	Chile[c]	WTE facility
Particulate Matter	mg/Nm^3	10	15	30	9
Opacity	%	---	10	---	Nil
Cadmium	ug/Nm^3	5*	8	100	8
Lead	ug/Nm^3	500**	107	1000	107
Mercury	ug/Nm^3	50	38	100	19
	% Elimination	---	85	---	> 85
SO_2	mg/Nm^3	50	61	50	49
	% Elimination	----	80	---	> 80
HCl	mg/Nm^3	10	29	20	20
	% Elimination	---	95	---	> 95
CO	mg/Nm^3	50	89	50	50
NO_X	mg/Nm^3	200	219	300	124
Dioxins/Furans (TEQ)	ng/Nm^3	0.1	0.13	0.2	0.1

December 2000 on the incineration of waste.

Standard for Cd + Ti ;Standard for Pb + Sb + As + Co +Cr + Cu +Mn + Ni + V*

a. Directive 2000/76/EC of the European Parliament on incineration of wastes, December 4, 2000 (www.ingvar.is/Sorp/FlueGasCleaning.pdf;

b. Federal Register, EPA 40 CRF Part 60, Dec. 19, 2005 (www.epa.gov/ttn/atw/129/mwc/fr19de05.pdf) c."Norma de Emisión para Inceneración y Coinceneración. Decreto 45 Fecha Publicación 05/10/2007"

Table 22 shows that the projected emissions of the Valparaiso WTE plant will be as low as the E.U. and U.S standards for WTE facilities and below the Chilean present limits.

7.11 Projected WTE plant costs

It should be noted that the costs presented in this report are estimates based on recently built facilities in Europe and the U.S. where the WTE plants are designed with a high quality grate combustion furnace, empty vertical passes and a vertical boiler followed by a semi-dry flue gas cleaning and a 75m stack; the WTE facilities are purchased in a competitive tender process in three mechanical lots and one civil lot; and a consultant is hired to coordinate the tender process and lot interfaces.

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i All concentrations are referenced to 11% O_2 dry gas basis at Normal conditions (0°C and 1 atm)

Therefore, these estimates do not take into account all the local conditions, and are also subject to many varying factors such as the price of steel and the cost of labor. Hence, they are considered to be within a plus or minus 20% accuracy.

Capital cost:

The site needed for the development of the facility is estimated roughly at 5 hectares (50,000 square meters). The cost per square meter at El Molle is equivalent to US$13. Accordingly, the land cost will be approximately 50,000 m^2 x US$13 = US$650,000. All the items in the capital cost are presented in Table 23.

Table 23 Capital cost estimate

Number of lines	2
Site preparation, access, landscaping (million US$)	14
Buildings, stack (million US$)	46
Grate, boiler, air supply, ash handling, electrical and mechanical systems (million US$)	94
Turbine generator (million US$)	23
Air pollution control system (million US$)	23
Contingency (million US$)	23
Land	2
Estimated total capital cost (million US$)	**225**
Estimated capital cost (US$/ annual ton of capacity)	**670**

Operating costs:

The operating costs, assuming a personnel of 43 people, and that the bottom and fly ash will be mixed and disposed at El Molle landfill are shown in Table 24.

Table 24 Operating costs

Number of lines	2
Ash disposal (million US$; US$3.75/ton)	1.3
Chemicals (million US$; US$4/ton)	1.3
Gas Cleaning (million US$; US$8/ton)	2.7
Maintenance (million US$; US$15.6/ton)	5.2
Miscellaneous (million US$; US$2/ton)	0.7
Personnel, employees (million US$)	1.2
Subtotal (million US$)	12.4
Contingency (million US$; 5%)	0.6
Subtotal	13.0
Insurance (million US$; 0.6%)	0.1
Estimated operating cost (million US$)	**13.1**
Estimated operating cost (US$/ton capacity)	**39.0**

7.12 Projected WTE plant revenues

Gate fees

Since the WTE facility is projected to be located at El Molle, the current gate fee charged in El Molle is considered. As noted earlier, El Molle receives MSW from municipalities and industrial waste from private sector with different prices for gate fee[45]:

- 16.3% of the waste disposed is industrial waste from private companies who pay a gate fee of US$22.8 per ton.
- 83.7% of the waste disposed is MSW from municipalities with an average gate fee of US$12 per ton of MSW

Therefore, the average gate fee is: 0.163 x US$22.8 + 0.837 x US$12 = US$14 per ton.

Collection costs are assumed to remain constant. However, considering the present high cost of MSW collection at Valparaiso and Viña del Mar, indicates that the collection system should be streamlined alongside with the construction of the WTE.

Sale of electricity

In Chile, the private sector is responsible for electric power generation, transmission and distribution. Thus, electricity market prices are a result of a free energy market, in contrast to other Latin American economies where governments fix electricity prices, electricity is sold on a spot market based on dispatch at a short term marginal cost; or in a market of contracts, whereby generators of electricity sell it sell it at stabilized prices in contracts with distributing companies and also with mining, industrial, and commercial clients.

Concessions or permits are not required for the installation of generation plants and other annexed works; however, they must fulfill the requirements that any industrial installation is subject to, including necessary environmental permits.

Non-conventional renewable energies have not been an important contributor to the Chilean energy generation system, mainly due to their high cost. However, in recent years, the use of renewable energy has started to be a motivating issue for the Chilean government, and for that reason several law amendments have been approved.

Spot Price

The spot price is influenced mainly by the level of water in the reservoir in the Central-South of Chile (if it is a dry year or not) and fossil fuel prices. Table 25 shows spot prices for the Interconnected Central System.

Table 25 Spot Prices (US$/MWh) [46]

Month	2007	2008	2009	2010	2011
January	57	247	115	116	157
February	123	272	142	135	217
March	144	325	134	135	236
April	145	280	121	133	205
May	171	252	95	141	221
June	252	181	108	148	
July	223	200	102	138	
August	208	143	96	157	
September	176	134	68	127	
October	154	155	104	128	
November	169	141	84.7	125	
December	215	127	80	163	

In past years, electricity spot prices in Chile have been high, but also very variable, because of droughts in the south central region. Also, the rise in fuel prices and international economic crisis have resulted in very high spot prices in the first half of 2011. It is assumed that when the new HidroAysen hydroelectric project starts up in 2017 spot prices will decrease, but there is no certainty about this assumption.

Price under Power Purchase Agreement (PPA)

A Power Purchase Agreement (PPA) can be signed either with an industrial, mining, distribution, or generating company. In 2011, the bidding processes for electricity contracts in Chile have shown prices between US$80 and 110 per MWh[46]. This price does not consider the "fine" or the "renewable energy attribute": As mentioned in Appendix 1 to the Chile Case Study, utilities are required to have at least 5% of their generation from non-conventional renewable sources between years 2010 and 2014 and then increasing gradually to 10% by 2024. In the case of waste, the law specifies that the biogenic fraction is under the category of biomass, but does not specify what fraction of the MSW would be considered for the renewable energy attribute.

The PPA mechanism was assumed for pricing the electricity to be generated by the Valparaiso WTE. With this mechanism, the electricity price is lower but it provides for a stable income for 20 years. This is a more reliable scenario for a WTE facility, even though the Chilean regulation allows for small facilities to supply electricity to the national grid at the spot price.

A PPA of US$90/MWh was assumed in this analysis. Accordingly, the revenue from the sale of electricity was estimated at US$46 per ton of MSW.

Carbon credits

For calculation of the carbon credits revenue, the factor of 0.6 tons CO_2/MWh was used, as provided by the United Nations Framework Convention for Climate Change (UNFCC). This was calculated for the Central Interconnected System that encompasses the Valparaiso Region and uses a combination of oil, coal and hydroelectric power generation that the WTE plant would displace. This factor is then multiplied by the estimated electric generation of the plant (182 GWh/year) to obtain the estimate of 109,200 tons of carbon dioxide credits.

The above calculation does not include the avoided emissions of methane, since the methodology used currently by the Clean Development Mechanism (CDM) recognizes only the first ten years of avoided landfill methane, which is a fraction of the overall methane actually avoided through WTE facilities (landfills can emit methane for 100 years or more). Therefore, the amount of avoided landfill methane creditable will most likely be comparable to the fossil CO_2 stack emissions from the WTE facility. Therefore, in this analysis, it will be assumed that only 109,200 CERs will be issued at a price of US$16 (Section 5.18 of the Guidebook - Revenues); this results in an income of only US$5 per ton of MSW.

Sale of metals recovered

As mentioned in Section 5.18 of the Guidebook, it is estimated that at least 50% of the metals contained in MSW can be recovered from the WTE bottom ash. Since the MSW in Valparaiso Region contains 3.9% metals (Table 20), then from every ton of MSW combusted approximately 19.5 kilograms of metal could be recovered. Therefore, the proposed facility at El Molle would recover an estimated 6,500 tons of metal per year. Given this figure and an estimated price of scrap metal in Chile of US$200 per ton, the WTE facility would have a revenue of US$1.3 million per year, i.e., US$3.9 per ton of MSW combusted.

7.13 Financial analysis of WTE for Valparaiso area

The approach used for the financial analysis was Net Present Value (NPV) and Internal Rate of Return (IRR) of the operating cash flows. This means that specific financing costs were not taken into account and therefore both, NPV and IRR, will most likely decrease once these costs are included. Also, variations in cash flows due to inflation or other factors were not included and could have an important impact in the analysis.

The scenarios considered for the financial assessment are the following:

- Base Scenario: PPA where electricity is sold at US$90/MWh, and there is no renewable energy attribute.
- Scenario 2: PPA with a generation company, which means that the renewable energy attribute is included, and therefore the price of electricity would be US$112.4/MWh.
- Scenario 3: Electricity is sold at the Spot Price. The electricity price assumed under this scenario is the average of the 2011 spot price, i.e. US$207/MWh.

The gate fee for the three scenarios was fixed at the present price of US$14 per ton. This fee is very low and inadequate for sanitary landfilling of MSW, but under the present circumstances where municipalities do not derive enough revenue to meet their waste disposal budget, it is not realistic to expect them to pay a higher gate fee for MSW disposal, despite the considerable energy and environmental benefits of the WTE alternative to the region and Chile as a whole.

The payback period used was 23 years, assuming approximately 3 years of construction and 20 of operation.

The discount rates used for the NPV calculation are 5%, 10% and 15%. The reason for selecting 5% is that this is the estimated cost of capital for the federal government of Chile in U.S. dollars; as of October 18, 2011, the 20-year spread of Chile over US treasuries was 2%, and 20-year US treasuries were trading at 2.7%[47]. The reason for also using the 10% and 15% discount rates is that if private investors participated in the WTE plant, the cost of capital would be higher than for the government of Chile.

Table 26 shows the NPV for the three discount rates and also the IRR for the three scenarios.

Table 26 NPV at 5%, 10%, and 15% discount rates, and IRR for the three scenarios

Scenario	NPV at 5% (million US$)	NPV at 10% (million US$)	NPV at 15% (million US$)	IRR (annual rate)
Base	(85)	(115)	(124)	-0.2%

Scenario 2	(42)	(89)	(108)	2.7%
Scenario 3	141	19	(39)	11.3%

The results show that at the current and very low gate fee, the only feasible scenario is scenario 3, when the cost of capital is less than 11.3%. The gate fees required for the plant to break even operationally (i.e., at NPV = 0), at 5%, 10%, and 15% discount rates in the three scenarios are shown in Table 27.

Table 27 NPV at 5%, 10%, and 15% discount rates, and IRR for the three scenarios

Scenario	**Gate fee (US$/ton)**		
	5% discount rate	10% discount rate	15% discount rate
Base	38	69	106
Scenario 2	26	56	94
Scenario 3	0	5	43

7.14 Stakeholders

When a new technology, such as WTE, is introduced in a society, there will be a range of reactions, from full support to outright opposition, by local stakeholders with diverse interests, information levels, and economic and organizational skills. It is necessary to understand their motivations and reactions before proceeding to the planning and implementation stages of the project.

An optimal MSW management system that will meet the needs of the community and provide environmentally friendly solutions requires prior identification and analysis of the stakeholders and their interests; and adequate dissemination of information.

Table 28 in Appendix 2 of the Chile Case Study lists the possible stakeholders who may become involved in the discussion and development of a WTE facility in the Valparaiso Region, their interests and their influence.

During the field visits to the Region of Valparaiso and the capital city of Santiago, the EEC team found a positive reaction to the concept of advancing sustainable waste management by implementing the first Chilean WTE in the Valparaiso Region. The major concern expressed, by government officials, industry, and academia, was the economic viability of such a project under the prevailing economic conditions.

7.15 Conclusions to Chile Study Case

The Valparaiso Region is considered to offer the most likely site for locating the first modern WTE facility in Chile, because of the urgent need to solve its current solid waste management problem and the prominence of this region within Chile and internationally. Most of the landfills in this Region have already reached full capacity or are expected to reach it within a few years; also, the geographic location and topography of the Region make the opening of new landfills a challenge.

The best option for the Valparaiso Region WTE facility is to be located at El Molle, where most of the required environmental permits have been already approved. El Molle is the largest waste disposal facility in the Region and receives the MSW of the cities of Valparaiso and Viña del Mar, with already settled waste disposal contracts. Collaboration with the company that is now operating this landfill would be advantageous in developing the WTE project and the company has expressed their interest in this Project. It is necessary to connect with all the other stakeholders listed in this report and discuss their concerns and special needs.

Unfortunately, despite all its environmental advantages, the financial analysis presented in this report has shown that, at current gate fees and energy prices in Chile, WTE is not yet economically feasible unless electricity is sold at spot price. Moreover, the gate fee would need to be at least US$38/ton (i.e. US$24/ton higher than the current landfill gate fee) for the project to break even operationally under the base scenario. However, El Molle up to date is a landfill that does not provide for protection of the groundwater nor of the global climate. On the basis of international experience, it is estimated that implementation of a truly sanitary landfill in the Valparaiso Region would require a gate fee of at least US$30 per ton MSW; such a gate fee would make the proposed WTE economically competitive with sanitary landfilling.

The present thinking is that municipalities are already stressed and have to cover the total annual cost of waste management from other sources of income; therefore they cannot afford a higher gate fee, even though the environmental benefits are obvious to them. Only part of the population foots the bill for waste management through the property tax bill and, also, this tax does not depend on the amount of waste generated.

The municipalities of the region already allocate a significant fraction of their budget to the management of solid wastes. In particular, of the total waste management budget of Valparaiso and Viña del Mar, the collection and transport cost represents 87% while the landfilling costs represent only 13% of the total budget. These high collection costs do not seem to be related to the distance of travel to the landfill. For example, the distance between the city of Valparaiso and El Molle is only ten kilometers while collection and transport cost US$77 per ton. The plan for a new WTE at El Molle should certainly consider a more efficient and less costly means of collecting MSW in Valparaiso and Viña del Mar.

Municipalities are fully responsible for solid waste management, therefore in charge of bidding processes for waste disposal. Future biddings should include the option of WTE technologies, as one municipality in the south of Chile has already done.

Recycling in the Valparaiso Region is informal and minimal. It is recommended that the plan for a WTE plant in Molle also consider the following recycling system:

a) The municipalities of Valparaiso and Viña del Mar request citizens to collect designated recyclables (e.g. mixed paper, metal and plastic containers, other metals) separately and once a week (e.g. on Saturdays) place them on the curb to be collected by the same collection trucks that during the rest of the week collect the trash that goes to MSW.

b) The single-stream collection is transported to a building adjacent to the WTE facility at El Molle, where workers sort out and bale the various recyclables (e.g., mixed paper, plastic containers, ferrous metal, non-ferrous metal) for transport to recycling plants in Chile or abroad. This program will reinforce the well-established principle that recycling goes hand and hand with WTE.

The economics developed in this Report are based on a 20-year life of the proposed WTE plant, although some modern WTE facilities have already reached their thirty fifth year and will continue operating in the foreseeable future.

In order to develop a state-of-the-art WTE facility in Valpariaso, it will be necessary for the national government to bring the issue of solid waste management higher up on its list of priorities, similarly to the government decision taken a decade ago regarding waste water treatment in Chile; nowadays, waste water is treated in modern facilities with a coverage of almost 95%. The first WTE project in Chile should be undertaken as an infrastructure decision similar to an earlier decision to develop national highways that has changed the infrastructure landscape of the country. For instance, in some other nations the government has supported the first WTE in the country by subsidizing the gate fee or co-financing a percentage of the capital investment, repayment of which represents the major cost item of the proposed WTE. Therefore, the national government may consider ways and means by which it may encourage the construction of the first waste-to-energy plant of the nation.

Additional financial support may be possible through carbon offsets and GHG mitigation mechanisms. More accurate carbon offset methodologies, that better reflect the net carbon impact of these facilities, will increase the monetary benefit from carbon-offset projects, and consequently, the viability of such projects[48].

This Project should be viewed as a genuine positive development with very beneficial impacts, both environmental and social, as a direct result of implementing, starting with the Valparaiso Region, a sustainable waste management system that includes recycling, energy recovery and sanitary landfilling. Chile is now an OECD member country and implementation of WTE can help the nation to meet the guidelines of this organization regarding environmental issues.

The development of projects like WTE will be more likely, due to the existence of fines for non-compliance with legally required green energy, as well as ongoing discussion at the Senate that may result in the requirement that 20% of energy generation in Chile be derived from non-conventional renewable energy sources. Also, the potential, ratified by law, of connecting such energy to the electric grid at a marginal cost and selling renewable energy at similar rates to those of big players will accelerate the implementation of smaller scale energy projects, such as WTE facilities.

Appendices to Chile Case Study

Appendix 1: Legal framework

1.1 Laws and regulations related to waste management

1. In 2007, the Organization for Economic Cooperation and Development (OECD) invited Chile to participate in this organization, which imposes a high environmental standard for public policies and the quality of growth. The OECD recommendations are designed to reduce the number of landfills and increase the recovery of recyclable material as well as thermal treatment of waste with energy recovery.

2. The Ministry of Health in 2007 issued the regulation on health and safety conditions in Sanitary Landfills (DS No189/2007 MINSAL) which required all open dumps to be converted into sanitary landfills or to submit to the Health Ministry closure plans by December 31, 2010 to ensure compliance with this standard. However, this and other "deadlines" have been extended due to lack of final disposal solutions.

3. The Politics of Integrated Solid Waste Management (La Politica de Gestión Integral de Residuos Sólidos) approved by the Board of Directors of the National Environmental Commission (CONAMA) in 2005, sets the standard for handling solid waste in Chile.

4. Decreto Supremo No. 95 of 2002 amends the rules of the Environmental Impact Assessment process.

5. Law 19300 of 1994: The Basic Law of the Environment (Ley de Bases del Medio Ambiente).

There are two more laws that are under study and are expected to be put into force during this administration: The General Law of Municipal Partnership (Ley de Asociamiento Municipal) and the General Law of Waste (Ley General de Residuos).

6. Valparaiso municipal law (Article 3.16). This law refers to the location of areas for solid waste disposal facilities. The area outside the urban area and rural areas will be allowed for municipal solid waste management under the plan established by the Intercommunal Valparaiso, in addition to land uses that are set forth in the law. The land where such facilities can be located should meet the following conditions:

- Respect a distance of 300 meters from local housing and more than 600 meters of a residence area.
- Respect a minimum distance of 2,000 meters of urban areas and urban residential area.
- Not to be located in protected areas.

- Respect a minimum of 600 meters from protected wildlife areas and priority sites for conservation of flora and fauna.

1.2 Laws and regulations related to energy

The General Law of Electrical Services DFL 4 (2006) is the legal framework that regulates concessions and electrical permits, easements, electrical energy transport systems, electrical services development and electrical energy supply.

The following is a summary of the most relevant aspects for non-conventional sources of energy:

1. Article 149 of DFL4 states that non-conventional generation sources, and small generation sources that are synchronized with an electrical system through installations belonging to distribution companies, will have the right to:

- Sell energy evacuated to the system at the Instant Marginal Cost (CMg); or,
- Subscribe a contract with big commercial and industrial clients in a Power Purchase Agreement (PPA).

2. A modification of the Energy Law, known as "Short Law I", introduced in 2004, established the first direct incentive for renewable energy generation (specifically in art. 71-7). The law partially or completely exonerates those generators that produce electricity from non-conventional sources from paying a transmission toll. Generators, which produce less than 9 MW, are completely exonerated while those that generate between 9 MW and 20 MW are partially exonerated, paying a percentage of the toll. For generators over 20 MW the transmission toll should be paid.

