

**Management of Municipal Solid Waste in Santiago, Chile:
Assessing Waste-to-Energy Possibilities**

by

Paula Estevez

**An Industrial Ecology Study
Advisor: Prof. Nickolas J. Themelis**

**Department of Earth and Environmental Engineering Fu Foundation
of School of Engineering and Applied Science,
Earth Engineering Center**

Columbia University

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Executive Summary

Chile has experienced tremendous economic growth in the last 15 years, but this growth has been coupled with the increase of industrial activity and the rise of significant and uncontrolled amounts of waste, creating countless environmental and social costs.

Santiago Metropolitan Region, with 6 million inhabitants, represents nearly 40% of the Chilean population. During 2001, the annual amount of Municipal Solid Waste (MSW) produced in Santiago was 2,267,743 metric tons. Studies of the solid waste problem in Chile are relatively new and began just a few years ago.

Until 1990 all the MSW produced in Santiago was disposed in “garbage dumps.” As a result of policies during the 1990s, at present, 100% of collected MSW in Santiago is deposited in authorized sanitary landfills. However, none of this waste is recycled or processed. Presently, it is not compulsory to separate trash in Chile. Where recycling exists, it is minimal, sporadic and accomplished in an informal and voluntary way. It is estimated that 9% of the total amount of MSW generate in Santiago is recycled.

Land in Santiago is scarce because of its high population, the large and increasing spread of urban areas, and its geographical location, making it difficult to find space for new landfills. Current landfills will be filled within the next 20 to 40 years. In addition, the use of potential greenfield sites for landfilling combustible materials, as is practiced in Santiago, represents a non-sustainable use of land because little can be done with this land after the landfill is closed. At this time, the three authorized landfills in Santiago use a land space of over 1000 hectares. Finally, landfills have been facing strong political opposition by the population and environmental NGOs.

It is clear that landfills in Santiago face important political, geographical and environmental challenges that make them a not sustainable alternative for MSW management. Therefore, there is an urgent need to investigate new waste management alternatives.

In this study, a preliminary assessment of a WTE plant for Santiago was made. Worldwide, about 130 million tons of MSW are combusted annually in over 600 WTE facilities that produce electricity and steam for district heating and recovered metals for recycling.

After reviewing different technologies and the advantages and disadvantages of each one the conclusion was that the most appropriate technology for Santiago is the mass burn plant. The current mass burn systems are very reliable and have been running successfully for a long time, thus are widely considered as a proven technology. In this category, the Martin Grate technology, with a capacity of 1,200 metric tons/day and an energy output of 600 Kwh per ton to be sold commercially, was selected.

Waste-to-energy facilities save valuable landfill space and produce clean and renewable energy through the combustion of MSW in specially designed power plants which are equipped with state-of-the-art pollution control technologies. The WTE facility that is proposed for Santiago will use a total space of 9 hectares. Trash volume is reduced by 90% and the remaining residue consistently meets strict EPA standards allowing reuse or disposal in landfills.

The project evaluation, using the criteria of Net Present Value (NPV), demonstrates that a WTE Plant for Santiago, with a capacity of 1,200 ton/day, would be able to generate enough income to have a positive NPV. In other words, the project generates more economic value than the cost of its investment. With a 7%/year real discount rate, the net income would be US\$ 13 million. The project is viable without requiring any substantial additional government support beyond the current municipal transfers. If the Central Government were to fully finance the investment costs of the Plant, the WTE plant would end up being a less costly alternative for Municipalities than landfills.

Santiago's current MSW management is based on short-term solutions that are not sustainable. In the coming decades Santiago is going to run out of landfill space. The implementation of WTE indicates that could be an environmental and economic solution to MSW disposal in Santiago. It is believed that Waste-to-Energy is a viable answer to address Santiago's long term solid waste management needs.

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1. Introduction

Chile has experienced tremendous economic growth in the last 15 years, but this growth has been coupled with the increase of industrial activity and the rise of significant and uncontrolled amounts of waste, creating countless environmental and social costs.

Santiago Metropolitan Region, with 6 million inhabitants, represents nearly 40% of the Chilean population. During 2001, the annual amount of Municipal Solid Waste (MSW) produced in Santiago was 2,267,743 metric tons. Studies of the solid waste problem in Chile are relatively new and began just a few years ago.

Until 1990 all the MSW produced in Santiago was disposed in “garbage dumps.” As a result of policies during the 1990s to control this problem, at present, 100% of collected MSW in Santiago is deposited in authorized sanitary landfills. However, none of this waste is recycled or processed; therefore, current landfills will be filled within the next 20 to 40 years. Land in Santiago is scarce because of its high population, the large and increasing spread of urban areas, and its geographical location, making it difficult to find space for new landfills. Finally, landfills have been facing strong political opposition by the population and environmental NGOs.

It is clear that landfills in Santiago face important political, geographical and environmental challenges that make them a not sustainable alternative for MSW management. Therefore, there is an urgent need to investigate new waste management alternatives.

The objective of this research is to examine what Santiago is doing regarding its municipal solid waste and to assess the use of relevant waste-to-energy technologies as a possible answer to Santiago’s current MSW management problems. This assessment incorporates environmental and economic considerations. The economic evaluation was based on the calculation of the major cash flow components of the project and its Net Present Value.