3. In April 2008, Law 20257 amended the energy law by redefining which non-conventional sources of energy are considered renewable. Under this law the biodegradable fraction of waste was classified as biomass, therefore a renewable source of energy. Before this law amendment, waste was not considered as biomass.

4. Article N°1 transitory, from Law 20257 requires utilities to have at least 5% of their generation from non-conventional renewable sources between years 2010 and 2014 (from 2015 increasing 0,5%) and 10% by 2024. Non-compliance will be punished with fines of 0.4 UTM/MWh (33 US$/MWh) and 0.6 UTM/MWh (49 US$/MWh) for repeating offenders. This law is valid until 2035, after which time it is expected that renewable energy sources will keep functioning without these incentives. Currently a new law is being discussed in the Senate, which is likely to succeed in its approval that is considering replacing the current mandate with a 20% target by 2020[49].

Appendix 2 to Chile Case Study: Potential stakeholders

Table 28 Potential Stakeholders' list

STAKEHOLDER	STAKEHOLDER INTEREST	POSSIBLE STAKEHOLDER INFLUENCE
Ministry of the Environment	The project requires an environmental impact assessment Supervision and oversight of the system Set environmental policies Seek to achieve international standards of environmental practices	Termination, delay, or change of the project Administrative and bureaucratic obstacles
Ministry of Health	The waste is managed properly and air emissions of the facility meet the emissions regulations	Termination, delay, or change of the project
Municipalities	Managing the waste management system Have an economically competitive alternative to waste disposal	Supply waste to the facility and payment for waste disposal Negotiation of contracts Management MSW problems Lack of clarity and transparency in the calculation of waste disposal tariffs Shortage of recycling initiative
Ministry of Energy	Propose and regulate incentives for clean energy	Regulate energy price
Valparaiso Government	Social, Environmental Health Benefit for the community Encourage continual improvement Incentive of the system	Demand for technical competence and resources to address issues of short and long term Resolve conflicts with various stakeholders
Scavengers	Change in waste management may affect or eliminate their source of income	Scavengers activities may affect the properties and amount of waste
Community groups and nearby citizens	Improved quality of life due to environmental improvements Project may lead to work opportunities. Negative impacts	Termination, delay, or change of projects due to community protests
Environmental NGOs	Reduce impact of waste management on the environment	Termination, delay, or change of projects due to NGOs protests or support if project due to positive environmental impact
Neighbors	Neighborhood free of noise, dust, traffic loading and visual impact. Impact of real estate prices	Termination, delay, or change of projects due to neighbors protests
Collection and transportation	Wish to maintain or expand their business	New requirements for sorting, containers and vehicles

companies		
Energy Generators	Prefer few energy suppliers and higher energy prices	Energy price variation due to fossil fuel prices and drought
Waste disposal facilities	Wish to receive more waste Apply and awarded bids for municipal services	May lower tipping fee due to increased competition
Municipalities nearby the area	Have an economically competitive alternative to waste disposal	Supply waste to the plant and payment for waste disposal

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[49] Bloomberg New Energy Finance 2011.

8 Case Study 2: Toluca, Mexico

8.1 Country facts

Mexico has a land area of 1.96 million km^2, a population of 112 million inhabitants (2010), and a population growth rate of 1.8% (2005-2010)[50]. The country is divided into 31 states plus the Federal District (Mexico City) and each state is divided into municipalities.

The GDP of Mexico is US$1.57 trillion (2010 est.)[51], the 12th highest in the world, and the highest in Latin America. The per capita GDP is US$13,900 (2010 estimate on basis of purchasing power parity)[51].

Mexico has a free market economy and about 90% of its trade is under free trade agreements with over 50 countries, including the North American Free Trade Act and the European Free Trade Area. The economy is based on a mixture of industry (food and beverages, tobacco, chemicals, iron and steel, petroleum, mining, textiles, motor vehicles, tourism) and agriculture (corn, wheat, soybeans, rice, beans, cotton, coffee, fruit, tomatoes). It is the 7th largest oil producer in the world, with a total production of three million barrels per day[52.]

8.2 Waste Management in Mexico

Each municipality is responsible for its waste management, including, collection, transportation, treatment and final disposal of solid wastes. However, the Federal Congress issues laws that help the Federal, State and Municipal Governments to manage effectively all their environmental protection matters (see Appendix 1- Mexico Case Study). Most of the municipalities manage these services directly, while a few do it through municipal autonomous companies, such as SERVILIMPIA in Mérida[53] or private companies, e.g., the sanitary landfill in Queretaro[53].

Citizens in Mexico do not pay directly for waste management; municipal governments are responsible for funding these services through real estate and other taxes. Therefore, the available funding may not be sufficient to provide quality services.

An estimated 66% of the MSW is disposed in sanitary landfills, 12% in regulated landfills, 12% in non-regulated waste dumps, 6% is burnt in open-air and 4% is discarded on land and waters[54]. In the metropolitan zones, where 56% of the population of Mexico lives, 77 - 96% of the collected MSW is disposed on either sanitary or regulated landfills; in semi-urban areas this fraction ranges from 29% to 34%, while in rural areas less than 3% is disposed properly[55,56].

8.3 Other relevant background information

Mexico has the advantage of having development banks that are part of the Federal Public Administration (Appendix 2-Mexico Case Study). Their main function is to facilitate access to funding and provide technical assistance to individuals and institutions. These development banks may help endeavors, such as a WTE plant, to become a reality in Mexico.

8.4 Reasons for selecting Toluca Municipality for the Mexico Case Study

The cities considered for the Mexico case study were:

- Mexico City
- Monterrey and its metropolitan area
- Toluca

The reasons for selecting Toluca for this case study were:

- It is a medium-sized city, which is more representative of cities in Latin America; and as opposed to Mexico City and Monterrey, which are both large cities.
- It is an industrial city with companies who may contribute high calorific value feedstock to the WTE plant and, also, can be potential buyers of the low-pressure steam produced by the facility.
- Toluca is the capital of the State of Mexico, the state with highest MSW generation in the country (Figure 44).

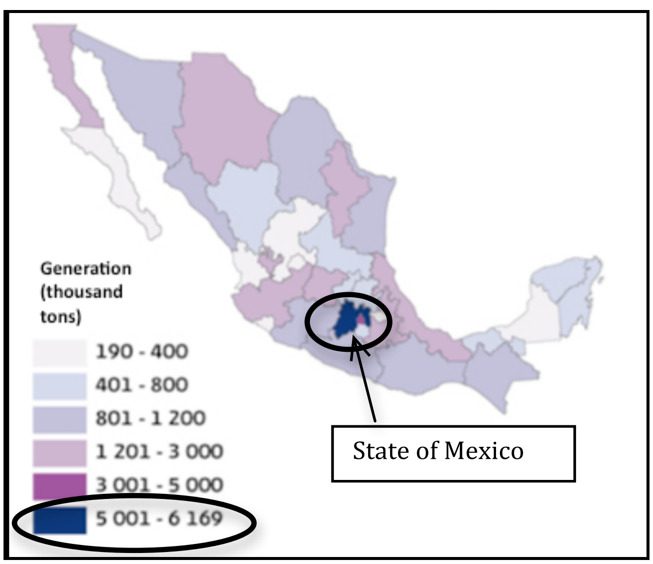

Figure 44 MSW generation distribution in Mexico (2008) (EEC)

8.5 Toluca overview

Toluca has a population 0.82 million inhabitants and is the capital of the State of Mexico, the most populous state in the country (14 million). It is located in the central part of the State of Mexico, about 72 kilometers east of Mexico City (Figure 45). Due to its high elevation (2.6 km above sea level), the yearly average temperature of Toluca is about 12°C.

Toluca is divided into 24 delegations. Because of its proximity to Mexico City, Toluca is both, cosmopolitan and industrial. Some of the most important Mexican industries can be found here, such as textiles, automobiles, beverages, and pharmaceuticals.

Figure 45 Geographic locations of Toluca and Mexico City (EEC)

8.6 Waste management in Toluca

According to the Biodiversity Code of the State of Mexico (Appendix 1 - Mexico Case Study), the management of solid wastes includes the following stages:

- Sweeping of common areas, streets, roads and any other type of public spaces.
- Collection and transportation of MSW to waste transfer stations and/or landfills.
- Temporary storage of MSW within selection plants for distributing materials to composting, re-usage, recycling, thermal treatment or any other treatment.
- Final disposal in sanitary or controlled landfills.

The General Direction of Public Services and Environment of Toluca Municipality has reported that it collects and transports 510 tons/day, at a cost of $39/ton of MSW. The reported disposal cost at the San Antonio la Isla landfill is $12.7/ton.

The generation per capita of MSW in Toluca has tripled from 0.11 to 0.36 tons per capita in the last fifty years and amounted to 295,000 tons in 2009. The composition of MSW in 2009 is shown in Figure 46.

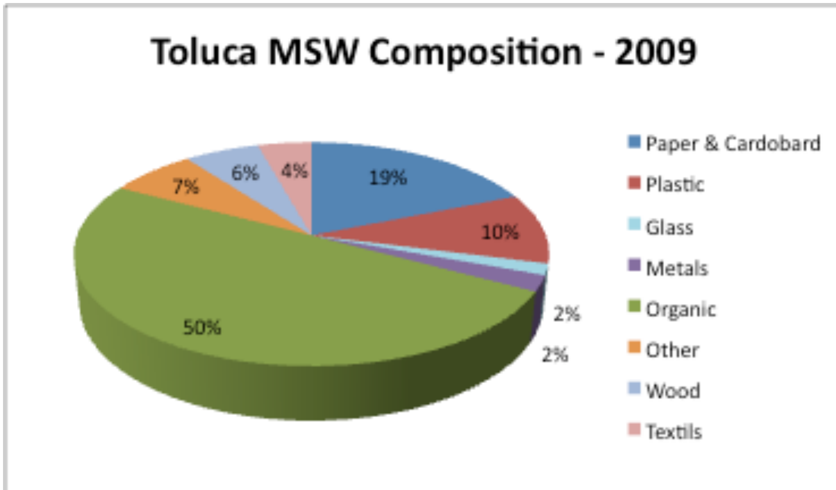

Figure 46 Toluca MSW Composition in 2009.[57] **(EEC)**

The lower heating value (LHV) for Toluca MSW is estimated at 10.4 MJ/kg (Table 29). This is near the middle of the range of calorific values of WTE plants operating in Europe and North America (7 MJ to 14 MJ/kg).

Table 29 Composition of Toluca MSW (2010) and heating value

Material	Percentage in MSW	MJ/kg material (Tchobanoglous Handbook)	Contribution to calorific value of MSW (MJ/kg MSW)
Food waste	50%	4.6	2.3
Paper and cardboard	19%	15.6	3.0
Wood	6%	15.4	0.9
Plastics	10%	32.4	3.2
Textiles	4%	18.4	0.7
Glass	2%	0	0
Metals	2%	0	0
Other	7%	4.0	0.3
Total	**100%**		**10.4**

By 2015, MSW generation is expected to increase to 0.45 tons per capita and increase slightly in calorific value. Figure 47 and Figure 48 show the projected growth and composition of MSW by 2015.

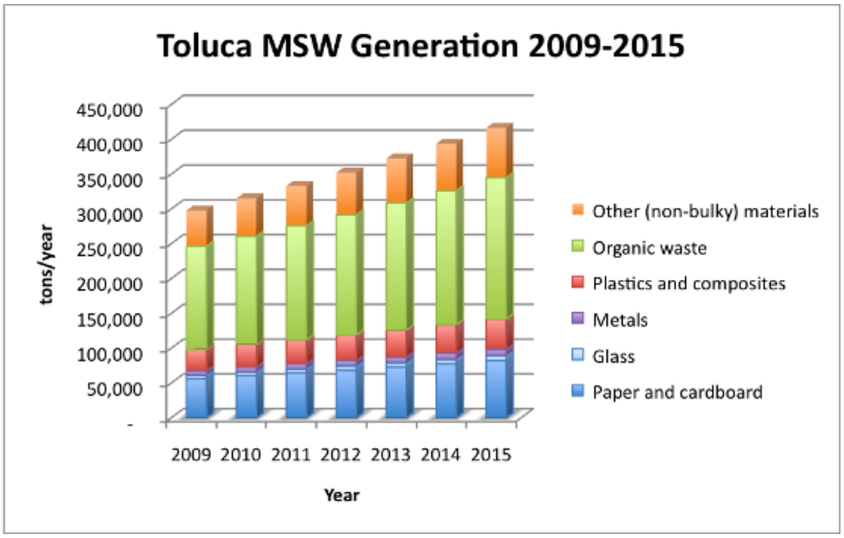

Figure 47 Projected MSW Generation in Toluca: 2009 – 2015 (EEC)

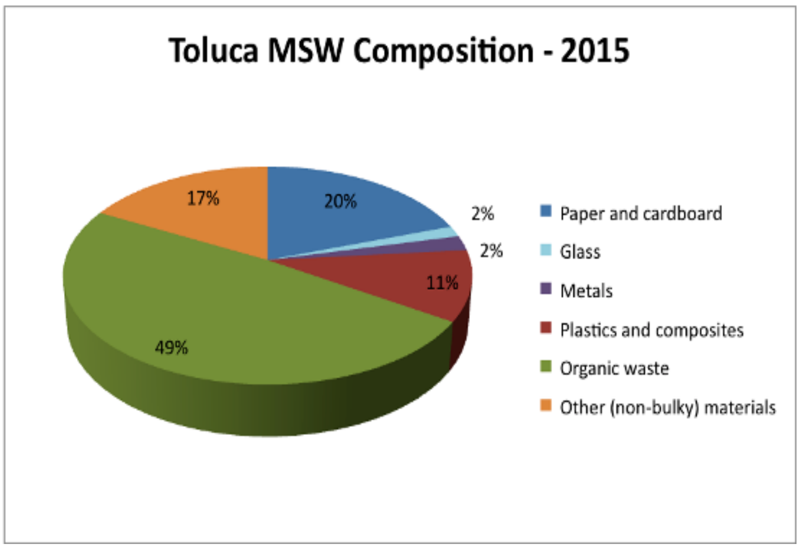

Figure 48 Projected Toluca's MSW Composition in 2015 (EEC)

8.7 Current disposition of MSW in Toluca

Collection

An estimated 186,000 tons[58] of MSW are collected annually in Toluca. This represents only 63% of the total MSW generated in Toluca; the remainder is discarded in non-regulated landfills.

Collection service is provided through the Direction of Solid Wastes to 9 delegations. The other 15 delegations are served since 2004 by the private company "Servicio de Transporte S.A. de C.V.". The 75 municipal trucks follow 193 routes, 148 in urban and suburban zones, and 45 in rural zones. Even though the 2007 Biodiversity Code states that citizens in the State of Mexico must separate their residues into organic and inorganic streams, residues are still not separated at the source. Collection service starts daily at 7:00 AM and continues until all assigned routes are covered. There are no waste transfer stations (WTS) in Toluca. All collected waste is transported to the final disposition sites when the collection route is completed, or the truck is filled up.

Recycling

As in the rest of Mexico, informal collection plays an important role in recycling in Toluca and amounts to an estimated 8% of the MSW generated. It is very common to see people going from house to house offering to buy or cart away all kinds of paper, cardboard, metal, and other materials. Also, in order to promote recycling by the citizens, the Toluca municipal authorities have created twelve "collection centers" located at different convenience stores and neighborhoods that accept paper, glass, plastic, metal, aluminum, batteries, wood, etc. For every kilogram of recycled material, citizens receive, in exchange, coupons called "Ecos". The Ecos have a monetary value and can be used to purchase some basic products such as rice, beans, detergents, etc.

In addition to this program, the Environmental Direction of Toluca encourages schools to create collection centers. Sixteen schools are participating in this project and receive certificates that can be used to acquire educational material or improve the school facilities. An important part in the operation of these centers is the creation of a "Vigilance Council" to ensure transparency in the use of revenues. A local newspaper, "Poder Edomex", reported in February 2011 that during 2010, these centers collected 300 tons[59] of recyclables such as aluminum, cardboard, paper, glass, and PET.

Composting

Although there are no official municipal composting activities in Toluca city, there are some composting sites such as the one at the San Antonio la Isla landfill that serves Toluca. During a visit of the project team, the manager of this landfill stated that green wastes ("yard wastes") are shredded and composted aerobically. Approximately 2 tons of wastes per day are processed here, generating about 500 kg of a compost product that is used for soil conditioning.

During a visit of the second sanitary landfill that serves Toluca, Zinacantepec, it was stated that they had tried to compost mixed MSW but it was not possible to produce a usable compost product from household mixed wastes.

Landfilling

The MSW collected by the municipality is disposed in two sanitary landfills. Nearly one half is disposed at the San Antonio la Isla (SALI) landfill that is located about 17 kilometers from the center of Toluca and serves the northern part of the city; the other half of the MSW, collected from the southern part of the city, is disposed at the Zinacantepec landfill, 15 kilometers away from the center (Figure 49). Both of these landfills collect and flare some of the landfill gas. Regarding the gate fees, the general manager of SALI reported that Toluca Municipality pays an average fee of about $13 per ton. FigurE 49 SHOWS LOCtion of other landfills in Toluca area.

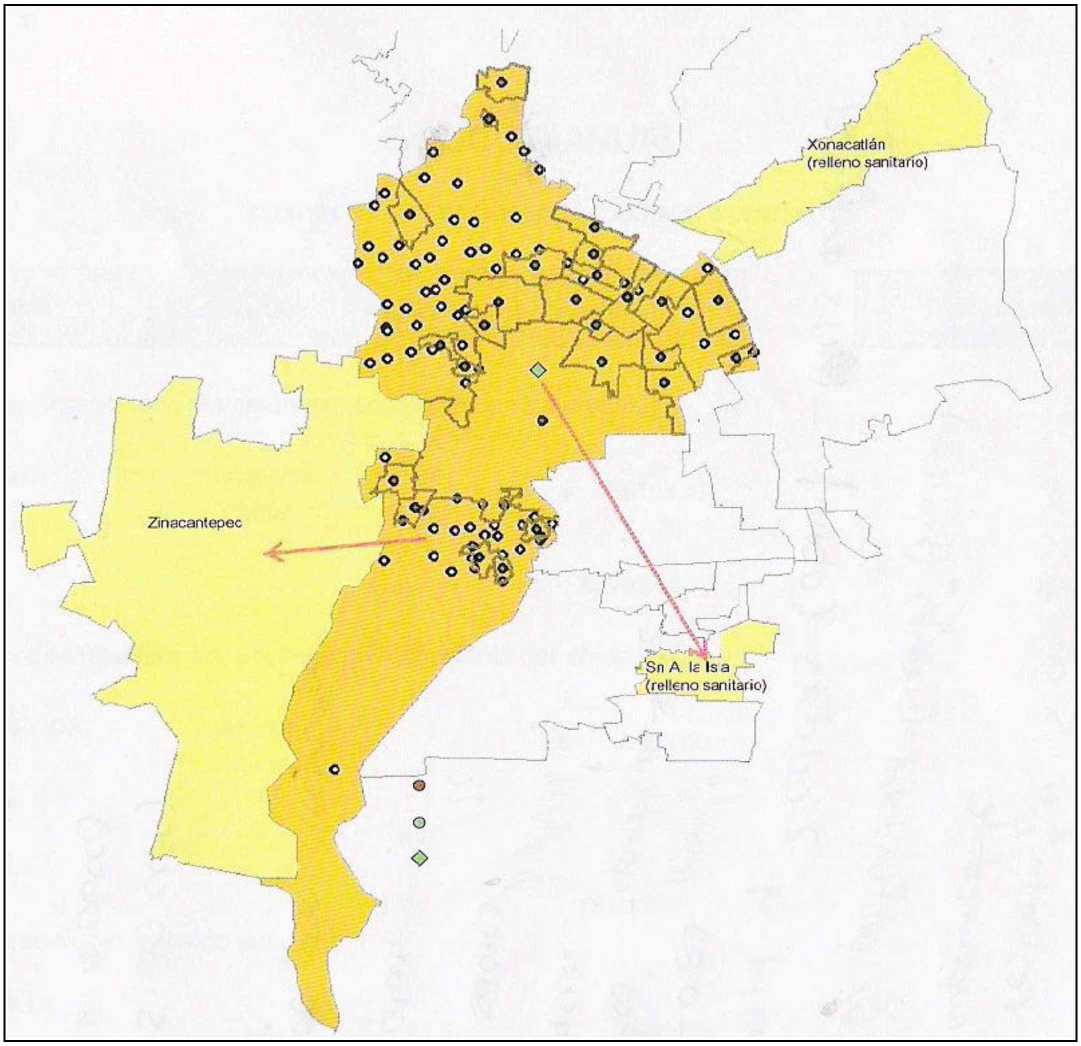

Figure 49 Location of the Toluca two sanitary landfills and non-regulated landfills[57] (EEC)

Table 30 Operating data of two sanitary landfills serving Toluca (November 2010)

	San Antonio la Isla	Zinacantepec
Distance from Toluca center (km)	17	15
Landfill total area (hectares)	10.5	8.5
Start up year	2007	2007
Average MSW received (tons/day)	850	600
Total capacity (million tons)	2.29	1.48
Tons/m^2 at full capacity	21.7	17.4
Useful life (years)	13	8
Remaining capacity (million tons)	1.78	0.88

8.8 Proposed capacity and energy generation potential

The WTE plant size selected for the Toluca case is a single line of 20 tons/hour capacity, i.e., 20 tons x 8,000 hours of operation per year = 160,000 tons per year. As mentioned earlier, the current generation of MSW in Toluca is about 300,000 tons per year and is projected to increase to 400,000 tons by 2015. The idea is to start with a relatively low cost plant and also allow room for increased recycling. On the basis of experience to be gained from this one-line plant, a second line may be added in the future, thereby doubling capacity to 320,000 tons per year.