2. Current Santiago Municipal Solid Waste Management

2.1 Amount

Santiago Metropolitan Region with 6 million inhabitants represents nearly 40% of the Chilean population (1). The city produces 1.1 kg of garbage per capita daily. As seen in Table 2.1, during 2001 the annual amount of MSW produced in Santiago was 2,267,743 metric tons. On a year-to-year basis, volume is growing at 5%. It is expected that by the year 2011 the annual amount of MSW will reach 3,693,914 metric tons (2).

Table 2.1: Santiago MSW year production

Year	Metric tons/year	Metric tons/month
2001	2,267,743	188,979
2002	2,381,130	198,428
2003*	2,500,187	208,349
2004*	2,625,196	218,766
2005*	2,756,456	229,705
2006*	2,894,279	241,190
2007*	3,038,993	253,249
2008*	3,190,942	265,912
2009*	3,350,489	279,207
2010*	3,518,014	293,168
2011*	3,693,914	307,826

* projected

Source: Conama, 2002

About half of all residential solid waste generated in Santiago is organic, while paper accounts for 18.8%, plastic 10.3% and textiles 4.3%. Metals and glass make up a smaller percentage, 2.3% and 1.6% respectively. (Figure 2.1).

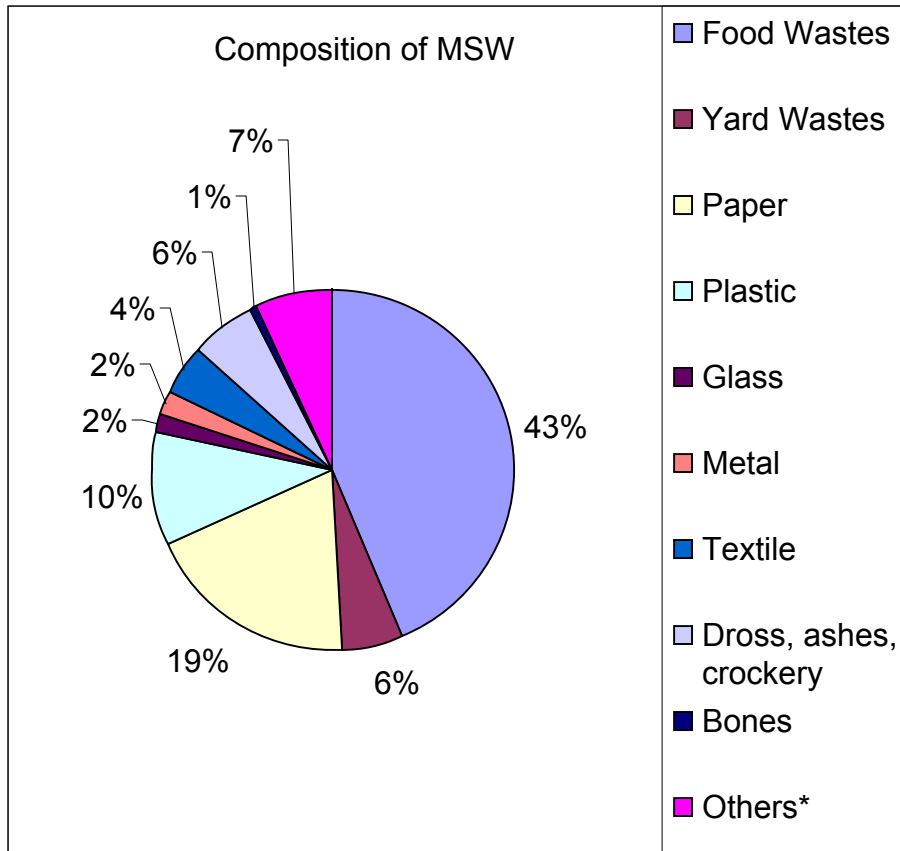


Figure 2.1: Composition of Santiago's MSW, Source: Conama, 2002.
 * Others: Batteries, styrofoam, diapers.

2.2 Institutional Framework

Santiago is divided in 44 municipalities which are responsible for the collection, transport and final disposal of municipal solid waste. The Environmental Health Department (SESMA) is responsible to oversee and inspect the operation and management of all the facilities intended for the treatment or disposal of solid waste and to guarantee the compliance with health standards and regulations. In addition, the National Environmental Commission (CONAMA) is responsible, based on an environmental assessment, of the approval of landfills or other industrial projects regarding the final disposal of MSW. CONAMA is also responsible for the imposition of penalties due to noncompliance of environmental regulations. Finally, the Santiago Regional Government (Intendencia Metropolitana) acts as coordinator, facilitator and, if required, a mediator between these bodies.

Although the Municipalities are in charge of MSW management, they contract all the waste management services out to the private sector.

Two companies, EMERES (Empresa Metropolitana de Tratamiento de Residuos Solidos) and KDM (Kiasa Demarco S.A.), a subsidiary of the U.S. based company Kenbourne, are the only players of the Municipal Solid Waste market in Santiago. EMERES is a private company created and controlled by 19 municipalities in the southern half of the Santiago Metropolitan Region. KDM S.A. is private company that in 1995 signed a 16-year contract with Cerros de Renca, a municipal organization that represents 20 municipalities in the northern half of Santiago.

2.3 Collection, Transport and Final disposal of MSW

Until 1990 all the MSW produced in Santiago was disposed in “Garbage dumps.” Municipal Solid Waste management and treatment legislation has been under study since 1994, leading in 2002 to the establishment of a basic infrastructure of MSW management for the Santiago Metropolitan Region that allowed the replacement of all the garbage dumps for authorized landfills, as shown in figure 2.2.

Consequently, 100% of MSW collected in Santiago is now deposited in authorized sanitary landfills. However, none of this waste is separated at its origin, prior to collection, or in the landfills. The rest of the waste that is not collected is either recycled in an informal way (see point 2.5) or deposited in: 1) controlled sites (which is a "pseudo-legal" dump); 2) illegal garbage dumps; or 3) dumped indiscriminately. According to the CONAMA estimates, there are still 66 illegal “garbage dumps” in Santiago.

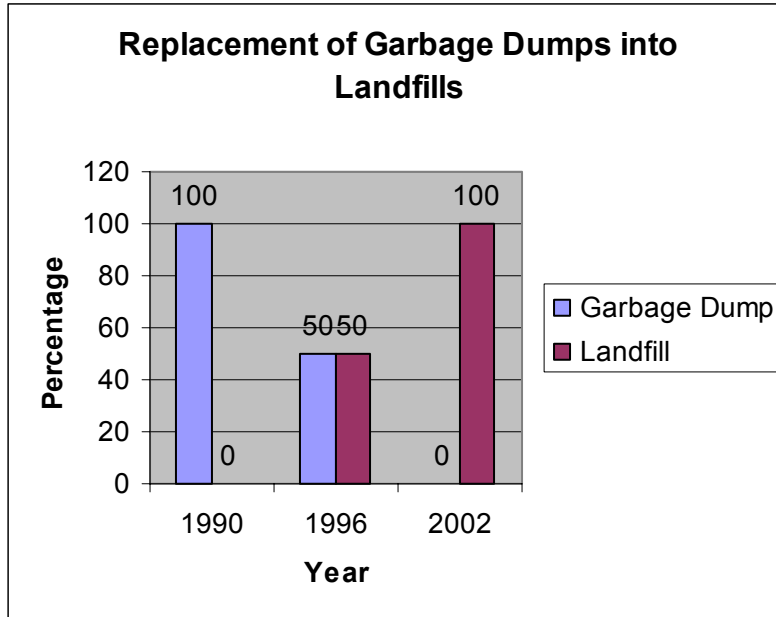


Figure 2.2: Replacement of Garbage Dumps into Landfills
Source: Conama, 2002.

2.3.1. MSW Flow

Figure 2.3 shows the flow of the MSW from its origin to its final disposal.

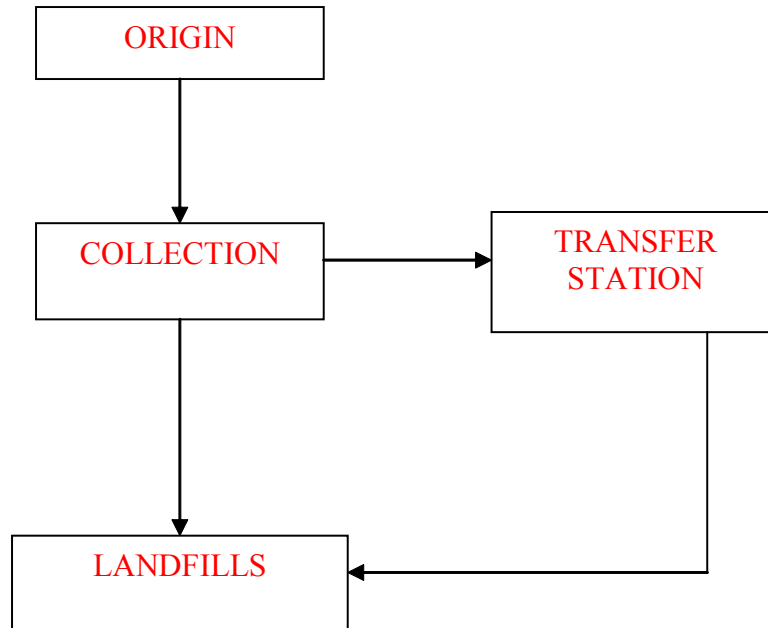


Figure 2.3 Santiago's Municipal Solid Waste Flow

Origin: The waste is produced at the household level and it is not separated. People leave all the waste in black plastic bags in the street to be collected.

Collection: The waste is collected 3 times a week by trucks.

Transport: The trucks, depending on the distance of the municipality to the landfill, take the waste directly to the landfill or to one of two transfer stations.

Transfer Station: The waste in this station is not separated or treated, it is only transferred to bigger or special trucks that will discharge the waste into the landfill.

Final disposal: The only final disposals are landfills.

2.3.2 Landfills

There are only three working authorized sanitary landfills in Santiago:

- Lomas Los Colorados with 140,000 metric tons/month,
- Santiago Poniente with 37,000 metric tons/month, and
- Santa Marta with 50,500 metric tons/month.