As shown earlier, the calorific value of the Toluca MSW is estimated at 10 MJ/kg. For such a heating value, and a capacity of 160,000 tons /year, the net electricity production is estimated at 0.6 MWh/ton MSW, i.e. 96,000 MWh annually and 12 MW of base load electricity to the grid. Since the average Mexican household consumes 1,660 kWh/year, the Toluca WTE would provide enough electricity for about 60,000 households.

8.9 Site selected for the WTE plant

The most suitable site for the Toluca WTE is next to "San Antonio la Isla" sanitary landfill, one of the two landfills that currently serve Toluca (Figure 50).

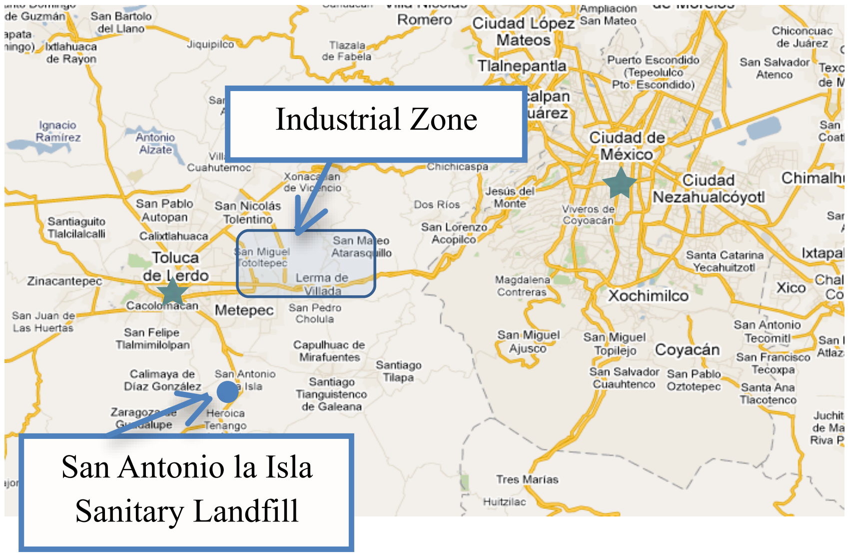

Figure 50 Map of Toluca showing potential site for the Toluca WTE plant (EEC)

It is estimated that the WTE facility would occupy approximately four hectares of San Antonio la Isla land property (see Section 5.5 of Guidebook). This estimate includes a Materials Recovery Facility and a Visitors Center that would illustrate the various methods of waste management, including the operation of the WTE. However, if additional land is required, and it is not available within San Antonio la Isla property, it could be purchased in the surrounding area (Figure 51).

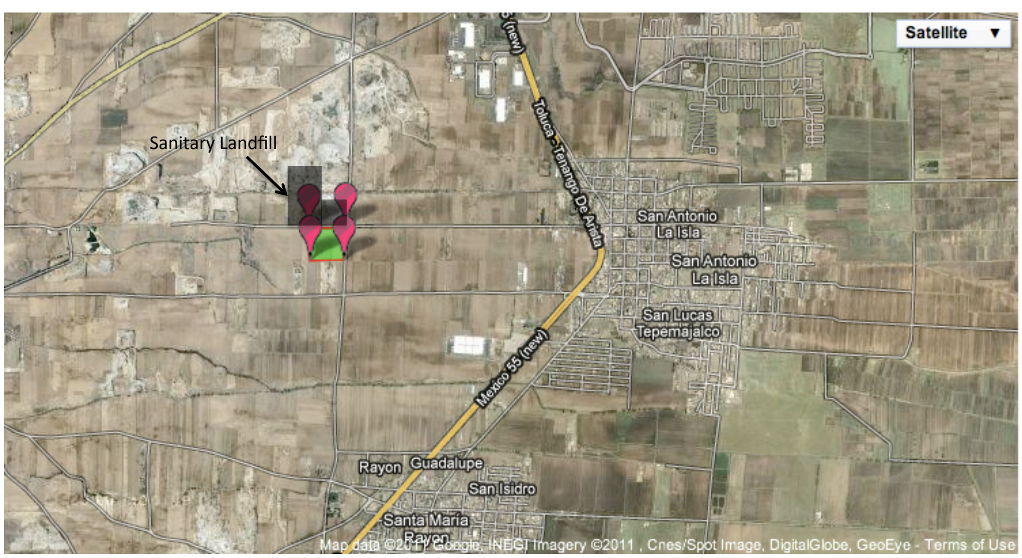

Figure 51 San Antonio la Isla area showing additional land surrounding the sanitary landfill (EEC)

8.10 Projected emissions limit

The emission standards for incineration facilities in Mexico are published in the NOM-098-SEMARNAT-2002 (Appendix 1 to Mexico Case Study). However, the Toluca WTE will be designed to meet the even more stringent E.U. standards (Table 17). Table 31 compares the current Mexican standards with the E.U. standards that will be met by the projected Toluca WTE facility. Although the Mexico standards require continuous monitoring of only carbon monoxide, the proposed WTE would also have continuous monitoring of all acid gases and of particulate matter.

Table 31 NOM-098-SEMARNAT-2002 emission standards for incineration facilities in Mexico compared to E.U. emission standards (11% O_2, dry basis)

<table>
<tr><th>Emission</th><th>Mexico standard (mg/m^3)</th><th>Measurement frequency (Mexico)</th><th>E.U. standard (mg/m^3)</th></tr>
<tr><td>CO</td><td>63</td><td>Continuous</td><td>50</td></tr>
<tr><td>HCl</td><td>15</td><td>Quarterly</td><td>10</td></tr>
<tr><td>NOx</td><td>300</td><td>Biannual</td><td>200</td></tr>
<tr><td>SO_2</td><td>80</td><td>Biannual</td><td>50</td></tr>
<tr><td>PARTICULATES</td><td>50</td><td>Biannual</td><td>10</td></tr>
<tr><td>CADMIUM</td><td>0.07</td><td>Biannual</td><td rowspan="2">0.05</td></tr>
<tr><td>TITANIUM</td><td rowspan="6">0.7</td><td rowspan="6">Biannual</td></tr>
<tr><td>SELENIUM</td><td rowspan="9">0.5</td></tr>
<tr><td>COBALT</td></tr>
<tr><td>NICKEL</td></tr>
<tr><td>MANGANESE</td></tr>
<tr><td>ARSENIC</td></tr>
<tr><td>LEAD</td><td rowspan="4">0.7</td><td rowspan="4">Biannual</td></tr>
<tr><td>CHROME</td></tr>
<tr><td>COPPER</td></tr>
<tr><td>ZINC</td></tr>
<tr><td>MERCURY</td><td>0.07</td><td>Biannual</td><td>0.05</td></tr>
<tr><td>DIOXINS AND FURANS (TEQ; ng/m^3)</td><td>0.2</td><td>Yearly</td><td>0.10</td></tr>
</table>

8.11 Projected WTE plant costs

As in the Chile and Argentina study cases, the cost estimates presented here are based on recently built facilities in Europe and the U.S. where the WTE plant is provided with a grate combustion high quality furnace, boiler, and state-of-the-art Air Pollution Control system.

The preliminary estimates shown in this section do not take into account the local conditions and are subject to many factors, such as the price of steel. Hence, they are considered to be within a plus or minus 20% accuracy.

Capital cost:

As mentioned before, the facility will need approximately 4 hectares of land (40,000m^2). The cost of land around "San Antonio la Isla" sanitary landfill is of approximately US$22 per m^2. This was determined after doing some research on the Internet of land prices over 2 hectares in that vicinity.

Therefore, the total land cost is:

22.41 US$/m^2 x 40,000 m^2 =US$900,000.

All the items in the capital cost are shown in Table 32.

Table 32 Capital cost estimate

Number of lines	1
Site preparation, access, landscaping (million US$)	6
Buildings, stack (million US$)	33
Grate, boiler, air supply, ash handling, electrical and mechanical systems (million US$)	38
Turbine generator (million US$)	16
Air pollution control system (million US$)	10
Contingency (million US$)	16
Land	1
Estimated total capital cost (million US$)	**120**
Estimated capital cost (US$/ annual ton of capacity)	**750**

Operating costs:

The operating costs, assuming a personnel of 40 people and combining bottom and fly ash for use as daily cover at San Antonio la Isla landfill are shown in Table 33 .

Table 33 Operating costs

Number of lines	2
Ash disposal (million US$; US$3.75/ton)	0.60
Chemicals (million US$; US$4/ton)	0.64
Gas Cleaning (million US$; US$8/ton)	1.28
Maintenance (million US$; US$21.1/ton)	3.38
Miscellaneous (million US$; US$2/ton)	0.32
Personnel, employees (million US$)	0.98
Subtotal (million US$)	7.19
Contingency (million US$; 5%)	0.36
Subtotal	7.55
Insurance (million US$; 0.6%)	0.05
Estimated operating cost (million US$)	**7.60**
Estimated operating cost (US$/ton capacity)	**47.50**

It is important to mention that salaries in Mexico are lower than in the United States and Europe; for example, "La Alianza Global Jus Semper" published in its report "Graphics of Salary Gaps in Mexico"[60] that in 2008, workers in the manufacture industry in Mexico earned 30% less than analogous workers in United States, which means that salaries may be overestimated in this case study. However, some other costs may be underestimated, for example, some materials needed for maintenance may not be available in Mexico and will have to be imported. Therefore, as previously mentioned, these estimates may change once local conditions are taken into account.

8.12 Projected WTE plant revenues

This section will present the plant revenues, including revenues from sale of electricity, gate fee, metal sale, and carbon credits.

Gate fees:

For this analysis, it was assumed that the gate fee paid to the WTE plant would be the same as the current fee for landfilling in Toluca. During the visit to San Antonio la Isla sanitary landfill, its manager, Ing. Jorge Mejía, stated that the average gate fee is $150 MXN per ton, which corresponds to about US$13 per ton of MSW[ii]. Therefore, the annual revenues from gate fees will be of approximately US$2 million.

Sale of Electricity:

In December 2004, the Official Gazette of the Federation amended the Law on Income Tax (Section XII of Article 40, Appendix 1 to Mexico case study); now taxpayers who invest in machinery and equipment for energy generation from renewable sources can deduct 100% of the investment in one period. The law stipulates that the equipment purchased must remain in operation for a minimum period of five years.

The World Bank, the Global Environmental Facility (GEF) and the Mexican Government have also created a strategic alliance for supporting renewable energy generation by means of a two-phase US$70 million grant that has the objective of compensating the differences that exist between renewable and conventional electrical energy sources. This Fund may provide incentive payments ranging from US$7.5 to US$15 per MWh of renewable energy over the price that the National Electricity Company pays to the generators. However, this support will only be granted for a limited number of years[61].

[ii] 1 USD = 11.78 MXN

Electricity revenues:

According to Mexican law (see Appendix 1 - Mexico Case Study), electricity produced by independent producers, such as a future WTE plant, can only be sold to the Federal Electricity Commission ("CFE"), while the thermal energy to be produced by the WTE plant cannot be sold to third parties. However, since the law allows the use of the electricity produced in one's property, independent power producers (IPP) in Mexico can overcome this problem by selling their electricity through Power Purchase Agreements by "leasing" the property where the plant is located to third parties. Under this scheme, third party users of this electricity pay less than what they would usually pay to CFE, while the IPP sells the electricity at a higher price than what CFE would pay.

Payments made by the CFE to the Independent Power Producers (IPP) consist of three major categories:

- Capacity fixed charges, intended to cover the capital investment.
- Fixed and variable operation and maintenance charges
- Cost of fuel, which is the main element of total cost of generation and is highly variable because natural gas is paid at market price.

The IPP delivers its electricity at the nearest point of interconnection to the network. There are no charges to the IPP for transmission of electricity and payment rates are the same for all producers regardless of the energy source (i.e., there are no incentives for renewables). The CFE payments for electricity, called "generation costs" in the period 2007-2010 are shown in Table 34.

Table 34 CFE Generation Costs

YEAR	Capacity Fixed Charges	Operation and Maintenance Charges	Subtotal	Fuels	Total
	US$ / kWh				
2007	0.014	0.007	0.021	0.049	0.070
2008	0.012	0.006	0.018	0.052	0.070
2009	0.014	0.007	0.020	0.031	0.051
2010	0.014	0.007	0.021	0.035	0.055
Average 2007 – 2010	0.013	0.007	0.020	0.042	0.062

The Toluca WTE plant, with a capacity of 160,000 TPY and net electricity generation of 0.6 MWh/ton, would provide a base load of 12 MW to the grid and an expected electricity output of 96 GWh per year. Consequently, assuming a payment of

US$62/MWh delivered, the revenue from the sale of electricity is estimated of US$5.95 million or US$37.2 per ton of MSW.

Moreover, if the carbon reduction incentives mentioned above were applied, the price of electricity would be between US$69.5/MWh ($62/MWh+$7.5/MWh) and US$77/MWh ($62/MWh +$15/MWh). In this case, the revenues from the sale of electricity would be between US$6.67 million and US$7.39 million, i.e., US$41.7 – US$46.2 per ton of MSW.

Carbon credits:

As discussed in the Guidebook, the projected reduction in greenhouse gas emissions due to the WTE operation would be 0.5 tons of carbon dioxide, in comparison to sanitary landfilling. As in the Chile case study the conservative value of US$5 per ton of combusted MSW was used, i.e. US$0.8 million annually for the Toluca.

Sale of metals recovered from bottom ash:

Toluca's MSW contains 2% metals (Table 29) and, as in the other two case studies, it will be assumed that 50% of this metal will be recovered. According to a study carried out by the Government of the State of Mexico and the GTZ, the average price of scrap metal in Toluca Valley is of US$93 per ton. Therefore, the total revenue from the metals recovered will be US$148,800, or US$0.93 per ton or US$149,000 annually.

8.13 Financial analysis of WTE for Toluca

Analogously to the other case studies, the approach used for the financial analysis was to calculate the Net Present Value (NPV) and Internal Rate of Return (IRR) of the operating cash flows. This means that specific financing costs were not taken into account and, therefore, both NPV and IRR will most likely decrease once these costs are included. Also, variations in cash flows due to inflation or other factors were not included and could have an important impact in the analysis.

The scenarios considered for the financial assessment are the following:

- Base Scenario: Electricity is sold at US$62/MWh (there is no renewable energy incentive).
- Scenario 2: There is a renewable energy incentive, and electricity would be sold at US$73.25/MWh (average between US$69.5/MWh and US$77/MWh).
- Scenario 3: The project obtains a grant equivalent to 50% of the capital investment from a development bank (see Appendix 2 for Mexico Case Study), and electricity is sold at US$62/MWh.

The gate fee assumed in both scenarios was the present gate fee at San Antonio la Isla landfill (US$12.75/ton).

The payback period used was 23 years, assuming approximately 3 years of construction and 20 of operation.

The discount rates used for the NPV calculation are 5%, 10% and 15%. The reason for selecting 5% is that it is the estimated cost of capital of the federal government of Mexico in US$ because, as of October 18, 2011, the 23-year Mexican sovereign bonds in US$ (UMS 34) were trading at 5%[62]. The reason for also using 10%, and 15% discount rates is that if there were to be private investors in the WTE plant, then the cost of capital would be higher than the cost of capital of the government of Mexico, and therefore 10% and 15% is used to illustrate this scenario.

Table 35 shows the NPV for the three discount rates and also the IRR for the three scenarios.

Table 35 NPV at 5%, 10%, and 15% discount rates, and IRR for the three scenarios

Scenario	NPV at 5% (million US$)	NPV at 10% (million US$)	NPV at 15% (million US$)	IRR (annual rate)
Base	-94	-90	-85	-10.8%
Scenario 2	-83	-83	-80	-7.0%
Scenario 3	-40	-41	-40	-6.3%

The IRR for all three scenarios resulted negative, which indicates that the project is not feasible for any cost of capital at the current gate fee. Moreover, since the project is so far from breaking even, the results obtained when calculating the NPV for these scenarios do not make sense.

The gate fees required for the plant to break even operationally (i.e. NPV = 0), with 5%, 10%, and 15% discount rates in the three scenarios are shown in Table 36.

Table 36 NPV at 5%, 10%, and 15% discount rates, and IRR for the three scenarios

Scenario	Gate fee (US$/ton)		
	5% discount rate	10% discount rate	15% discount rate
Base	69	103	145
Scenario 2	62	97	139
Scenario 3	36	53	74

The results show that even with a 50% grant (scenario 3), the gate fee of the WTE facility would have to be at least twice the gate fee currently paid in San Antonio la Isla landfill.

This can be attributed to the lack of environmental policies in Mexico that support the generation of energy from renewable sources and to the very low gate fees that are currently charged in Mexico. Moreover, increasing gate fees seems unlikely since the municipal government would be required to pay more than twice what it currently pays for disposal.

8.14 Stakeholders

With the introduction of a new technology such as a WTE plant in Mexico, a diverse type of stakeholders will play a vital role either supporting or opposing the project. Their interests may range from levels such as economic, social, environmental, and legal. It is important to identify the main stakeholders that need to be advised and consulted during the whole duration of a project like a WTE facility installation in Mexico, especially since there exists very little information and many paradigms have been created regarding these technologies.

The identification of stakeholders will allow project managers to also develop action plans and mechanisms for maintaining close contact with them and sharing all the information that might be useful or interesting for them.. Table 37 in Appendix 3 to the Mexico Case Study lists the most important stakeholders who may play a role during the discussion, planning and development of a WTE facility in Toluca municipality, their interests and influence.

During the visit to the sanitary landfill of San Antonio la Isla and the meeting with different stakeholders in the city of Toluca (universities, government officials and landfill manager), the team found a very positive feedback from all contacts, stating that they had a change in views regarding combustion and energy generation and air pollution generated by it. Additional to this, the manager from the landfill commented to the Project team that they are already considering offers to capture and use the biogas form the landfill to produce electricity. Participants at these meetings suggested that the main obstacles for developing this technology in Mexico are the necessary financing, the legal framework for renewable energy generation, the fact that electricity is provided by only by one company (CFE - and therefore electricity from private generators can only be sold to CFE), and public opposition due to inadequate information as to the benefits of WTE.

<u>Mechanisms for maintaining close contact with stakeholders</u>

The wide range of interests and participation of stakeholders may lead to the creation of different mechanisms in order to maintain close contact with them. It is very important to have an open information policy and to promote the stakeholders participation in this project. If they become involved, it is more likely that they will have a positive influence on any of the stages of the project.

During the first phases, it is crucial to maintain regular contact with government agencies, nearby communities, private companies related with MSW management, NGOs, and any other figure interested in this project through meetings and/or presentations. This will allow stakeholders to understand better what WTE is, how it works and how it is beneficial for the community and the environment especially when compared to typical waste disposition methods (such as waste dumps and sanitary landfills); in a survey conducted in Toluca in year 2010, it was found that "waste incineration" is seen as the most dangerous waste disposition/treatment method after waste dumps[63]. Therefore, it is necessary to change this paradigm in order to receive the support from the stakeholders.

Another basic channel to keep the stakeholders informed is the web, which can be done through the creation of an official webpage of the facility, where anyone can find out more information about the plant, FAQs, general information about WTE, examples of WTE plants around the world, etc., and even a section to receive suggestions and/or commentaries. The webpage can also provide a newsletter service where through a membership people can receive periodical news with more information regarding WTE and the facility itself.