Lomas Los Colorados and Santa Marta have their associated transfer station: Quilicura and Puerta Sur, respectively. (Figure 2.4).



Figure 2.4 Locations of Landfills in Santiago.

2.3.2.1. Landfills: Loma Los Colorados

This landfill, managed by KDM S.A and in operation since June 1996, is located in the Municipality of Til-Til (63,5 km north of Santiago). It covers an area of 600 hectares and is expected to reach final official capacity in year 2046. It is designed to receive 150,000 metric tons of solid waste per month, coming from the Municipalities in the northern part of Santiago that serve a population of 3,437,270 inhabitants. The covered Municipalities are: Cerrillos, Cerro Navia, Colina, Conchalí, Curacaví, Huechuraba, Independencia, Isla de Maipo, La Cisterna, La Reina, Lampa, Las Condes, Lo Barnechea, Lo Prado, Maipo, Ñuñoa, Providencia, Pudahuel, Quilicura, Quinta Normal, Recoleta, Renca, San Bernardo, San Joaquín, San Miguel, Santiago, Til Til, Talagante, Vitacura (3).

2.3.2.2. Landfill: Santa Marta

This landfill, managed by EMERES S.A., is located 12 km south of Santiago in Talagante. It started operations in April 2002 and was designed to receive 60,000 final metric tons of solid waste per month. This landfill covers an area of 296 hectares and it is expected to reach final capacity in 2022. It serves a population of 1,212,896 inhabitants from the Municipalities located in the southern part of Santiago: La Florida, La Pintana, Macul, San Ramón, Puente Alto, Buin, Calera de Tango, Padre Hurtado, Paine, Peñaflor, Pirque (3).

2.3.2.3. Landfill: Santiago Poniente

This landfill, managed by EMERES S.A., is located in “Fundo la Ovejería de Rinconada”, Municipality of Maipo. It started operations in October 2002 and is designed to receive 40,000 tons of MSW per month, serving a population of 1,349,834 from the eastern central Municipalities of Santiago: Cerrillos, Estación Central, Pedro Aguirre Cerda, Peñalolén, Puente Alto, El Bosque, la Florida, La Granja, Lo Espejo (3).

2.4 Current MSW Management Costs

The municipalities are responsible for the management and financing of MSW. The service of collection, transport and final disposal of MSW is bid to the private sector and the municipalities are only the intermediaries between the users and the service providers responsible for the collection and disposal of this waste. The total budget Municipalities allocate to this service is approximately US\$150,000 a day for the whole Santiago Metropolitan Region, which represents an average cost of US\$25 per metric ton (2). Figure 2.5 shows the composition of this cost.

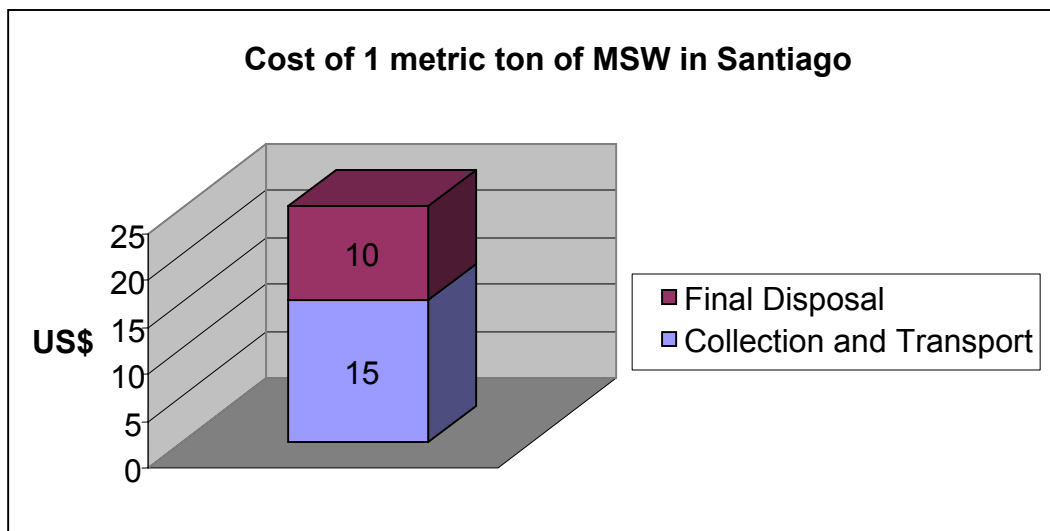


Figure 2.5 Cost of 1 metric ton of MSW in Santiago, Source: Conama, 2002

2.5 Recycling

Presently, it is not compulsory to separate trash in Chile. As a consequence, there is little recycling consciousness among the citizens. In a 2001 survey (2), close to 70% of Chileans said they never or almost never separate their trash. Where recycling exists, it is minimal, sporadic and accomplished in an informal and voluntary way. It is estimated that 9% of the total amount of MSW generate in Santiago is recycled (2).

Most waste recuperation in Chile is done through rudimentary methods. The recovery, accumulation and commercialization of recyclable material is done manually. This informal economic sector is made up of street cardboard collectors ("cartoneros") and scavengers ("cachureros") who as individuals recover small volumes of paper, glass and aluminum cans from homes and businesses. Another informal commercial sector buys the collected material and sells it to a handful of recycling companies (2).

The paper recycling industry is dominated by a paper collection company, known as SOREPA (Sociedad Recolectora de Papeles) that sells recycled material to the three major paper companies in Chile. The largest users of recycled paper are: Compañía Manufacturera de Papeles y Cartones that uses 70,000 metric tons of recycled paper per year; Papeles Carrascal S.A. with 25,000 metric tons; and Papeles Industriales S.A. with 7,000 metric tons per year. The glass industry is dominated by Cristalerías Chile that produces 80% of the country's glass.

There are small pilot projects but volumes are insignificant. Still, some government authorities are trying to raise recycling consciousness through the use of collecting containers, household compost projects, encouraging recycling in public offices and universities, educational programs in schools, and training courses. However, as long as trash separation is not compulsory, recycling will continue to be very limited.

2.6 Future policies and strategies

In April 1997 the "Commission of Ministers of Productive Development" was established. This Commission approved the National Policy for Municipal Solid Waste Management which has as principal objective to set the basis for the future development of an Integrated Waste Solid Management System that minimizes environmental impact, eliminates harmful human health effects and is economically viable. The commission set up the following principles and strategies:

Principles:

1. To encourage the use of the best available technologies and the employment of clean technologies, through strengthening the innovation processes. It is recognized that although this could require major investments, they are associated with greater profitability and new competitive advantages.
2. The generators of solid waste have to assume the responsibilities of its production and accept the cost that its final treatment or final disposal implies.
3. Make an effort to reduce solid waste from its origin (industries, house holds, hospitals)
4. As possible, choose technological treatments or final disposal of solid waste with the least environmental impact, to make sure future generations will enjoy access to renewable resources and are careful with the use of the non renewable ones.

Strategy:

The National Policy establishes a basic strategy that focuses on the following priority objectives regarding MSW: 1st, to prevent MSW creation; if not possible, 2nd to minimize its creation; 3rd MSW treatment; and 4th, disposal of MSW that couldn't be treated.

3 Waste-to-energy Assessment for Santiago

3.1 Why Waste-to-energy for Santiago

Landfills in Santiago face important political, geographical and environmental challenges that make them a not sustainable alternative for MSW management.

In Santiago there has been enormous public opposition to the development of landfills, especially from the communities that reside close to them. Some of these landfills have faced legal challenges to operate or confronted public demonstrations that have affected their normal operations. New landfill developments are likely to

face greater challenges. On top of this, land in Santiago is scarce because of its high population, the large and increasing spread of urban areas, and its geographical location, trapped between Los Andes Mountain Range and the Coastal Mountain Range, (figure 3.1 and 3.2). As a consequence, there will be not enough space for more landfills around the city in the coming decades. It is expected that the actual landfills will be filled within the next 20 to 40 years (3).



Figure 3.1 Map of Santiago, Chile



Figure 3.2 A view of Santiago

In terms of environmental impacts, for every ton of MSW landfilled, greenhouse gas emissions of carbon dioxide increase by at least 1.2 tons (4). During the life of a modern landfill, and for a mandated period after that, the aqueous effluents are collected and treated chemically. However, reactions within the landfill can continue for decades, or even centuries after closure. There is a potential for future contamination of adjacent waters (6). Landfills also have methane and volatile organic compound emissions (4). The use of potential greenfield sites for landfilling combustible materials, as is practiced in Santiago for cost reasons, represents a non-sustainable use of land because little can be done with this land after the landfill is closed. In consequence, accumulation of such a large volume of waste for long time is dangerous for the environment.

Hence, one possible way to solve these problems with landfills in Santiago is to reduce waste volume by burning through Waste to Energy technology.

Waste-to-energy (WTE) has been recognized by the U.S. EPA as a clean, reliable, renewable source of energy. Worldwide, about 130 million tons of MSW are combusted annually in over 600 WTE facilities that produce electricity and steam for district heating and recovered metals for recycling. (4)

In a WTE plant, non recyclable MSW is combusted at high temperatures. The heat of combustion is used to produce steam that drives a generator of electricity. A WTE plant that provides 550 KWh/ton of MSW of net electricity output to utilities is equivalent to a saving of 50 gallons of fuel per ton. In addition, a sophisticated air pollution control system is used to remove particulate and gaseous pollutants before the processes' gas is released into the atmosphere (5).

Trash volume is reduced by 90% and the remaining residue is regularly tested and consistently meets strict EPA standards allowing reuse or disposal in landfills. The combined bottom and fly ashes amount to 10 to 20% of the original MSW (5).

In conclusion, Santiago's MSW management is based on short-term solutions that are not sustainable. Therefore, there is an urgent need to implement new solid waste management systems that could address Santiago's long term needs.

3.2 Available Technologies

Depending upon the pretreatment methodology, there are mainly two types of MSW combustion technologies available.

3.2.1 Unprocessed Solid Waste Combustion Technology (also known as Mass Burning)

3.2.2 Processed Solid Waste Combustion Technology (also known as RDF Burning)

3.2.1 Mass burning

This is the most common and dominant WTE technology because of its simplicity and relatively low capital cost. The MSW is burned without significant fuel preparation, as discarded. The MSW undergoes only limited processing to remove non-combustible and oversized items. Mass burn technologies include water wall furnace, water-cooled rotary combustion furnace, and controlled air furnace. Except some design changes, in all types of furnaces, the mass burning of MSW is primarily performed on a grate system that enables combustion air to be provided through the furl bed with a variety of alternative methods of feeding fuel to the grate (6).