8.15 Conclusions to Mexico Case Study

There is no doubt that waste-to-energy is the only proven means for replacing landfilling of the wastes remaining after recycling and composting. In particular, WTE could be most beneficial in places such as Toluca, where it has been reported that there are no remaining landfill sites[64]. In countries such as Mexico, where there have been no WTE facilities, it is recommended to use a well-proven technology, such as grate combustion.

Due to its closeness to Mexico City, a medium-size city like Toluca is a good site for installing the first WTE en Mexico. For this study, the chosen location for the facility was next to one of the two sanitary landfills where Toluca disposes its waste: San Antonio la Isla. The reasons being that MSW is already being transported to that area, and also, during the visit of the team to the sanitary landfill, it was mentioned that the people in charge on the landfill is already interested in installing technology that recovers energy from waste. Nevertheless, other possible locations can be considered such as the northern part of the city, since in this location the esthetic appearance and architecture of the plant could also be used as a touristic attraction and as motivation for the rest of the cities in Mexico.

However, even with the numerous advantages, environmental benefits and the necessity of replacing landfills in Mexico, the financial analysis has shown that the gate fee of the WTE facility would have to be increased substantially in order for the project to be feasible, which implies that WTE is not competitive with landfilling in Mexico. This is mainly due to the lack of economic and public policy strategies that align the legal framework, for example in electricity prices, with the economic factors of electricity generated from renewable sources.

Moreover, the only realistic scenario under which the plant could be built is if it is publicly owned and the government builds it as a showcase to advance the nation in waste management, despite the fact that in the short term it will be costlier than sanitary landfilling.

Finally, based on the current MSW management situation in Toluca, where informal and formal recycling has been estimated to be less than 10%, it is very important to plan for increasing the current recycling rate by means of collection of source-separated recyclables, as discussed in the Guidebook (Section 5.14), in parallel with the WTE plant implementation.

Appendices to Mexico Case Study

Appendix 1: Legal framework

1.1 Laws and regulations regarding waste management

Waste management (WM) in Mexico is regulated by laws established in the Constitution of the United Mexican States: The General Law for the Ecologic Equilibrium and Environment Protection, the Official Mexican Standards and the General Law for the Prevention and Integrated Management of Wastes.

The Constitution of the Mexico specifies (115th Article) that the municipalities are responsible of the sweeping, collection, transportation, treatment and final disposition of solid wastes. Hereby, it is clear that each municipality has the freedom to institute its own waste management system. However, the 73th Article states that the Federal Congress has the ability to issue laws that help the Federal, State and Municipal Governments to manage effectively all their environmental protection matters. Also, based on this Article, legislators created the "Ley General del Equilibrio Ecológico y la Protección al Ambiente" (General Law for the Ecologic Equilibrium and Environment Protection) that resulted in the formulation of the Official Mexican Standards (Normas Oficiales Mexicanas, NOM) for controlling the location, design, construction and operation of the different landfills used for MSW final disposition.

Specifically, the NOM concerned with management of municipal solid wastes at a Federal level are:

NOM-083-SEMARNAT-2003: It regulates the final disposition of MSW, stating that everything concerned with these final disposition sites (location, construction, operation, closing, monitoring and complementary works) should be carried out according to technical guidelines that guarantee environmental protection and minimize pollution effects related to inappropriate waste management.

NOM-098-SEMARNAT-2002: This NOM makes reference to waste incineration, stating that incineration of any kind, including hazardous waste, has toxic effects that pollute the environment, damaging the ecosystems and the human health, which is why preventive actions must be adopted in order to achieve acceptable level of emissions. About the preventive actions, it also states that these have to consider the integral control of the emissions into the air, as well as management of ash.

The General Law for Health favors the prevention and control of the toxic effects of environmental factors to the public health; however, there is not a single article that makes reference to any specific type of wastes and its effect on the public health.

In October 8 2003, the General Law for the Prevention and Integral Management of Wastes (Ley General para la Prevention y Manejo Integral de Residuos, LGPGIR) was published in the Official Federal Journal (Diario Oficial de la Federación), filling in many of the regulation gaps regarding Municipal Solid Waste Management (MSWM). This Law considers waste from two points of view; first, as a potential contaminant that must be avoided, reduced and managed in an environmentally adequate manner, including a payment for this; and second, as material endowed with a value, that could be employed through reuse, recycling or by recovering the energy contained in it—as long as this is done in an environmentally adequate manner.

Along with the federal laws and regulations on waste management, each state and municipality has their own regulatory framework. In the State of Mexico these are: Code for the Biodiversity of the State of Mexico (Código de Biodiversidad del Estado de México), Program for the Prevention and Integral Waste Management of Municipal Solid Wastes and Special Wastes of the State of Mexico (Programa para la Prevención y Gestión Integral de Residuos Sólidos Urbanos y de Manejo Especial del Estado de México), Municipal Organic Law of the State of Mexico (Ley Orgánica Municipal del Estado de México), the Law for the Protection of the Environment and the Sustainable Development of the State of Mexico (Ley de Protección al Ambiente para el Desarrollo Sustentable del Estado de México) and State Environmental Technical Standards. Additional to these laws, Toluca is regulated by the Municipal Code 2010 (Bando Municipal).

The Code for the Biodiversity of the State of Mexico provides the basic outline for planning and implementing waste management programs. In order to comply with this Code, the Program for Prevention and Integral Waste Management was published in April 2009. Some of the actions proposed in this document are: the support of new waste treatment and waste re-use technologies that are feasible, economical and socially accepted, MSW source-separation, separate collection and differentiated treatment. Also, this program mentions that the SEMARNAT has the responsibility to coordinate those activities. The municipal authorities must implement all these actions, programs, strategies and the waste management system itself (Municipal Organic Law Articles 31 and 12).

The Law for the Protection of the Environment and the Sustainable Development of the State of Mexico focuses on the promotion of re-use and recycling, the installation and operation of facilities, and encouraging the citizens to participate in the planning, execution and evaluation of environmental policies.

Regarding the State Environmental Technical Standards, the ones concerned with solid waste management are:

NTEA-006-SMA-RS-2006: which establishes the requirements for the production of soil improver, or compost, made from organic waste.

NTEA-010-SMA-RS-2008: which establishes the requirements and specifications for the installation, operation and maintenance of the infrastructure for collection, transfer, separation and treatment of MSW and special handling.

NTEA-011-SMA-RS-2008: which establishes the requirements for managing the waste resulting from construction activities in this State.

Finally, the 17th Article of Toluca's Municipal Code establishes that it is an obligation for all the citizens to separate the solid wastes properly into organic and inorganic. Also, the 77th article classifies as an infraction non-compliance with this obligation. Nevertheless, none of these two articles are really implemented.

As mentioned earlier, incineration of any kind of waste in Mexico is subject to the NOM-098-SEMARNAT-2002, and also to the General Law for the Prevention and Integral Waste Management (Ley General para la Prevención y Gestión Integral de los Residuos, LGPGIR) and the Stockholm Convention.

1.2 Laws and regulations regarding electricity generation

Electricity supply and generation is regulated by the Law for the Public Supply of Electricity (Ley del Servicio Público de Energía Eléctrica, LSPEE). This law forbids the free trade of energy between individuals. However, there is a provision for individuals to generate energy for their own use. Furthermore, individuals may generate energy in order to supply the network operated by CFE under the external energy producer and small producer schemes, as well as for the export market.

Regarding cogeneration, the Article 104 of the Regulation of the LSPEE, establishes that the usage of cogeneration in an installation is allowed as long as:

- The produced steam, thermal energy or produced fuels are used by the same installation that produced them.
- The owners of the cogeneration plant are co-owners or partners of the installation.

This last point indicates that, under present legislation, a WTE plant in Toluca cannot provide thermal energy to an industrial park of this city. This is of course counter-productive and may be modified in the near future.

On November 2008, the Law for the Improvement of Renewable Energies Utilization and Financing of Energy Transition was published. Even though this law has the objective of regulating the use of renewable sources of energy, its first article explicitly excludes the generation of electricity by means of combustion or other thermal treatment of waste.

This of course would preclude the use of WTE in Mexico and is fully contrary to legislation in the E.U., U.S., China, Japan, and some other nations.

Appendix 2 to Mexico Case Study: Development banks

As explained previously, Mexico has development banks that can provide funding and grants for diverse projects. In particular, the National Works and Public Services Bank (Banco Nacional de Obras y Servicios Públicos, Banobras)[65] is in charge of promoting and financing infrastructure projects and public services, such as waste management facilities. Banobras' services include: Sub-national financing, project financing, structuring of infrastructure projects, financial Guarantees, trust management, and specialized technical assistance.

Banobras is also the trustee of the National Infrastructure Fund (FONADIN), which is a Mexican government trust fund destined to support the development of infrastructure in Mexico, in the communication, transportation, water, environment (including energy and waste), and tourism sectors.

The fund supports the planning, design, construction, and transfer stages in infrastructure projects with social or economical impact in which the private sector participates.

Some of the products FONADIN offers are:

- Non-recoverable Contributions: The fund provides non-recoverable contributions to agencies of the federal public administration to finance infrastructure projects subject to some eligibility criteria. Among these criteria the project should have:
    - Its own payment source.
    - Participation of the private sector.
    - Feasibility studies that show its technical viability, its social impact, and justification for requesting the Fund's support.
    - The support of the Fund should not exceed 50% of the total investment, unless justified.
- Grants: With the objective of maximizing private capital investments in infrastructure projects promoted by agencies of the federal public administration, and with low economic profitability, but high social impact. Some of the eligibility criteria are:
    - The project should have its own payment source.
    - Participation of private sector with at least 25% of the total project investment.

    - Show that projected cash flows are not attractive for private investors.
    - Feasibility study showing technical, social, and financial viability including the grant.
    - The support of the Fund should not exceed 50% of the total investment, unless justified.
- Guarantees: The fund provides guarantees in order to facilitate access to financing, e.g. bank loans, and bond emissions. The guarantees are for up to 50% of the credit, loan or emission.
- Subordinated loans: The fund assigns subordinated or convertible loans to private entities that receive concessions, permits or contracts that allow public-private associations for infrastructure projects.
- Venture Capital: The fund is authorized to make temporary capital contributions (up to 49%) to help infrastructure projects.
- Studies: The fund provides support financing studies and consulting services for infrastructure projects.

The support that the FONADIN provides is not limited to one product. For example, one particular project can be financed with the following scheme:

15% FONADIN grant

25% Private capital

20% FONADIN subordinated loan

40% Debt guaranteed by FONADIN / Banobras

Appendix 3 to Mexico Case Study: Potential stakeholders

Table 37 Stakeholders involved in the development of a WTE facility in Toluca, México

STAKEHOLDER	STAKEHOLDER INTEREST	POSSIBLE STAKEHOLDER INFLUENCE
Ministry of the Environment in the Municipal, State and Country level	The project requires an environmental impact assessment Supervision and oversight of the system Set environmental policies Seek to achieve international standards of environmental practices	Termination, delay, or change of the project Administrative and bureaucratic obstacles
Ministry of Health	Proper management and disposal of the waste Regulated air emissions of the facility	Termination, delay, or change of the project
Sub ministry of Waste Management of the Municipalities	Managing the waste management system Have an economically competitive alternative to waste disposal	Supply waste to the facility and payment for waste disposal for an accorded time period Negotiation of contracts MSW management problems Lack of clarity and transparency in the calculation of waste disposal tariffs Affect recycling initiative
Treasury Secretariat (Secretaría de Hacienda y Crédito Público, SHCP)	Determines the prices of public services such as electricity	Possibility of determining a preferential energy tariff when coming from a renewable source
Ministry of Energy (SENER)	Propose and regulate incentives for clean energy Establishes the general policy guidelines and assures the coherence of the national energy policy.	Regulate energy price Determine policies to support renewable energy
Energy Regulatory Commission (Comisión Reguladora de Energía, CRE)	Regulation of the natural gas and the electricity industry Approves the framework of contracts for the provision of energy, Provides the methodology used to calculate the prices received by the private sector energy suppliers	Regulation of the framework for providing energy to the gridline. Supporting the creation of a new methodology to calculate prices from private energy suppliers of renewable energy
Federal Electricity Commission (Comisión Federal de Electricidad, CFE)	Provides the electricity Controls the country's transmission network Issues permissions to allow private energy generation Approves the regulatory instruments regarding the generation of electricity, and participates in the determination of electricity supply and sale tariffs	Grants permissions to use the network Buying the generated electricity
Toluca and State of	Social, Environmental, Health Benefit for the	Demand for technical

Mexico Government	community Encourage continual improvement Incentive of the system Long term solution for waste disposal Taking advantage of creating the first WTE in Mexico to use it as a tourist attraction	competence and resources to address issues of short and long term Resolve conflicts with various stakeholders Financial incentives Facilitate the allocation of the plant
Scavengers	Change in waste management may affect or eliminate their source of income.	Scavengers activities may affect the properties and amount of waste Scavengers may block or protest against the construction of the facility
Community groups and nearby citizens/neighbors	Improved quality of life due to environmental improvements Project may lead to work opportunities. Neighborhood free of noise, dust, traffic loading and visual impact. Impact of real estate prices around the area	Termination, delay, or change of projects due to community protests
Environmental NGO``s	Reduce impact of waste management on the environment	Termination, delay, or change of projects due to NGOs protests or support if project due to positive environmental impact
Collection and transportation companies	Wish to maintain or expand their business	New requirements for sorting containers and vehicles. Contracts to supply waste from private generators they serve (industries, restaurants, etc.)
Sanitary Landfills	Wish to receive more waste Apply and awarded bids for municipal services	May lower tipping fee due to increased competition. May integrate landfill gas recuperation and energy generation.
Municipalities nearby the area	Have an economically competitive alternative to waste disposal	Supply waste to the plant with payment for waste disposal

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9 Case Study 3: Buenos Aires, Argentina

9.1 Country facts

Argentina has a population of 40 million and a per capita GDP of $14,700. It is the second largest country (2.8 million square kilometers) in South America, its population is 92% urban, and it increased 10.6% in the last decade.

The country is rich in natural resources, and used to be one of the wealthiest countries in the world, but it has suffered many severe financial crises in the last decades. Although the GDP growth rate in 2010 was 7.5%, the inflation rate in the same year was 22%, and 30% of its population is below the poverty line[66].

An important part of Argentina's economy is based on commodities and exports (soybeans, petroleum, natural gas, vehicles, corn, wheat). Exports are mainly to Brazil, China, Chile, and the U.S.

9.2 Waste management in Argentina

In Argentina, each municipality is responsible of managing its own waste. This has led to a wide variation in the services provided in different parts of the country and, in many areas, the MSW is disposed in non-regulated landfills. A 2005 study by the Secretary of Environment and Sustainable Development reported (

Table 38) that 12.3 million tons of MSW were generated nationally; there is wide variation in per capita generation, ranging from 0.16 tons in Misiones Province to 0.55 tons per capita in the City of Buenos Aires. The same study estimated that the MSW contains about 50% of food plus yard/green wastes and about 15% of paper and cardboard[67].

Table 38 MSW generated in Argentina in 2004[67]

Province	Population	MSW generation (kton/yr.)	MSW generation per capita (ton/yr.)
Buenos Aires	14,312,138	4,268	0.30
Catamarca	359,963	90	0.25
City of Buenos Aires	2,721,750	1,493	0.55
Cordoba	3,177,382	1,204	0.38
Corrientes	979,223	306	0.32
Chaco	1,053,335	232	0.22
Chubut	433,739	148	0.35
Entre Rios	1,209,218	261	0.22
Formosa	518,000	122	0.24
Jujuy	650,123	166	0.26
La Pampa	314,131	111	0.36
La Rioja	315,744	88	0.28
Mendoza	1,637,756	678	0.42
Misiones	1,033,676	163	0.16
Neuquen	508,309	169	0.34
Rio Negro	571,013	178	0.32
Salta	1,157,551	316	0.28
San Juan	655,152	226	0.35
San Luis	399,425	161	0.41
Santa Cruz	211,336	63	0.30
Santa Fe	3,079,223	1,235	0.41
Santiago del Estero	852,096	255	0.30
Tierra del Fuego	113,363	26	0.23
Tucuman	1,405,521	369	0.27
TOTAL	*37,669,167*	*12,328*	*0.33215*

There are some industrial plants in the urban areas of the country that recycle paper and cardboard, metals, and some types of plastics and glass. Most of the recycling is informal, carried out by people called "cartoneros", who collect recyclable materials from the streets, or by "cirujas", who collect recyclables from MSW disposed at landfills. Formal recycling of source-separated materials is practiced only in a few municipalities.

Composting is formally practiced mainly in small cities, although the metropolitan areas of the country – Gran Buenos Aires, Gran Córdoba, and Gran Rosario – also have some windrow composting operations.

The landfills vary across the country, from open dumps to more advanced sanitary landfills. Most of the existent landfills have passive vents, which avoid the pressurization and consequent fissures of the surface, accompanied by lixiviate leaks. On the other hand, passive vents release greenhouse gases to the atmosphere faster. Therefore, a few years ago, some landfills incorporated active venting with subsequent flaring of the biogas, which allows them to apply for carbon credits as per the Kyoto Protocol, thus generating revenue for the waste management facility.

The more advanced option of using the landfill gas (LFG) for producing electricity or heat has not been implemented by many landfills because of the relatively low thermal efficiency of LFG. However, some pilot plants have been built, e.g., one in Santiago del Valle de Catamarca where the collected LFG is combusted to generate steam for sterilizing hospital waste in an autoclave; also there is an electricity generation plant under construction at the Acceso Norte III landfill that serves Buenos Aires.

At the other end of the landfill spectrum are the open and uncontrolled dumps, often in areas susceptible to floods or close to water bodies. In addition, there are issues related to saturation and end of life of the open dumps and the cost of remediating such dumps or converting them to sanitary landfills.

9.3 Reasons for selecting the Metropolitan Area of Buenos Aires for the Argentina Case Study

The following locations were considered in this study for the first WTE plant in Argentina:

- City of Buenos Aires: The largest city in Argentina in terms of population and waste generation.
- A location within the Metropolitan Area of Buenos Aires (outside the city of Buenos Aires): This area receives the waste generated in the city of Buenos Aires and its neighboring municipalities.
- City of Cordoba: It is a medium size city, which makes it a good candidate for installing a WTE plant.

The Metropolitan Area of Buenos Aires was considered the best of the three alternatives for this case study because:

- The "747 Law of Zero Waste" of the City of Buenos Aires (see Appendix 1) at this time prohibits incineration, with or without generation of energy within the City, and therefore it is not possible to build a WTE facility in this city.
- There is the precedent of an earlier effort to build a WTE facility in Cordoba that failed, because of non-proven technology and inadequacies in the bidding process.

9.4 Metropolitan Area of Buenos Aires overview

The Metropolitan Area of Buenos Aires (Gran Buenos Aires) comprises the city of Buenos Aires, consisting of 48 neighborhoods occupying about 200 square kilometers (Figure 52), and 33 adjacent municipalities (Figure 53).

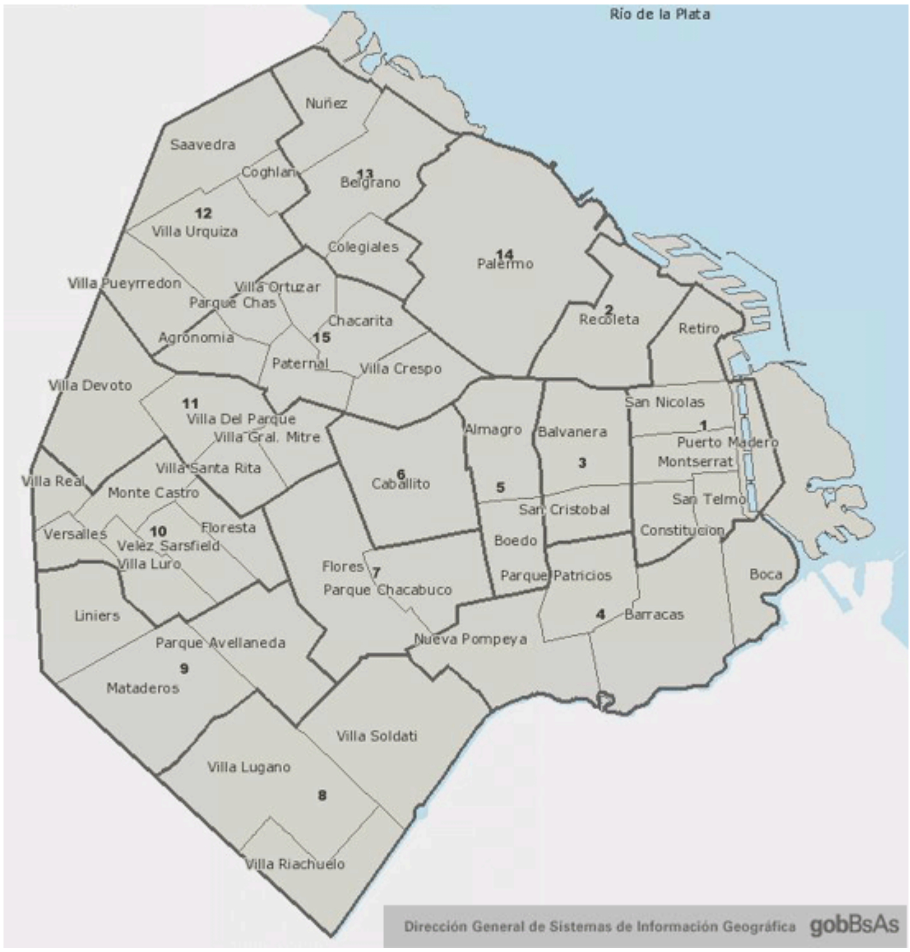


Figure 52 The City of Buenos Aires and its 48 neighborhoods[68] (EEC)

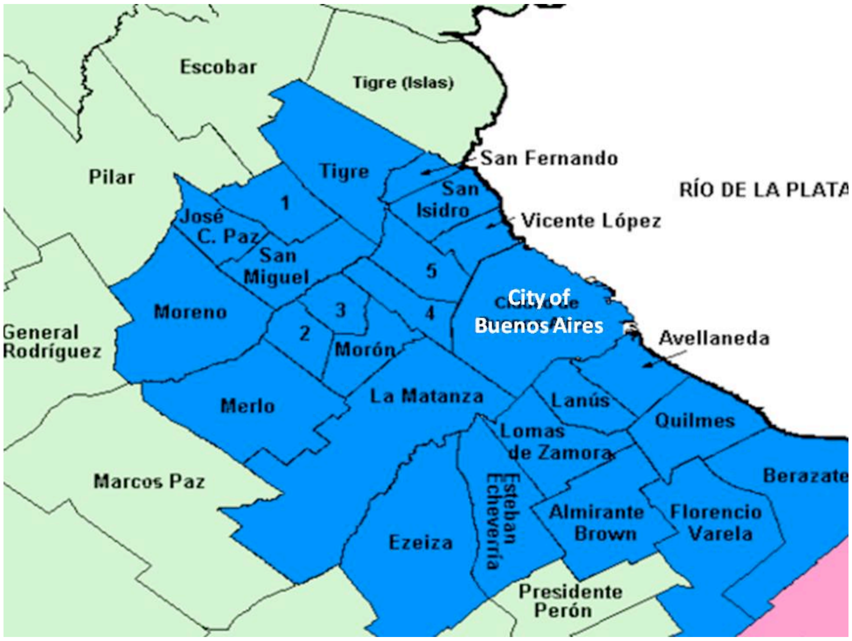


Figure 53 The City of Buenos Aires and Gran Buenos Aires (in blue)[69] (EEC)

The population of the City of Buenos Aires is 2.9 million, plus an estimated 1.6 million commuters[70], while the rest of Gran Buenos Aires has a population of 9.9 million. During the last decade, Gran Buenos Aires had the highest population growth in Argentina (Table 39).

Table 39 Population growth in the City of Buenos Aires, Gran Buenos Aires, and Argentina[71]

	Population 2001	Population 2010	Percentage of 2010 Argentina Population	2001-2010 growth
City of Buenos Aires	2,776,138	2,891,082	7%	4%
Rest of Gran Buenos Aires	8,684,437	9,910,282	25%	14%
Argentina	36,260,130	40,091,359	100%	11%

9.5 Waste management in the Metropolitan Area of Buenos Aires

In 1978, a public company was created, named CEAMSE (Coordinación Ecológica del Área Metropolitana Sociedad del Estado), by the province of Buenos Aires and the city of Buenos Aires with the objective of managing the solid wastes generated in the Metropolitan Area (as defined above). It is the largest waste management company in Argentina. At present, CEAMSE collects and disposes the waste from the City of Buenos Aires plus the 33 municipalities of the greater metropolitan area.

9.5.1 Solid Waste Management in Buenos Aires City

9.5.1.1 "Generation" of MSW in the City of Buenos Aires

It should be noted that the statistics shown below refer to solid wastes received for final disposal by CEAMSE and does not include informal recycling and other wastes that are not collected by CEAMSE. In 2010, CEAMSE received 2,108,000 tons of MSW from the City of Buenos Aires. Of this amount, 690,000 tons were construction and demolition, green/yard, and bulky wastes. The rate of generation does not change much with season, with the exception of the Christmas and Easter periods where there is a slight increase.[72]

9.5.1.2 Characterization of Buenos Aires MSW

The rate of MSW generation in Buenos Aires varies appreciably with economic level of the community[73]. Figure 54 shows the results of a study conducted by Prof. Marcella Delucca of the Instituto de Ingeniería Sanitaria of the University of Buenos Aires.

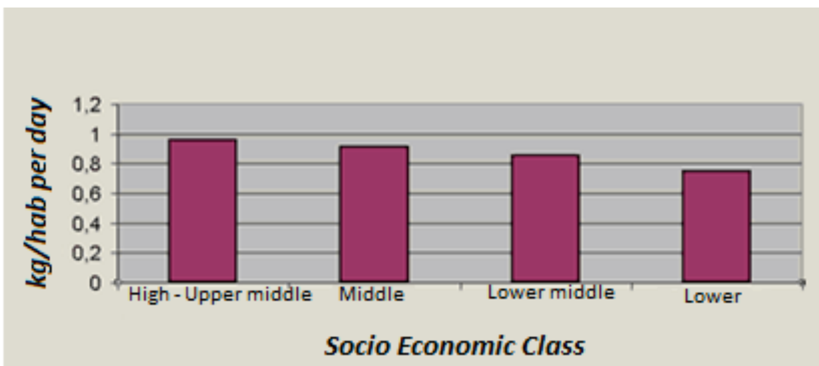


Figure 54 MSW generation rates in City of Buenos Aires[70] (EEC)

The Project team met with Prof. Delucca who has conducted extensive characterization studies of the Buenos Aires MSW over several years.

Table 40 shows the composition of the MSW landfilled in 2008, the heating values of its components, and their respective contribution to the heating value of the total MSW (10.3 MJ/kg).

Table 40 Composition of Buenos Aires MSW (2008[70]) and heating value

Material	Percentage in MSW	Heating value of material[30] (MJ/kg)	Contribution to heating value of MSW, MJ/kg
Food waste	43.2	4.6	2.0
Paper and cartons	14.6	15.6	2.3
Plastics	10.5	32.4	3.4
Yard waste	7.7	6	0.5
Disposable diapers	4.3	10	0.4
Textiles	4.0	18.4	0.7
Wood	1.6	15.4	0.2
Leather, rubber and cork	1.0	22	0.2
Glass	5.5	0	0.0
Ferrous metals	0.9	0	0.0
Non-ferrous metals	0.3	0	0.0
Construction and demolition	1.8	6	0.1
Hazardous waste	0.4	10	0.0
Medical waste	0.4	10	0.0
Miscellaneous fines, <12.7 mm	3.2	10	0.3
Other	0.6	0	0.0
Total	**100.0**		10.3

The same study showed that the density of the "as collected" MSW in 2008 was about 280 kg/m^3. The fraction of potentially recyclable materials in the collected MSW was estimated at 15.7%, corresponding to 274,000 tons[70]. As stated earlier, this number does not include the recyclable materials collected informally.

9.5.1.3 Recycling

Recycling in Buenos Aires is now carried out by different cooperatives of "cartoneros". There is no official data but the waste management association of Argentina (ARS) estimates that approximately 70,000 tons per year are salvaged by these cooperatives. Informal recycling increased in 2002 following an economic crisis that resulted in unemployment and an increase in the price of commodities such as metals and paper. The combination of these two factors resulted in a large increase in the number of "cartoneros" in Buenos Aires. There are no official statistics regarding the number of cartoneros currently operating in the City but it has been estimated at 5,000 to 9,000 people, operating in small groups or alone.

Prior to 2002, law forbade scavenging but this activity was legalized in January 2003 (Law 992). The government intended to encompass the cartoneros to the formal system, but a main concern has been that the cartoneros operate on their own and are not interested in formal jobs. Also, if the work of the cartoneros is formalized by paying the corresponding benefits and taxes, providing uniforms, and health and safety benefits, the revenues from the collected recyclables will not be sufficient to cover the costs of this program[74]. This issue is discussed in the Recycling Section of the Guidebook.

The study by Prof. DeLucca[70] estimated that 274,000 tons of the MSW collected by the City is potentially recyclable; therefore, the recycling rate of Buenos Aires could be increased appreciably. As of 2007, there has been some effort to separate the MSW into a "wet" stream that is landfilled and a "dry stream that is directed to recycling centers where recyclables are sorted out. There are more than 9,000 "dry" containers placed around the city for this purpose[75].

In planning for increasing the rate of recycling in Buenos Aires, it is necessary to start with public information and proper collection systems. In a 2010 survey of 300 professional people, conducted by the Earth Engineering Center in Buenos Aires, 82% responded negatively to the question "are you interested in recycling"; when they were asked "why not", 59% responded that they believed that during collection recyclables are mixed with MSW and end up in landfills anyway (Appendix 2 to Argentina Case Study).

9.5.1.4 Collection

The collection of waste in the City is carried out by five companies: Cliba, Urbasur, Aesa, Níttida, and Integra. However, a request for proposals is under way for providing a new collection service. The city will be divided into four zones for the "wet" MSW instead of the present six zones (Figure 55); also, the "dry" MSW collection will be divided into 15 zones across the City[76]. The dry stream collected is probably the 60,000 tons of formal recycling discussed earlier.

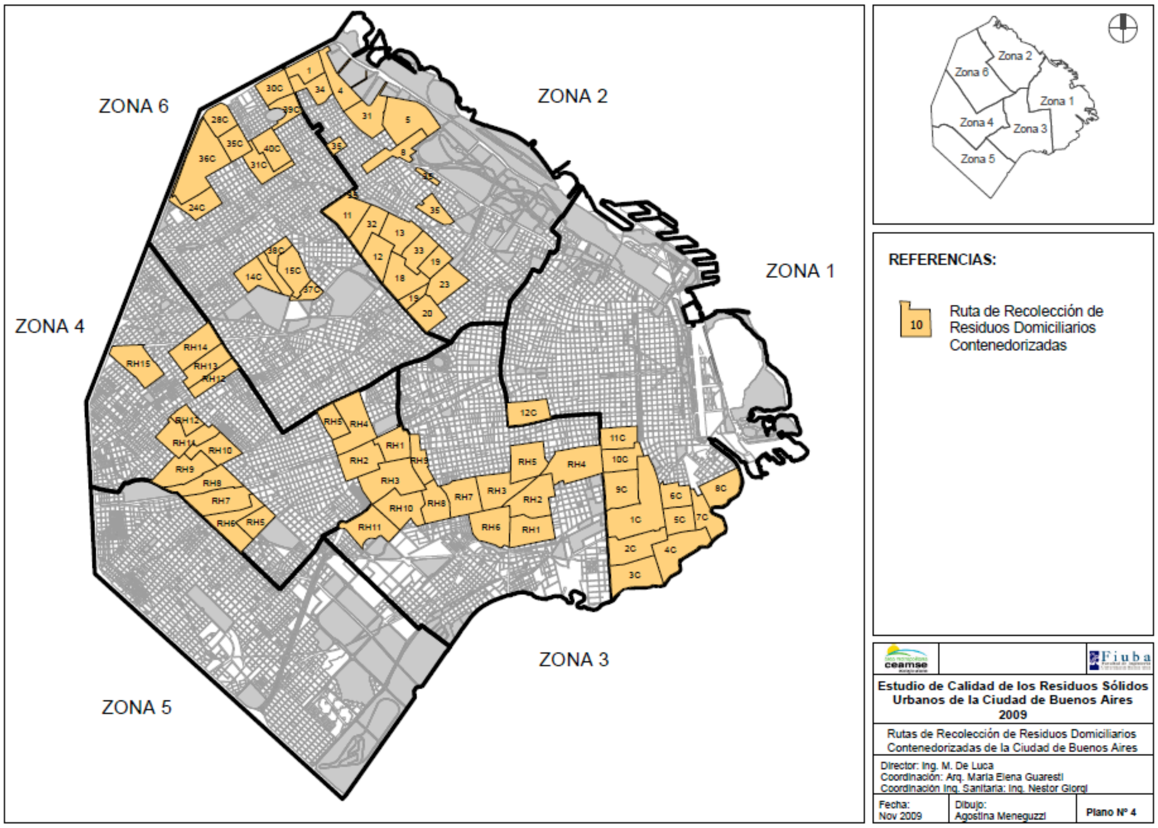


Figure 55 MSW collection routes in the City of Buenos Aires[75] (EEC)

9.5.1.5 Waste transfer stations (WTS)

There are three waste transfer stations (WTS) in the City, located in the Pompeya, Flores, and Colegiales areas (Figure 56). Each WTS handles about 65,000 tons of MSW per month and has additional capacity for the near future. As shown in Figure 56 and Figure 57, the furthermost WTS from the landfill is located at Pompeya in the east part of the City and 22.7 km from the Acceso Norte III landfill (air distance). The WTS Flores is directly west from Pompeya and 18.5 km from Norte III.

The closest WTS to the landfill, in the north part of the city and 15.7 km from the Acceso Norte landfill is Colegiales. It is located in the middle of a fairly well-to-do area of the city and although it was built in 1979, it is very well designed and operated. Across its fence there is a public park with playing fields. There is no dumping of MSW on the floor, and therefore no detectable odors, as is the case with some waste transfer stations in New York City. The collection trucks drive up a rump and dump their load in a horizontal bin. A piston mechanism then pushes and compacts the MSW into the container of the large trucks that transport it to the landfill. The Colegiales WTS would be a good source of feedstock for the hypothetical WTE of Buenos Aires.

There is a fourth transfer station named Varela that is only for demolition, green and bulky waste.

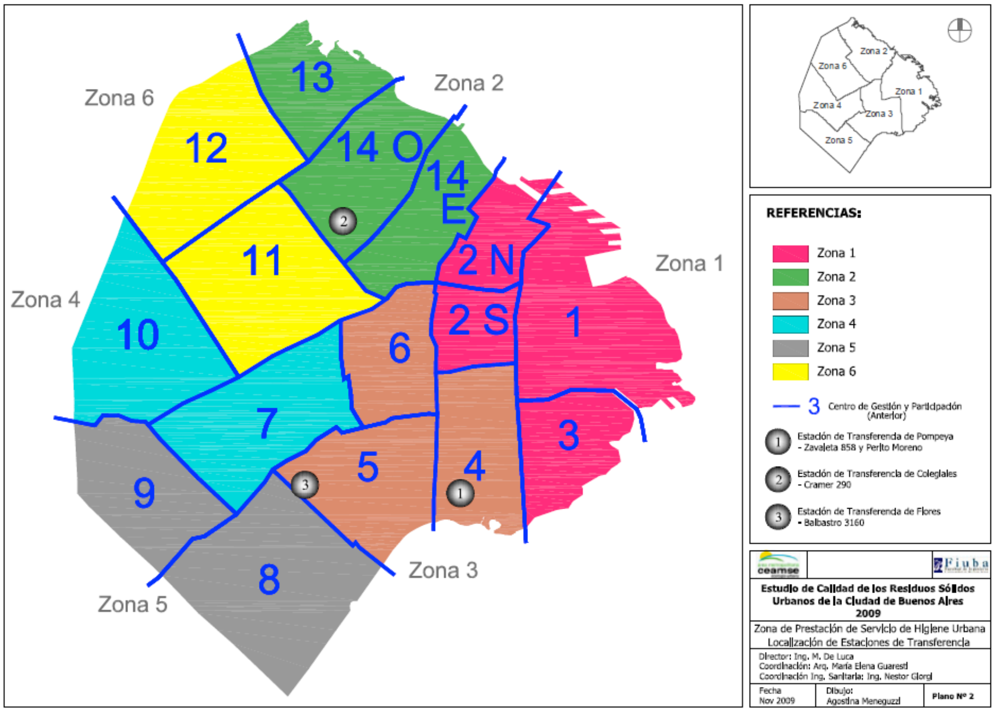


Figure 56 Present division of the City into six zones and location of the three transfer stations (EEC)

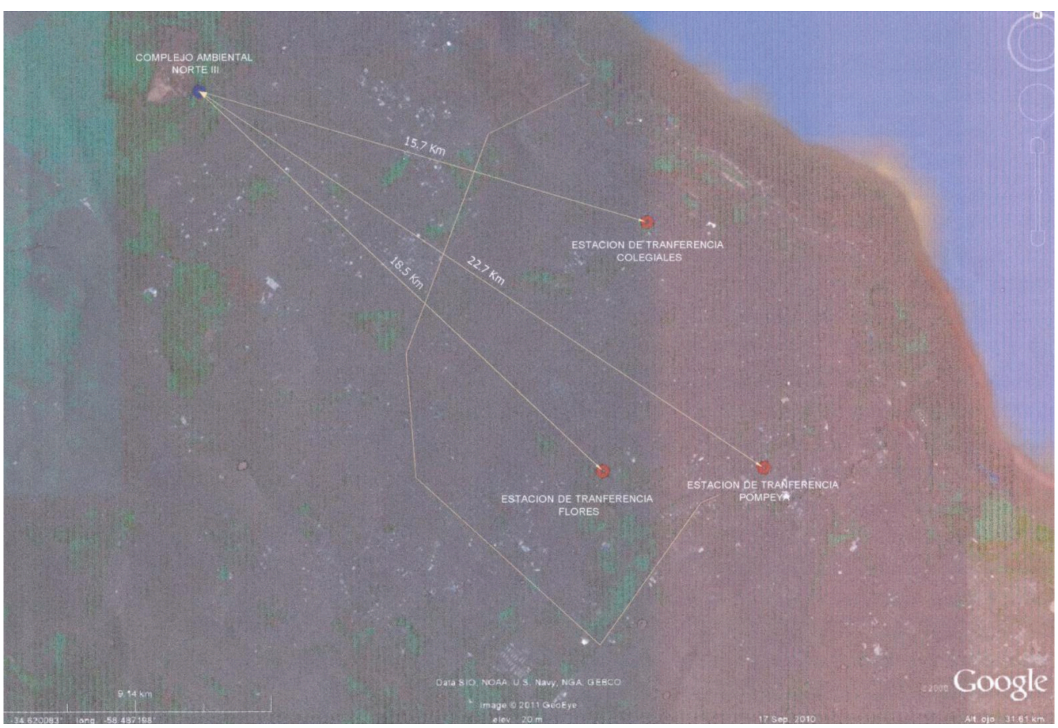


Figure 57 Map showing the Acceso Norte III landfill and the three transfer stations serving the City of Buenos Aires (EEC)

There are 226 routes along the city (Figure 58), and approximately one thousand collection trips are made daily between the city streets and the transfer stations[77].