The most common grate technology, developed by Martin GmbH (Munich, Germany), has an annual installed capacity worldwide of about 59 million metric tons (year 2000). A second very popular mass burning technology is provided by Von Roll Inova Corp (Switzerland) with an installed worldwide capacity of 32 million tons (4).

Schematic diagram of the Mass Burn Waste-to-Energy Process

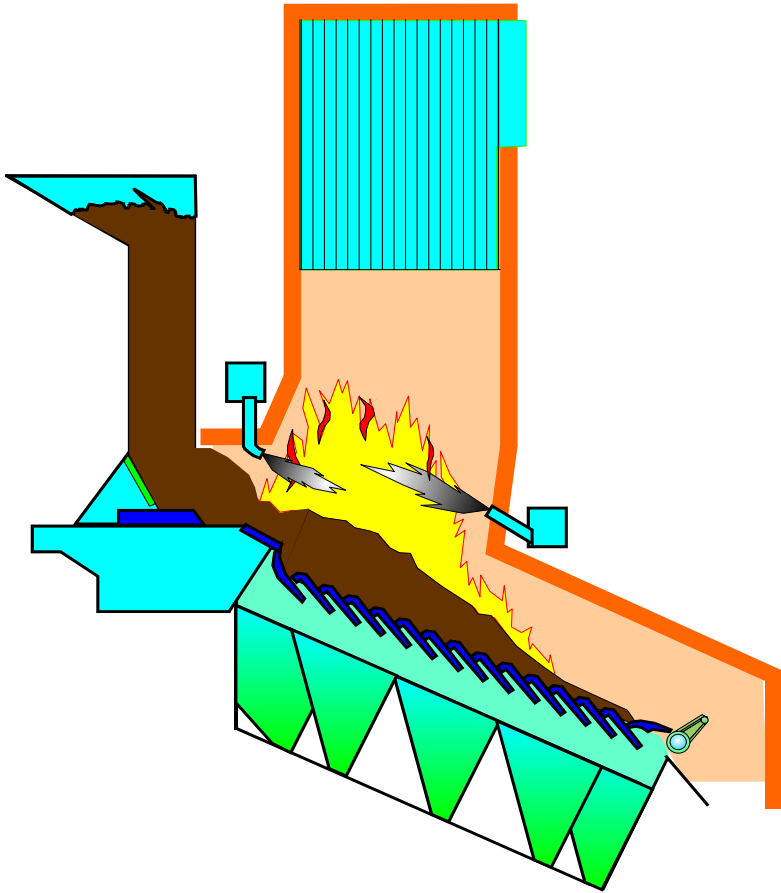


Figure 3.3 Schematic diagram of the Mass Burn

3.2.3 RDF burning

This technology involves various processes to improve physical and chemical properties of solid waste. Basically, RDF systems are used to separate MSW into combustible and non-combustible fractions. The combustible material is called RDF and can be used in boilers. The MSW receiving facility includes an enclosed tipping floor called municipal waste receiving area, with a storage capacity equal to about two days of typical waste deliveries. The sorted MSW is then fed to either of the two equal capacity processing lines. Each processing line includes primary and

secondary trommel screens, three stages of magnetic separation, eddy current separation, a glass recovery system and a shredder (6).

The SEMASS facility in Rochester, Massachusetts, USA, developed by Energy Answers Corp. and now operated by American Ref-Fuel, has a capacity of 0.9 million tons/year and is one of the most successful RDF-type processes. See figure 3.4. The MSW is first pre-shredded, ferrous metals are separated magnetically, and combustion is carried out partly by suspension firing and partly on the horizontal moving grate (4).