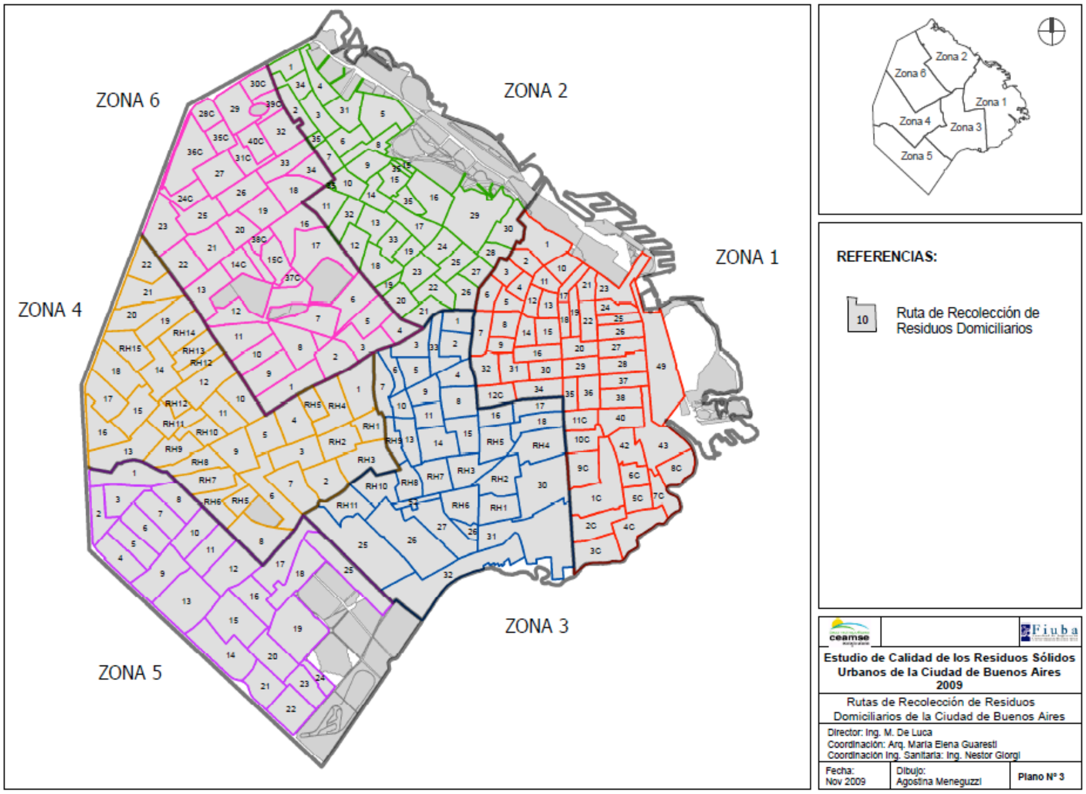


Figure 58 Collection routes in the City of Buenos Aires (EEC)

9.5.2 Solid Waste Management in Greater Buenos Aires

As noted earlier, the Greater Buenos Aires consists of the City of Buenos Aires and the 33 municipalities that send their solid wastes to CEAMSE.

9.5.2.1 Composting

In the area of the Acceso Norte III landfill there is a windrow composting facility that processes green wastes aerobically. The estimated capacity of this process is 2,000 tons of green wastes per month. In 2010, 14,400[68] tons of green waste were processed and 4,320 tons of compost were produced. Some of this product was distributed free of charge to municipalities closer to the landfill and were used as soil conditioner in public spaces. The rest was used for landfill maintenance. It should be noted that this compost is certified by SENASA (Servicio Nacional de Sanidad y Calidad Agroalimentaria) as a soil conditioner. This is the only composting plant in the Metropolitan Area.

9.5.2.2 Landfilling

CEAMSE operates three landfills in the Metropolitan Area of Buenos Aires: The Ensenada landfill that receives waste from La Plata, Ensenada, Beriso and Brandsen municipalities; the Gonzalez Catán Landfill that receives waste from La Matanza Municipality; and the Norte III Landfill that serves Buenos Aires and the rest of municipalities of Gran Buenos Aires (Almirante Brown, Avellaneda, Berazategui, Escobar, Esteban Echeverría, Ezeiza, Fcio. Varela, Gral. Rodríguez, Gral. San Martín, Hurlingham, Ituzaingó, José C. Paz, Lanús, Lomas de Zamora, Luján, Malvinas Argentinas, Merlo, Moreno, Morón, Pilar, Presidente Perón, Quilmes, San Fernando, San Isidro, San Miguel, Tigre, Tres de Febrero, and Vicente López).

Norte III is by far the largest landfill in Buenos Aires and is expected to reach full capacity by the end of 2012. This sanitary landfill is owned and operated by CEAMSE and is equipped with leachate treatment facilities and with capture of landfill gas that is currently flared.

Currently, the Norte III landfill receives about 90% of the MSW generated in the metropolitan area excluding the city of Buenos Aires. This amount represents an average of 9,000 tons per day. Also, about 6,200 tons/day are transported by truck from the three Waste Transfer Stations (WTS) that serve the City of Buenos Aires. Acceso Norte III consists of three cells that have been filled up and a fourth that is expected to fill up by the end of 2012. The closed cells are well maintained with grass, bushes, and small trees growing on them. Details of these modules are presented in Table 41. The maximum landfill height at closure was estimated at about 35 meters. As it can be seen in the last column of this Table, the Acceso Norte III landfill has had similar capacity (16-17 tons of MSW per square meter) as the observation of the Earth Engineering Center that one square meter of land is converted to landfill for every 10-20 tons of MSW, depending on topography, use of daily cover, and final height of landfill. Table 41 also shows that the daily tonnage landfilled in Norte III has more than doubled in the first decade of this century.

Table 41 Characteristics of the modules of the Acceso Norte III landfill[72]

Module	Start Date	End Date	Area (Hectares)	MSW disposed (Tons)	Tons (MSW/day)	Tons per square meter
Norte III	Oct, 1994	Dec. 1, 2001	64	10,501,269	4,062	16
Norte III a	Dec. 1, 2001	Nov. 2, 2006	64	10,944,878	5,900	17
Norte III b	Dec. 1, 2005	Jun. 30, 2010	84	14,054,675	8,406	17
Norte III c	Apr. 5, 2008	Mar. 30, 2013	90	11,294,228	10,169	21

9.6 Gate fee

At present, the City of Buenos Aires pays CEAMSE a gate fee of 23 Argentine pesos (about US$5) per ton of waste landfilled. However, CEAMSE estimates the actual cost to be around US$15/ton.

9.7 Proposed WTE plant capacity and energy generation potential

From the viewpoint of lower cost per ton of MSW and highest energy production, the first WTE in Buenos Aires should be a 3-line, 3,000-ton per day plant. At the projected 90%+ plant availability (i.e., 8,000 hours per year operation), this WTE will process one million tons per year, which is equivalent to approximately 20% of the waste landfilled in Acceso Norte III.

However, taking into account that the gate fee required for economic viability of such a plant will be considerably higher than what costs to landfill MSW in Buenos Aires currently, it would be prudent to start with a one-line, 1000-ton/day WTE, with provision to add two more parallel lines in the near future. However, since a plant of this capacity is discussed in the Case Study for Chile (Valparaiso Region), for illustration purposes the Argentina Case Study exemplifies the 3-line, 3,000-ton per day plant.

The estimation of the electricity generation potential of the WTE plant requires the calorific value of the waste that will be processed in the facility. The calorific value of waste in the metropolitan area of Gran Buenos Aires is not available, but since the waste generated in the city of Buenos Aires disposed in Acceso Norte III represents 40% of the waste disposed in this landfill, the calorific value of the city of Buenos Aires MSW (10.3 MJ/kg;

Table 40) was used for estimating the energy generation potential.

Replicating the calculations explained in Section 5.8 of the Guidebook (Energy Recovery), the net electricity generation is estimated conservatively at 0.6 MWh per ton of MSW, i.e., 604,800 MWh per year.

9.8 Site selected for the WTE plant

The EEC study recommended that the first WTE plant in Argentina be located at CEAMSE´s landfill Norte III landfill, for the following reasons:

- The future of solid waste disposal in the Metropolitan Area of Buenos Aires is unclear. The Norte III landfill is expected to reach its full capacity by April 2013. The Ensenada landfill will be closed soon and the municipality of La Matanza, where the Gonzalez Catan landfill is located, does not allow importing waste from other municipalities;
- There is no suitable land for a new landfill within the Metropolitan Area of Buenos Aires.
- Several attempts during the last ten years to locate a sanitary landfill outside the Metropolitan Area to receive its waste have failed due to the "not in my backyard" effect.
- The existence of an experienced public company (CEAMSE) with skilled professionals and good management.
- The potential support of the project by the City of Buenos Aires and the Province of Buenos Aires (the two most important districts of Argentina).
- The dire necessity of using an alternative technology to the sanitary landfill.
- The ample supply of MSW from the Metropolitan Area and the City of Buenos Aires.
- Relatively close connection from this location to the electrical grid, seven kilometers away.

The approximate land area for the proposed plant is 11.5 ha (see Section 5.5 of Guidebook). Figure 59 shows the geographic location of Acceso Norte III landfill.

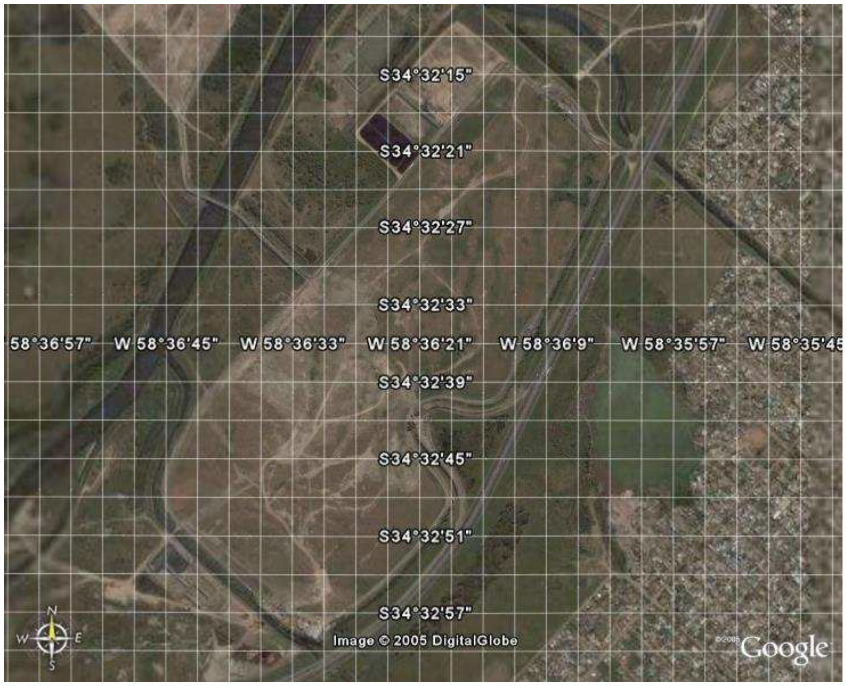


Figure 59 Coordinates of the Acceso Norte III landfill (EEC)

9.9 Projected WTE Plant Costs

Similarly to the other case studies, this section presents estimates of capital and operating costs based on recently built facilities in the U.S. and Europe, and therefore do not take into account all the local conditions, and are also subject to many varying factors such as the price of metals and cement. Hence, they are considered to be within plus or minus 20% accuracy.

Capital cost

A three-line, 1000-ton per day per line plant, will have an annual capacity of 990,000 tons of MSW (330 days per year operation). The capital cost of such a plant is estimated to be in the order of US$600 million ($595 per ton of annual capacity).

The estimated breakdown of the capital cost into the various components of the WTE plant is shown in Table 42 below.

Table 42 Capital cost estimate

Number of lines	3
Site preparation, access, landscaping (million US$)	37
Buildings, stack (million US$)	119
Grate, boiler, air supply, ash handling, electrical and mechanical systems (million US$)	254
Turbine generator (million US$)	62
Air pollution control system (million US$)	62

Contingency (million US$)	62
Land	4
Estimated total capital cost (million US$)	**600**
Estimated capital cost (US$/ annual ton of capacity)	**595**

Operating costs

The three-line WTE will require a personnel complement of sixty. Assuming that the bottom and fly ash will be mixed and disposed at the Acceso Norte III landfill, the estimated operating costs are shown in Table 43 below.

Table 43 Operating costs

Number of lines	**3**
Ash disposal (million US$; US$3.75/ton)	3.78
Chemicals (million US$; US$4/ton)	4.03
Gas Cleaning (million US$; US$8/ton)	8.06
Maintenance (million US$; US$15.6/ton)	11.19
Miscellaneous (million US$; US$2/ton)	2.02
Personnel, employees (million US$)	1.21
Subtotal (million US$)	30.29
Contingency (million US$; 5%)	1.51
Subtotal	31.81
Insurance (million US$; 0.6%)	0.19
Estimated operating cost (million US$)	**32.0**
Estimated operating cost (US$/ton capacity)	**31.8**

9.10 Projected WTE Plant Revenues

Revenues from electricity

There is increasing interest in Argentina for WTE power plants, particularly because of the renewable energy incentive. A national law requires that by 2016, 8% of the energy generated in the country to be provided by renewable energy sources, excluding hydropower. Also, the program "GENREN" launched in 2009 by the public company ENARSA (Energía Argentina S.A.) established criteria in a request for proposals to supply up to 1,000 MW of electricity from renewable resources. Of this amount, up to 160 MW can be provided from the combustion of MSW in WTE plants; the suggested WTE for Buenos Aires would generate 75 MW. A financial incentive provided in this program is the price of US $120 per MWh for renewable electrical energy, vs. about $80/MWh for fossil based energy. Since the energy from the Buenos Aires MSW is projected to be over 55% biogenic, the price of electricity produced by the WTE is calculated to be $102/MWh, at assumed ratio of 55/45 of bio to fossil energy in the MSW.

Therefore, at the projected price for partly renewable energy of $102/MWh, the revenue from electricity will be 0.6 x 102 = $61/ton MSW.

Gate fee

As previously mentioned, the City of Buenos Aires pays CEAMSE a gate fee of about US$5 per ton of waste landfilled, while the actual cost is estimated at about US$15. It is clear that even this gate fee is much lower than that required to sustain a new WTE plant for Buenos Aires. For the time being, the gate fee will be assumed to be $20, but the financial analysis section calculates the gate fee required for various levels of internal rate of return to the investors.

Carbon credits revenues

For the calculation of the carbon credits revenue an emission factor must be used. The emission factor in Argentina is 0.481 tons of CO_2 per MWh (Ministry of Planning and Public Investment); it is calculated by considering that the electricity generated by the WTE plant will reduce the current combination of oil, coal and hydroelectric power generation in the Buenos Aires area, This factor is then multiplied by the plant's electricity production for the grid to obtain the corresponding carbon emission credits (tons CO_2). As mentioned in Section 5.18 of the Guidebook, the value of credits per ton of avoided carbon emissions (CER) is estimated at US$16. Therefore, the carbon credits value of the 0.6 MWh per ton of MSW, to be generated by the WTE are 0.481 x 16 = $7.7/per ton MSW.

In addition to replacing fossil energy, as noted in Section 5.18 of the Guidebook, diverting MSW from landfills also reduces the amount of methane emitted by landfills and one volume of methane emitted to the atmosphere has the greenhouse gas effect of 21 molecules of carbon dioxide. Due to these two factors, one ton of MSW combusted rather than landfilled results in decreasing carbon emission by up to 1 ton of carbon dioxide, depending on the efficiency of LFG capture at the landfill alternative. In this case, the carbon credits maybe as high as 1 ton CO2/ton MSW, i.e. $16/ton MSW. However, the currently applicable Clean Development Mechanism (CDM) recognizes only ten years worth of avoided landfill methane, i.e., a fraction of the overall methane actually avoided through WTE facilities. Therefore, in this analysis, we assumed that the revenue from Carbon Credits would be only the US$7.7/ton of MSW, as calculated in the previous paragraph.

Revenue from metal recovery

As noted in Section 5.18 of the Guidebook, a very conservative estimate is that about 50% of ferrous metals and 8% of non-ferrous metals in the MSW will be recovered from the WTE bottom ash. Since the Buenos Aires MSW contains 0.9% ferrous metals, and 0.3% non-ferrous metals (

Table 40), for every ton of MSW combusted approximately 4.74 kg of metal (4.5 kg of ferrous, and 0.24 kg of non-ferrous) can be recovered. Therefore, the proposed WTE facility, will recover 4,800 tons of metals annually. For an assumed market price in Argentina of US$200 per ton of recovered metal, the facility will have revenue of US$960,000 per year, i.e. US$0.96 per ton of MSW combusted.

9.11 Financial analysis of WTE for Buenos Aires

A in the other case studies, the approach used for the financial analysis of the Buenos Aires WTE was the Net Present Value (NPV) and the Internal Rate of Return (IRR) of the WTE plant cash flows. This means that specific financing costs were not taken into account and therefore both NPV and IRR will most likely decrease once these costs are included. Also, variations in cash flows due to inflation or other factors were not included and could have an important impact in the analysis.

As in the other case studies, the payback period used was 23 years, assuming 3 years of construction and 20 of operation; and the discount rates used for the NPV calculation ere 5%, 10%, and 15%. Table 44 shows a summary of the costs and revenues used in this analysis.

Table 44 Summary of costs and revenues

Item	Cost	Revenue
Capital cost (million US$)	600	
Operating Cost (million US$/yr.)	32	
Electricity sale (US$/MWh)		102
Gate fee (US$/ton)		20
Carbon Credits (US$/ton)		7.7
Metals (US$/ton)		200

Table 45 shows the Net Present Value for the three assumed discount rates, and the Internal Rate of Return, for the conditions shown in Table 44.Table 44 .

Table 45 NPV at 5%, 10%, and 15% discount rates, and IRR

NPV at 5% (million US$)	NPV at 10% (million US$)	NPV at 15% (million US$)	IRR (annual rate)
80	(125)	(215)	6.5%

The results show that at a gate fee of US$20/ton, the plant is economically feasible only when the cost of capital is less than 6.5%, (e.g., in the case of a 5% discount rate). The gate fees required for the plant to break even (i.e. NPV = 0), with 5%, 10%, and 15% discount rates are shown in Table 46.

Table 46 Gate fee required at 5%, 10%, and 15% discount rates

Gate fee (US$/ton)		
5% discount rate	10% discount rate	15% discount rate
12	40	73

For a gate fee of US$15/ton (i.e., the current cost of waste disposal at the Norte III landfill), the NPV is zero at the discount rate of 6%.

9.12 Conclusions to Buenos Aires Case Study

Buenos Aires needs urgently a more sustainable solution for managing its MSW than sanitary landfilling. This is because the Acceso Norte III landfill is expected to reach its full capacity by the end of 2012, the Ensenada landfill will be closed soon, and the municipality of La Matanza, where the Gonzalez Catan landfill is located, does not allow importing waste from other municipalities. Moreover, there is no suitable land for a new landfill within the Metropolitan Area of Buenos Aires, and several attempts during the last ten years to locate a sanitary landfill outside the Metropolitan Area have failed due to the “not in my backyard” effect.

The proposed WTE facility (1 million ton per year capacity) would be able to process approximately 20% of the waste currently disposed at Acceso Norte III landfill, the WTE facility would be a much more sustainable solution than building a new landfill, and would move the country closer to its renewable energy goals. The main problem with this solution is that the gate fee would most likely be higher than the current landfilling cost at Acceso Norte III (US$15/ton), unless the cost of capital investment in this plant is lower than 6%, which is a highly optimistic scenario. Furthermore, if the cost of capital is 10%, the gate fee will be at least US$40/ton. It should be noted that on the basis of experience in the U.S. and E.U., the truce cost of sanitary landfilling, including application of daily cover, collection and use of landfill gas, and landfill maintenance for a 30-year period after closure, is over $40/ton MSW; e.g., at the Mexico City workshop organized by IDB (November 2011), the number of >40 euro per ton was mentioned by A. Mavropoulos of ISWA.

Programs for increasing recycling and composting should also be reinforced through programs such as education campaigns to move Buenos Aires up in the hierarchy of sustainable waste management. In particular, the plan for a WTE facility should be accompanied by source separation and collection of designated recyclables that would be brought to a Materials Recycling Facility, adjacent to the WTE, as discussed in the Guidebook part of this report (Section 5.14).

Appendices to Argentina Case Study

Appendix 1: Legal framework

The following are the existing principal National laws related to solid waste management:

- National constitution: A brief can be found at http://www.ambiente.gov.ar/observatoriorsu/grupo.asp?Grupo=8078&Subgrupo=8235
- Law No. 26,011: The Stockholm Convention – *on persistent organic pollutants*
- Law No. 25,916: Integrated Urban Waste Management. National law
- Law No. 25,675: National law, General law of the environment. Explanation of the coordination between national, provincial, and municipal laws
- Law No. 26,190:National Law of Renewable energies: Establishes that by 2016 8% of the energy has to be supplied by an alternative resource.
- Resolution of the National Secretary of Energy No. 712: Regulates supply´s contracts of renewable energy
- Constitution of the Autonomous City of Buenos Aires Art. 28
- Law 1,854 - City of Buenos Aires: Integrated urban solid waste management
- Law 992 – City of Buenos Aires: the cartoneros are recognized as part of the solid waste management.
- Law 13,592 – Province of Buenos Aires – Integrated Urban Solid Waste Management
- Decree Law 9.111/78, it regulates the Final disposition of waste – creation of CEAMSE
- Law of Protection of the Atmosphere Nº 11.723 OBSERVED law for ORDINANCE 4371/95
- Law 11.382 Modifying of the Ordinance Law 8.031/73
- Law 11.459 Industries taking roots
- Decree Regulation 1.741/96 modified by Ordinance 1712/97
- MUNICIPAL ORDINANCE 39.025 (B.M. 17.049 - published on the 13/6/83)
- Code of Prevention of the Environmental Contamination of the City of Buenos Aires
- Ordinance 33.581 (BM 15.540) Modified by Ordinances 33.681 (BM 15.575) and 38.188 (4/10/82); it modifies Articles 4, 6, and 7
- Ordinance 33.691 (BM 15.577); ratified by Dec. Nac. 3457/77 BO 21/11/77; it approves former Agreement MCBA/Pcia. of BA of 07/01/77 06/05/77

- Ley 992 de cartoneros

The municipal law in force is law No. 1854 of ‘zero waste’ – 747 also is modification of the law No. 154. Original text:

http://boletinoficial.buenosaires.gob.ar/areas/leg_tecnica/boletines/20060112.htm#3

http://www.cedom.gov.ar/es/busca/

Summary of this law: Zero waste is the name given to the efforts towards reducing the amount of solid waste for final disposition through recycling, reusing, and reduction of the amount of waste produced. This law aimed to reduce 75% of the amount of SMW by 2017, taking the year 2004 as the reference. The Article No. 7 explicitly bans the combustion of any MSW, with or without energy production.

Appendix 2: Waste management survey in Buenos Aires

Survey pool: Citizens of the City of Buenos Aires

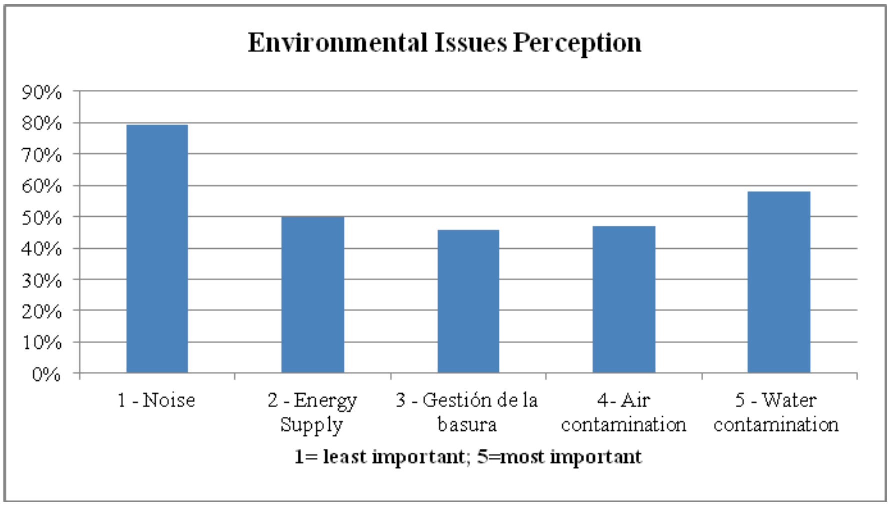
Pool Size: 200+ Date of survey: May 2011

Question 1: Occupation

Occupation		
Answer Options	**Response Percent**	**Response Count**
Student	28.0%	61
House wife	0.5%	1
Employee	14.2%	31
Professional Employee	50.5%	110
Independent	17.4%	38
Public Administration	4.1%	9
Retired	1.8%	4
Other	4.1%	9
	Answered question	**218**
	Skipped question	**0**

Question 2

Order the following environmental issues according to the risk they represent, in your opinion, to human life							
Answer Options	**1 = Lowest risk**	**2**	**3**	**4**	**5 = Highest Risk**	**Rating Average**	**Response Count**
Water Contamination	7	9	18	52	121	4.31	207
Air Contamination	4	16	37	97	54	3.87	208
Waste Management	5	52	95	41	14	3.03	207
Energy Supply	27	104	51	15	11	2.42	208
Noise	164	27	7	2	8	1.38	208
						Answered question	**208**
						Skipped question	**10**

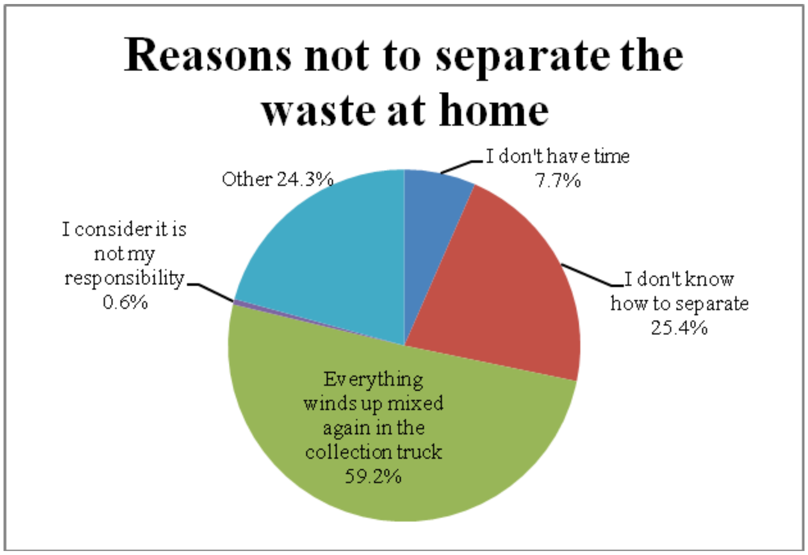


Question 3

Do you separate the waste at home?		
Answer Options	**Response Percent**	**Response Count**
Yes	19.1%	39
No	81.9%	167
Answered question		**204**
Skipped question		**14**

Question 4

If your previous answer was No, what is the reason?		
Answer Options	**Response Percent**	**Response Count**
I don't have time	7.7%	13
I don't know how to separate the waste	25.4%	43
Everything winds up mixed again in the collection truck	59.2%	100
I consider it is not my responsibility	0.6%	1
Other:	24.3%	41
Answered question		**169**
Skipped question		**49**

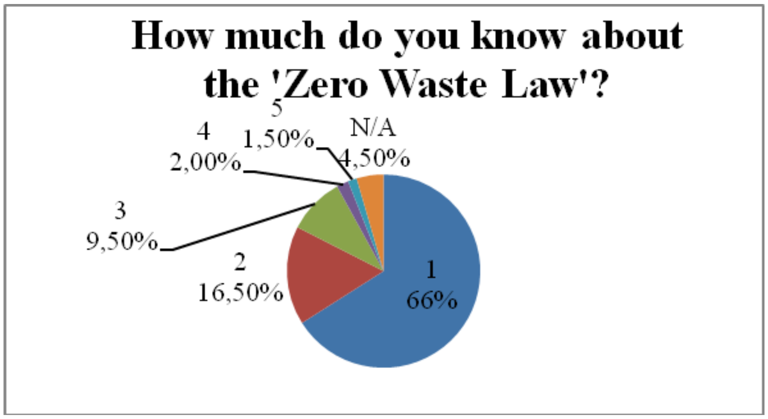


Question 5

What do you know about the composting process?		
Answer Options	**Response Percent**	**Response Count**
I understand the process and I know the different types of composting	8.5%	17
I understand the basics	34.5%	69
I don't know anything about the process	57.0%	114
Answered question		**200**
Skipped question		**18**

Question 6

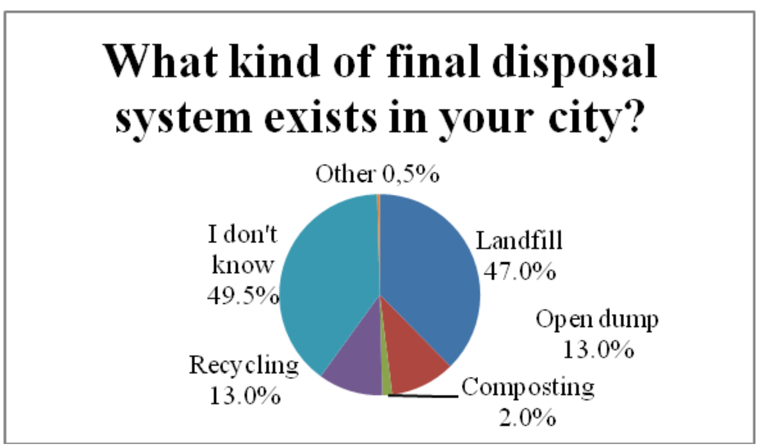
Please answer the following questions (1=Very little/ Very poor, 5=A lot/Excellent)								
Answer Options	**1**	**2**	**3**	**4**	**5**	**N/A**	**Rating Average**	**Response Count**
How much do you know about the collection system of residues in your city?	68	57	45	25	3	2	2.18	200
How would you qualify this service?	28	58	71	30	2	11	2.58	200
How much do you know about the 'Zero Waste Law'	132	33	19	4	3	9	1.50	200
How would you qualify it?	53	22	15	15	5	88	2.06	198
If you know, what is the collection frequency? (days, hours)								98
Answered question								**200**
Skipped question								**18**



Reference code: 1= Very little/Very Poor; 5: A lot/Excellent

Question 7

What kind of final disposal system exists in your city?		
Answer Options	**Response Percent**	**Response Count**
Landfill	47.0%	94
Open Dump	13.0%	26
Composting	2.0%	4
Recycling	13.0%	26
I don't know	49.5%	99
Other (please specify)	0.5%	1
	Answered question	**200**
	Skipped question	**18**

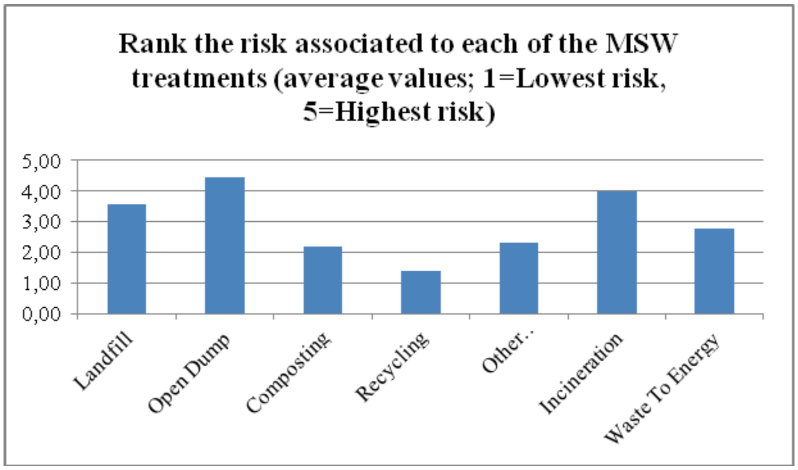


Question 8

How much do you know about Waste to Energy?		
Answer Options	**Response Percent**	**Response Count**
I don't know what it is	44.7%	80
I heard about it once	29.6%	53
I know the basics	24.0%	43
I am knowledgeable	3.4%	6
If you know, please explain briefly		24
	Answered question	**179**
	Skipped question	**39**

Question 9

Rank the risk associated to each of the following municipal solid waste treatments							
Answer Options	**1 = Lowest risk**	**2**	**3**	**4**	**5 = Highest risk**	**Rating Average**	**Response Count**
Landfill	15	15	51	52	46	3.55	179
Open dump	4	5	18	31	121	4.45	179
Composting	57	57	51	7	7	2.16	179
Recycling	131	35	9	2	2	1.37	179
Other mechanical or biological treatments	35	81	44	11	8	2.31	179
Incineration	3	17	30	61	68	3.97	179
Waste to Energy	20	48	71	33	7	2.77	179
Comments							29
						Answered question	**179**
						Skipped question	**39**



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10 Application of WTE in Islands

10.1 Introduction

The island borrowing members of InterAmerican Development Bank (IDB) are The Bahamas, Barbados, Dominican Republic, Haiti, Jamaica, and Trinidad and Tobago (Table 47). They have a total population of 24.4 million inhabitants[78], i.e., about 4% of the population of the 26 borrowing members of the IDB; a total land area of 102,000 km^2 (0.5% of the land area of the 26 borrowing members)[78]; a GDP of US$164 billion (2.6% of the GDP of the 26 borrowing members)[78]; and an average GDP per capita of US$15,000 (vs. the $10,500 average of the 26 borrowing members US$10,500)[78].

Table 47 IDB Island borrowing members' area, population and GDP[78]

	Area (km^2)	Population (Jul 2011 est.)	GDP (Billion US$)	GDP/capita (US$)
Bahamas	10,010	313,312	9	28,700
Barbados	430	286,705	6	21,800
Dominican Republic	48,320	9,956,648	87	8,900
Haiti	27,560	9,719,932	12	1,200
Jamaica	10,831	2,868,380	24	8,300
Trinidad and Tobago	5,128	1,227,505	26	21,200
Total	**102,279**	**24,372,482**	**164**	**15,017[1]**

[1] Average

These six islands, along with Belize and El Salvador (land area of 23,000 and 21,000 km^2, respectively)[78] are the smallest of the 26 IDB borrowing members. This fact may imply that these countries have limited space for landfills and therefore a more urgent need for alternatives to landfilling, such as waste to energy (WTE). Also, the economies of these islands, with the exception of Haiti, depend strongly on tourism; this increases their need to have advanced waste management systems, in order to be clean and remain attractive to tourists.

Another factor that, in some cases, motivates islands to build WTE facilities is their lack of energy resources. Of the six islands borrowing members of the IDB, only Barbados and Trinidad and Tobago have oil and natural gas. Barbados produces 9% of the oil that it consumes and Trinidad and Tobago produces more than it consumes and exports the rest[78]. Moreover, Bahamas, Barbados, and Trinidad and Tobago, are the borrowing member countries with the highest GDP per capita, which could mean that they have better possibilities of building a waste to energy facility.

This study showed that two other islands in the Caribbean, Martinique and St. Barth, and also Bermuda in the north Atlantic Ocean, have already built WTE plants due to the lack of space and desire to improve their waste management systems. Jamaica has also plans to build two WTE plants in order to improve its waste management system and increase its indigenous sources of energy; also, in June 2010, the government of Barbados issued an invitation for qualifications of companies that may build and operate a WTE facility[79].

In the next section, the cases of Bermuda, Martinique, and St. Barth are presented, with the objective of illustrating how these islands evolved to WTE, as examples for other island nations who are IDB member countries. However, it is important to mention that these three islands have had the advantage of being overseas territories of France and England, countries with economic resources and experience for implementing WTE.

After exploring the Bermuda, Martinique and St. Barth cases, a description of Jamaica's waste situation and plans for WTE is presented, also as an example for other IDB borrowing member countries.

10.2 Bermuda

Bermuda is a self-governing overseas territory of the United Kingdom. It is an archipelago formed by 138 small islands (the largest seven connected by bridges), comprising an overall land area of 53 km^2. It is located in the North Atlantic Ocean, 1,000 km southeast of North Carolina, USA. It has a population of 68,000 (2010 est.[78]), and a population density of approximately 1,300 people/km^2; Bermuda is actually the seventh most densely populated country in the world (2008[80]). The GDP per capita of Bermuda, in 2009, was US$86,758[81], one of the world's highest. The main contributors to the GDP are international business (such as insurance and reinsurance) and financial intermediation (accounting for over 70% of the GDP). Tourism is also important to the economy, even though it has declined somewhat in recent years. Agriculture and manufacturing make only small contributions to the economy, which is highly dependent on imported goods and provision of services.

The amount of waste generated in Bermuda is reported to range between 80,000[82] and 100,000 tons/yr.[83], i.e. between 1.17 and 1.46 ton/capita/yr., and has a calorific value ranging seasonally from 9 to 11 MJ/kg[84]. The amount of waste per capita and calorific value are high, due to tourism and the fact that Bermuda imports 85% of the items the locals consume; also, the imports need to be well packed (mainly using plastics) in order to arrive in good condition to the archipelago. Figure 20 shows the composition of residential waste in 2000.

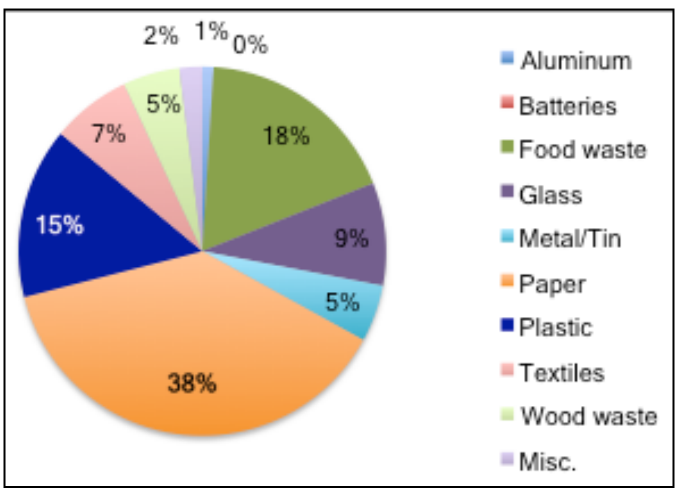

Figure 60 Composition of the Bermuda MSW (2000)[83] (EEC)

In the past, MSW was disposed in the Pembroke Dump, which received around 80% of the island's waste. In 1975, this landfill was reaching its maximum capacity and a shredding plant was installed to extend its life. Nevertheless, it was apparent that the landfill had a very short lifetime. Therefore, in 1977, the Government decided to replace it with a waste-to-energy facility. In 1987, Von Roll Ltd. of Switzerland was commissioned to build this grate combustion WTE facility. Construction began in 1991and the plant started operation in late 1994. The cost of the facility (nominal capacity: 96,000 tons) was US$70 million[85] and was financed entirely by the Government of Bermuda. Pembroke Dump closed after the opening of the WTE facility (called "Tynes Bay Waste Treatment Facility") and most of it is used for windrow composting of green ("yard") wastes and is called the Marsh Folly Composting Facility.

Figure 61 Tynes Bay waste treatment facility[85] (EEC)

The Tynes Bay waste-to-energy facility consists of two lines, each capable of incinerating 6 tons/hr., and producing a total of 3.6MW of electricity[85]. On average, in the period 2000-2009, this facility combusted 68,000 tons of waste per year[86]. The waste incinerated is composed of residential waste (≈35%), commercial waste (≈45%), and wood waste (≈20%). The facility produces about 18,000 MWh[86] of electricity per year corresponding to 2.7% of the country's electricity consumption. Approximately 40% of the electricity produced was consumed by the WTE facility and to run a Reverse Osmosis desalination plant and the remaining 60% was sold to Bermuda Electric Light Company Limited (BELCO). On the average, 160 kWh were exported to the grid per ton of waste burned. The on-line time for the WTE plant was 6,660 hours/year.[86] Currently, higher volumes of waste have resulted in lower electricity production, due to the fact that the facility does not have the capacity to use the extra heat, but it requires more energy to process the additional waste. Tynes Bay facility is planning to refurbish the two existing lines and expand the plant capacity by adding a third, more efficient, stream.

Regarding emissions control, the facility has to be permitted annually by the Environmental Authority of Bermuda. Particulate matter is removed (99%) from combustion gases using electrostatic precipitators. Carbon monoxide, sulphur dioxide, and hydrogen chloride emissions are monitored to comply with the established limits. The WTE emissions reported in 2009 are shown in Table 48. The dioxin emissions are much higher than the E.U. and U.S. standard (0.1 ng TEQ/Nm^{3}) which indicates an inadequate system for injection of activated carbon.

Table 48 Stack emissions[86]

Pollutant	Units (11% O_2)	Actual	Bermuda Standard
Particulate Mater	Mg/Nm^3	33	35
Carbon Monoxide	Mg/Nm^3	8	80
Hydrogen Chloride	Mg/Nm^3	351	1,200
Sulfur Dioxide	Mg/Nm^3	20	200
Dioxins and Furans (TEQ)	ng/Nm^3	4	1

Ferrous metals are removed from the bottom ash with a magnetic separator, and the remaining ash is mixed with concrete to form two-ton, one-cubic meter concrete blocks that are used for shore protection and land reclamation at the Bermuda airport. On the average, 1,000 tons/year of metal were recovered and 11,700 m^3 of concrete ash cubes were produced, in the period 2007-2009[86]. According to the Ministry of the Environment, "Studies by the Benthic Lab at the Bermuda Biological Station for Research (BBSR)" have shown that the ash blocks remain relatively stable when placed in the marine environment with little or no adverse effects on marine organisms"[83].

Bermuda incinerates approximately 80% of the waste generated, composts around 15%, and landfills only bulky items (e.g. cars, tires, A/C units) and special waste (e.g. batteries). The recycling rate is still low, but the government is trying to increase the rate though educational programs.