Schematic diagram of the SEMASS process at Rochester, Massachusetts, USA

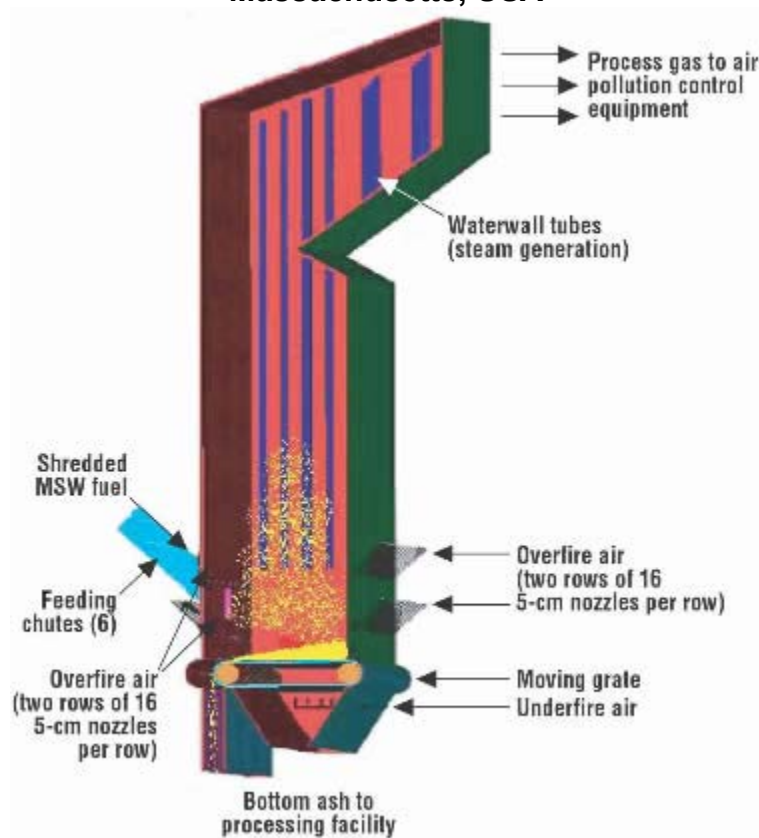


Figure 3.4 Schematic diagram of the SEMASS process

3.3 Selecting the Appropriate Technology

As mentioned in section 2.5, Santiago lacks a regulated system of trash separation. For this reason, the most appropriate technology for Santiago is the mass burn plant with manual pre-sorting of some recyclable materials before combustion (such as metals, glass and papers). The current mass burn systems are very reliable and have been running successfully for a long time, thus are widely considered as a proven technology.

In this category the Martin Grate technology was selected because it is the most widely used. A simple technology, such as Martin Grate, is easier and less expensive to install than RDF burning. With RDF facilities, operators generally have more difficulties. In Japan, for example, the pre-process of MSW had some trouble controlling the exothermic reaction of organics, which led to some self-ignition and even two explosions. Another advantage of mass burning is that it offers ample flexibility for the kind of feedstock you supply, e.g. you can co-fire other fuels such as waste tires or sewage sludge residues from waste water treatment plants.

Figure 3.5 illustrates a schematic diagram of a Martin Grate mass-burn combustion chamber, like the one to be used in Santiago. This diagram was taken from the Brescia (Italy) plant, one of the newest WTE facilities in Europe.

The Martin Grate Combustion System

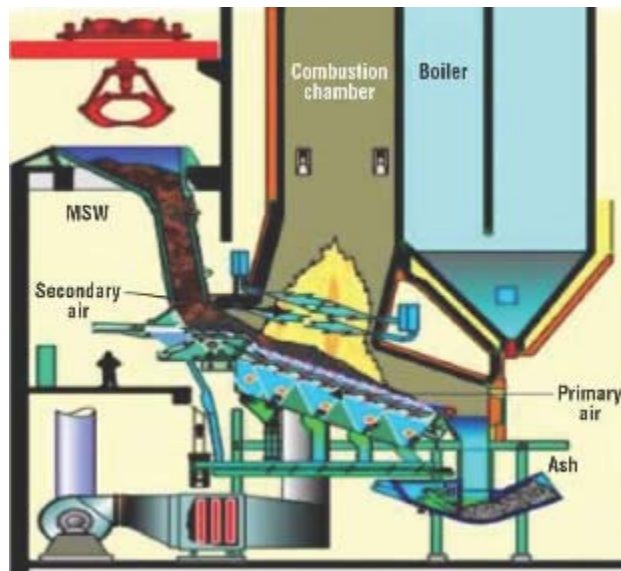


Figure 3.5 The Martin Grate Combustion System

3.4 Input/Output Assessment

In order to calculate the feasibility of a Waste to Energy plant in Santiago, the major cash flow components of the project must be assessed. Firstly, we will review the cash outflows (investment and operational costs) and later the potential sources of income (energy output and municipal transfers). The project evaluation, based on net cash flows, will be determined in section 3.5.

3.4.1 Cash Outflows

3.4.1.1 Investment

The investment has two major components: the building cost of the plant (construction and equipment) and the cost of the property where the plant will be constructed.

3.4.1.1.1 Building costs

The following steps were followed to calculate the cost of construction of a WTE plant in Santiago:

1. Determine the plant capacity
2. Determine the costs of building an industrial plant in Santiago and compare it to U.S.'s cost in order to calculate an adjustment construction cost factor.
4. Prorate the adjustment factor for all equipment and buildings that will be procured in Chile.

In addition, some assumptions were made:

1. 70% of the costs of equipment and building construction are procured at Chilean costs and 30% at U.S.' costs (plant equipment) (7).
2. A cost of construction in the U.S. of US\$100,000 per daily ton of capacity of MSW (short tons) (5).
3. The plant works 335 days per year (7).