The Bermuda WTE facility has operated successfully for 17 years. It was a solution for the managing their high waste volume in such limited space and was made possible by Government financing. It is relevant to mention that Bermuda went from disposing the waste in a non-sanitary landfill to WTE, without the usually recommended intermediate step of sanitary landfilling.

10.3 Martinique

Martinique is part of the Windward Islands, an overseas region of France located in the Caribbean, southeast of the island of Dominica. It occupies an area of 1,100 km^2 [87], has a population of 403,000[88], and a population density of 366 people/km^2. Martinique's GDP in 2009 was US$24,900[89] per capita. The economy is primarily based on tourism and services.

The waste generated in Martinique is estimated at 370,000 tons/year, i.e. about 0.92 tons/capita[90]. The composition of the solid wastes is shown in Figure 22.

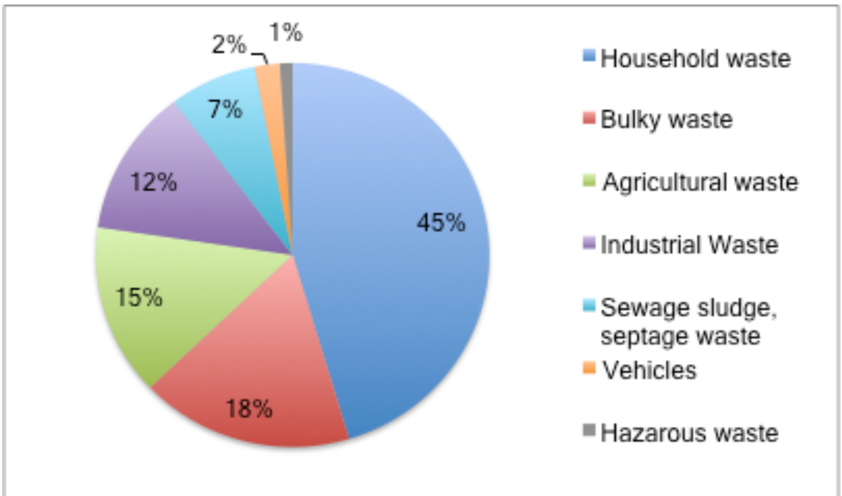

Figure 62 Waste sources in Martinique[90] (EEC)

Waste management is the responsibility of four public entities: CACEM (Communauté d'Agglomération du Centre de la Martinique), CCNM (Communauté de Communes du Nord Martinique), CAESM (Communauté d'Agglomération de l'Espace Sud de la Martinique), and SMITOM (Syndicat Mixte pour le Traitement des Ordures Ménagères de la Martinique).

The island has the following facilities for the disposal of its waste: Three non-sanitary landfills, three open regulated landfills, two transfer stations (with 5 additional planned), one anaerobic digestion composting facility capable of receiving 20,000 t/yr. of organic waste, and one waste to energy facility.

The WTE facility started operations in 2002 and was developed by CACEM to treat the waste of its four municipalities. The plant capacity is 112,000 tons/year[91] (i.e., 30% of the island's waste) and it includes 600 tons of medical waste. The facility consists of two grate combustion lines of 7 tons/hour each and its reported availability is 8,000 hours/year (90%).[91] The calorific value of the waste received at the facility ranges from 4.2 to 8.4 MJ/kg[91] and the plant provides the grid 40,000 to 45,000 MWh/year[91] of electricity (4% of Martinique's electricity consumption).

Figure 63 The Martinique WTE plant[92] (EEC)

The bottom ash is conveyed to a unit where ferrous and non-ferrous metal are collected. Ash is first separated to a fine fraction (0-40 mm.) and a coarse fraction (40-200 mm). Ferrous metals are separated magnetically from both streams. Very light carbonaceous particles are separated from the coarse fraction by air classification and returned to the furnace for complete combustion. The fine fraction is passed through an eddy current separator to extract non-ferrous metals for recycling (200 tons recovered/year[93]). The remaining ash "clinker" is stored for three months for curing and it is then used for road construction (22,000 tons/yr.[91]).

The Air Pollution Control system includes urea injection to reduce NOx levels, lime scrubbing to remove acid gases, activated carbon injection to remove volatile metals and dioxins (to less than 0.1 ng TEQ/Nm^3), and fabric filter baghouse to remove particulate matter. The fly ash containing the pollutants trapped in the baghouse is sent to France, where they are stabilized and neutralized (3,000 tons/yr.[91]). The facility was designed to meet the Dutch emission standards (Table 49), which in 2002 were lower than the French standards (by now they are the same).

Table 49 Guaranteed emissions[93]

Pollutant	Guaranteed maximum	French standards (2002)	Dutch standards (2002)
Dioxins (ng TEQ/Nm^3)	0.1	1	0.1
HF (mg/Nm^3)	0.8	1	1
Hg (mg/Nm^3)	0.5	0.5	0.5
SO_2 (mg/Nm^3)	20	50	40
HCl (mg/Nm^3)	10	10	10
PM (mg/Nm^3)	5	10	5

The cost of the Martinique WTE plant was about US$74 million [91]. The four municipalities of the CACEM funded 10% of the project; the other 90% was provided by the European Regional Development Fund, the French government Agency for Environment and Energy Management (ADEME), the French Government, and the Regional Council and General Council of Martinique. A consortium of CGEA-ONYX, Vinci Environment, CT Environment, and SOGEA Martinique constructed the facility and the companies SEEN and ONYX are operating it.

The Martinique WTE plant has operated successfully for nearly nine years. It was made possible by funding provided by France and by the European Union. It should be noted that a large part of the Martinique MSW is still disposed in sanitary and also non-sanitary landfills.

10.4 St. Barth

Saint Barthelemy (St. Barth) is part of the French West Indies. It has an area of 21 km^2, a population of 7,406 (2010 est.[78]), and a population density of 353 people/km^2. The GDP of St. Barth is estimated at US$35,100 per capita[89]; the economy of the island is based in tourism and duty-free luxury commerce. The island has limited freshwater resources and imports nearly all its food, energy, and most manufactured goods.

St. Barth has a WTE facility that treats nearly all the solid wastes of the island. This plant is coupled with a thermal (Multiple Effect Distillation) desalination plant. There is not much recycling prior to bringing the MSW to the WTE, but a campaign has started to promote some source separation of recyclables. The idea is to separate: trash, paper/cardboard, and plastic bottles/containers and other combustibles to be sent to the WTE facility; glass to be pulverized and then used to create sub-strata for road paving, bedding for water pipes, and water filters for swimming pools; aluminum and other metals exported for recycling; and batteries to be sent to Guadeloupe for disposal or recycling.

Figure 64 The St. Barth WTE plant[92] (EEC)

The WTE-desalination plant started operation in 2001 with the two-fold objective of improving the waste management system of the island and meeting the freshwater needs during the peak tourist season; it was built and is owned by the French waste management company, Groupe TIRU. The WTE process used is combustion with energy recovery in a Cyclerige oscillating kiln that processes 1.5 tons/hour. Its annual capacity is 9,000 tons[94], and the amount of steam delivered allows the production of 1,200 - 1,720 m^3 of drinking water per day[95]. Tiru reported[96] that in 2008 and 2009, 9,762 and 9,038 tons of waste were incinerated, respectively; and that the amount of energy (in form of heat) sold in those two years was 20,666 MWh, and 19,876 MWh, respectively. The sources of waste combusted in 2009 are shown in Figure 65.

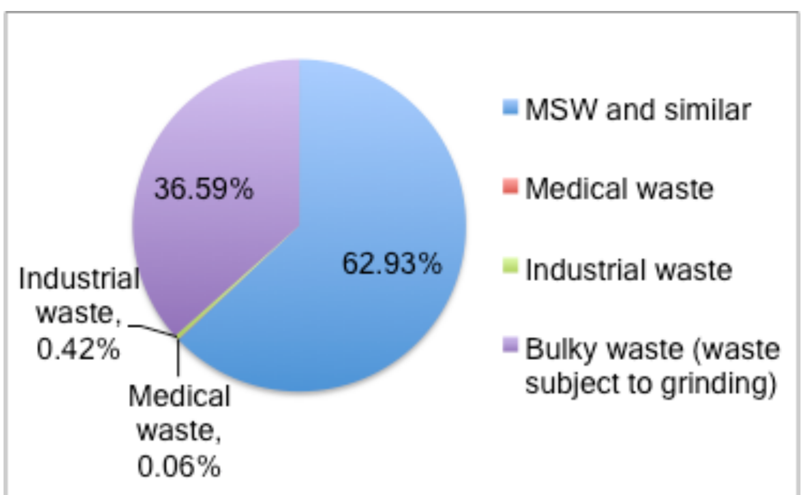

Figure 65 Sources of waste at St. Barth (2009)[96] (EEC)

The reported emissions of the WTE facility in 2009 are shown in Table 50.

Table 50 Emissions 2009[96]

Pollutant	Average emission	Regulatory limit
Dioxins (ng TEQ /Nm^3)	0.003	0.1
NOx (mg/Nm^3)	226	400
SO_2 (mg/Nm^3)	2.65	50
HCl (mg/Nm^3)	3.93	10
PM (mg/Nm^3)	2.57	10

The ash residues from the WTE facility are transported to Guadeloupe for landfilling. The amount of water desalinated by the coupled plant provides approximately 40%[95] of the island's water demand; a Reverse Osmosis desalination plant supplies the rest.

Similarly to the case of Martinique, St. Barth's WTE has been operating for nearly ten years and was made possible by the funding and "know-how" of France. It is important to note that, apart from the WTE facility, St. Barth has no other legal way of disposing waste. Whatever is not sent to the WTE facility, is either illegally dumped or burned, or sent to Guadeloupe for landfilling. It is also worth noting that the WTE was realized because of the dual need of managing waste and desalinating seawater.

10.5 Jamaica

Jamaica is a Caribbean island located south of Cuba and west of Haiti. It has a population of 2.9 million[97], an area of about 10,831 km^2, and a population density of 246 people/km^2. The GDP per capita in 2010 was US$4,700 at the official exchange rate, and US$8,300 taking into account purchasing power parity[78]. The main contributors to the GDP (over 50%) are the service industries (e.g. finance, real estate, tourism). The principal foreign exchange earners for the country are tourism and bauxite (alumina) mining.

Jamaica imports 91% of its energy (petroleum based fuels), and generates the remaining 9% from renewable sources (solar, mini-hydro, wind, and biomass). The Government of Jamaica has set as target, to generate 20% of the energy consumed from renewable sources by 2030, as part of its "Vision 2030 Jamaica" development plan; Petroleum Corporation of Jamaica (PCJ) is responsible for planning and building two waste-to-energy facilities.

The amount of municipal solid waste (MSW) generated in Jamaica is estimated between 1.2 and 1.4 million tons/year (0.44 to 0.52 tons/capita[98,99]). It is estimated that 70% of the waste generated is residential, 20% commercial, and 10% industrial. The National Solid Waste Management Authority (NSWMA) is the agency responsible for the management (collection, transportation, storage, recycling, reuse and disposal) of solid waste in Jamaica). In 2006, this agency conducted a characterization of waste study and the results are shown in Figure 66.

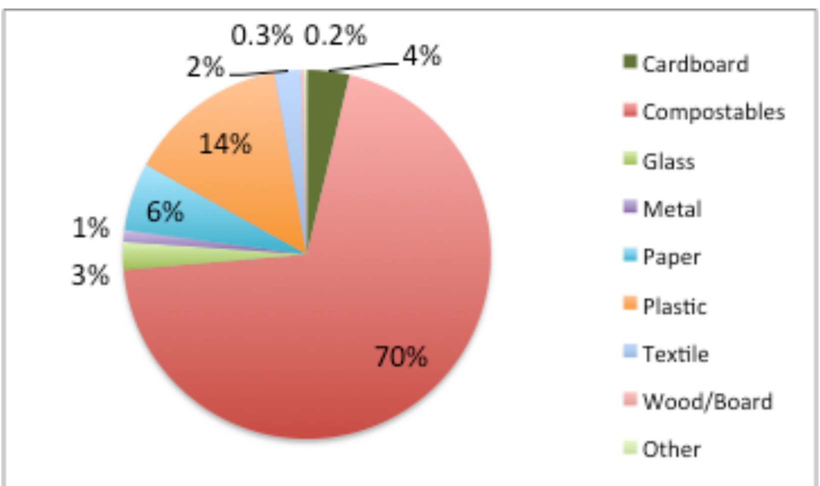

Figure 66 Jamaica waste characterization[100] (EEC)

In 2010, NSWMA estimated that 70%-75% of the waste is collected[100] while the rest is burned, buried or dumped in open lots or gullies. The average cost of collection and disposal of waste on the island was estimated to be US$100/ton[100].

There is very little recycling in Jamaica. There is some glass recycling and a few private companies collect paper, PET bottles and scrap metal for export, provided mainly from informal recycling. The only bright spot is scrap metal collection by scavengers because it is well paid and exports were valued at US$100 million in 2009[100]. This has the benefit of encouraging metal recycling, but it has also created the problem of stealing metal from the island's infrastructure, such as road signs and drain covers. Due to such incidents, in April 28, 2010, the Government issued a ban on scrap metal trading, with the exception of primary scrap generated by manufacturers[101].

NSWMA has divided Jamaica into four "wastesheds" for purposes of waste management (Figure 27).

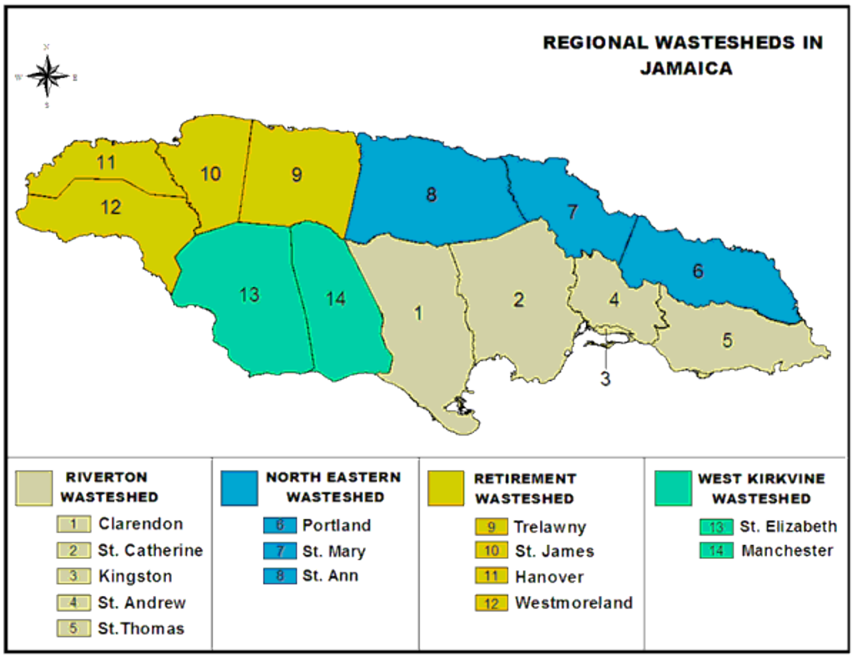

Figure 67 Wastesheds of Jamaica[102] (EEC)

Jamaica has a total of eight disposal sites, none of which is a sanitary landfill. The sites selected for the proposed WTE plants are close to the main two disposal sites. These are Riverton in the Parish of St. Catherine (in No.2 of Figure 67); and Retirement, in the Parish of St. James (No.10). Riverton receives 60% of the island's waste and is expected to reach its maximum capacity in 2014[100]. Some improvements have been made to the Riverton landfill (construction of access road, landfill equipment, installation of lighting, and construction of administrative offices). Also, there were plans to build a sanitary landfill adjacent to it, but the project was discontinued due to lack of funds. The Retirement landfill is close to two sand mines, and receives waste mainly from residences and hotels, representing about 20% of the island's MSW.

The projected WTE facility near Riverton will receive 545,000 tons of waste and will have the potential to generate 45 MW of electricity[103]. The WTE plant near Retirement will receive 219,000 tons of waste, and will generate 20 MW[98]. Therefore, in total the two facilities will process 764,000 tons of waste (55%-60% of the island's total MSW) and produce a total of 65 MW of electricity. Since the plants are expected to run approximately 7,150 hours./year.[98,103], they will provide 465,000 MWh to the grid, which is equivalent to about 7% of Jamaica's electricity consumption.

Petroleum Corporation of Jamaica (PCJ) has already invited bids and selected the Miami-based company, Cambridge Project Development Company Inc., to form a joint venture with PCJ. The joint venture will finance, build, own and operate the two WTE facilities. Currently, the parties involved in this project are negotiating and the proposed financing scheme is a public private partnership and a bank loan for 80% of the capital cost. The proposed revenues for these two facilities will be the sale of electricity through a Power Purchase Agreement with the Jamaica Public Service, and a gate fee to be negotiated with NSWMA.

This project is yet to be implemented, but it is interesting to note, that as in the case of the islands discussed earlier, if it materializes Jamaica will be advancing from non-sanitary landfills to WTE without the intermediate step of sanitary landfilling, and also with the advantage of having a relatively organized collection system. It should also be noted that even though improving Jamaica's waste management system is an important objective of the project, the main motivation for building the two WTE facilities is to increase the indigenous sources of energy.

10.6 Conclusions to Application of WTE in islands

Islands have increasing amounts of waste, limited space, very limited or inexistent sources of energy, and in some cases, inadequate freshwater resources. These conditions lead to opportunities for advancing from landfilling to waste-to-energy.

In all cases analyzed in this study, the use of dumps for waste disposal is, or used to be, the common practice. Governments are now aware of the environmental consequences of such practices and are trying to improve their waste management systems.

It is usually recommended to improve a waste management system one step at a time, that is, to go from dumps to sanitary landfills and then to waste to energy. However, it is interesting to note that in some islands, they skipped the regulated landfill step, and went directly from dumps to WTE. This phenomenon can be partly attributed to the scarcity of land and partly to the desirability of developing local and renewable energy sources. Therefore, WTE represented a solution for the island's waste problem and also eased the burden in the energy front.

Table 51 presents a summary of the GDP and waste generation per capita of the four islands discussed in this section.

Table 51 GDP and waste generation per capita

Island	GDP per capita (Billion US$)	Waste generation per capita (tons/yr.)
Bermuda	86,758	1.46
Martinique	24,908	0.92
St. Barth	35,100	1.22
Jamaica	8,500	0.52

The three islands where WTE was implemented successfully (Bermuda, Martinique and St. Barth) have a higher rate of waste generation and also higher GDP per capita than Jamaica. In fact, all the island members of IDB have lower GDP per capita than these islands, with the exception of Bahamas, which has a higher GDP per capita than Martinique, and considering that Bermuda has one of the highest GDP in the world. However, these three islands are territories of highly developed nations with long experience in the benefits of WTE. Therefore, the local government had at its disposal the "know-how" and the economic resources of the mother country.

Building a WTE facility in a developing country may be complicated as the nation may have other priorities before waste management. Also, in the case of the islands where the use of dumps is still the primary waste disposal method, the tipping fees are low or non-existent; hence the WTE alternative would appear to be very costly. It is therefore very important to ensure that the proposed WTE will be very energy efficient and that both electricity and "waste" steam are used to provide an indigenous and renewable source of energy.

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LIST OF ACRONYMS USED

ACI: Activated carbon injection to remove organic and inorganic molecules from process gas
APC: Air Pollution Control system used to clean the WTE process gas
C&D: Construction and demolition debris
CDM: Clean Development Mechanism
EEC: Earth Engineering Center of Columbia University (www.eecny.org), author of WTE Guidebook
GDP: Gross domestic product
GHG: Greenhouse gases (CO2, CH4, etc.) contributing to the observed global warming and climate change
IDB: InterAmerican Development Bank (sponsor of this WTE Guidebook)
IRR: Internal rate of return of an investment
LAC: Latin America and Caribbean region
JHV: Lower heating value of a fuel does not include the condensation heat of water vapor in the combustion gases.
MBT: Mechanical biological treatment of MSW consisting of bioreacting or biodrying the natural organics in MSW and separating MSW to recyclable, compost and RDF fractions.
MSW: Municipal solid waste; all solid wastes generated in a city, except C&D.
NPV: Net present value of an investment
OECD:_Organization for Economic Cooperation and Development
PPA: Power Purchase Agreement
SCR: Selective catalytic reduction of NOx compounds in WTE process gas
SNCR: Selective non-catalytic reduction of NOx compounds in WTE process gas
WTE: Waste to energy processes fo recovering the energy content of MSW

WTS: Waste transfer station where the load of collection trucks is transferred to long distance trucks.