In terms of the plant capacity, it was assumed that the “Santiago Poniente” landfill will be replaced with a WTE facility. This is the smaller landfill in Santiago, with a capacity of 37,000 metric tons/month on average (1,233 metric tons/day), and does not have a transfer station associated. **I will therefore propose a Martin Grate plant with a capacity of 1,200 metric tons/day.**

The cost of building an industrial plant in Santiago, in steel structure, is US\$157/m² (8). The cost of building an equivalent industrial plant in Washington (US) is US\$ 49/square feet or US\$ 527/m². (9)

Chilean cost : US \$ 157/m²

US cost : US \$ 527/m²

Conversion factor: Chilean Cost / U.S. cost = 0.2979

As mentioned in the assumptions, 70% of the costs of equipment and building construction will be procured at Chilean costs and 30% at U.S.’ costs (plant equipment). Therefore, the cost of equipment and construction of a Waste-to-energy plant in Santiago is:

- 0.7 x US\$100,000 per daily ton of capacity x 0.2979 = US\$20,854

- 0.3 x US\$100,000 per daily ton of capacity = US\$30,000

=> US\$ 58,924 per daily ton of capacity (short tons)

But US\$ 58,924 per daily ton of capacity (short tons) is equivalent to US\$ 64,816 per daily metric ton of capacity. Consequently, the **cost of construction of a WTE plant in Santiago is US\$65,000/per daily ton of capacity (metric ton).**

Required capacity: 1200 metric ton/day

Estimated building cost of a WTE plant in Santiago: US\$ 65,000 per daily ton of capacity x 1,200 metric ton/day = **US\$ 78 million**

3.4.1.1.2 Land

The Martin Grate WTE is projected to be located in the area of the Municipality of Maipu (near the replaced landfill). The plant will be placed in an area of 24 acres = 97.000 m².

The Cost of 1 m² in the industrial area of Maipu is CH\$ 5,950 = US\$9.15, at an exchange rate of CH\$ 650 per US\$ (11).

Total Land Cost = 97,000 m² x US\$9.15 = US\$ 887,550

3.4.1.2 Operational Costs

The operational cost has three major components: labor, material supplies and ash disposal.

3.4.1.2.1 Labor

i. Management:

- General Manager CH\$ 5,000,000/month = **US\$ 7,700 per month**

- Managers CH\$2,500,000/month = US\$ 3850 month

4 Managers: 4 x US\$ 3850 = **US\$ 15,400 per month**

ii. Chilean workers

- Workers CH \$ 400,000/month = US \$ 615 per month

US\$ 615 x 45 workers = **US\$ 27,675 per month**

Total Labor Cost = US\$ 50,775 per month

3.4.1.2.2 Material Supplies

The cost of material supplies will be US \$ 3/daily metric ton (7).

1,200 metric tons x US\$ 3 x 335 days = US \$1,206,000/year

=> **US\$ 100,500 per month**

3.4.1.2.3 Ash Disposal

In a WTE plant the remaining residue is the combination between bottom and fly ashes. The total amount of ashes is approximately 10 to 20% of the original tons of MSW. These residue ashes can be reused or disposed into landfills. In this project evaluation it was assumed that 3% of the total amount of MSW is converted into fly ash that goes into landfills; the remaining residues are reused. Bottom fly ash could be used as road base material, cement blocks, asphalt or concrete applications.

As was discussed in point 1.4, the cost of discharge MSW into landfills is US\$25 per metric ton, which includes collection, transport and final disposal. The plant will process an approximate amount of 33,500 metric tons a month, with a residue of 3% of fly ash (1,200 metric tons/day x 335 days = 402,000 metric tons per year or 33,500 metric tons per month).

- 0.03 x 33,500 metric tons = 1,005 metric tons of fly ash per month.
- **The cost of landfilling this ash is 1,005 metric tons x US\$ 25 per metric ton = US\$25,125/month**

The electricity that it is used by the plant is also an operational cost. In this case it was considered free of cost, because the plant generates more energy than the energy sold.

Total Operational Cost: US\$ 176,400/month

3.4.2 Cash Inflows

3.4.2.1 Energy Output

Concerning the energy recovery from MSW, it is a function of the heating value of a given material composition. Therefore, each type of MSW has its own heating value. In the case of Santiago, Table 3.1 shows a calculated heating value of 10,040 Kj/kg (4,397 BTU/lb).

Table 3.1 Heating Value of MSW in Santiago

Material	Composition %	Energy Content (Kj/Kg)
Food Wastes	43.7	5,350
Yard Wastes	5.6	6,050
Plastic	10.3	32,000
Paper	18.8	16,000
Textiles	4.3	17,445
Glass	1.6	--
Metal	2.3	--
Miscellaneous	13.4	2,300
Total	100	10,040

Miscellaneous: Bones, Batteries, styrofoam, diapers, dross, ashes and crockery.

Source: P. O'Leary, P. Walsh and F. Cross, Univ. of Wisconsin Solid and hazardous Waste Education

As a result, a heating value of Santiago's MSW of 10,000 KJ/KG would be used as input. This is a very high calorific value and fully sufficient for combustion, thus no supplemental fuel is needed. At this high calorific value it is expected, in the lower case, that the Martin Grate Plant will produce 720 kwh/metric tons of MSW. Out of this energy output, 600 Kwh/metric ton will be sold commercially (7).

The price at which the net electricity is sold for to Santiago's Electric Distribution System is CH\$ 21.87 per kWh (US\$ 3.4 cents per kWh at an exchange rate of CH\$ 650 per US\$). This price is set by the Regulatory Agency (National Commission of Energy) based on an optimization model of generation and distribution costs of electricity. It is based on fair market prices (10).

As mentioned, the plant will generate 600 kwh/metric ton. Receiving 1,200 metric tons of MSW a day it process 33,500 metric tons a month (1,200 metric tons x 335 working days = 402,000 a year).

Therefore, the plant will produce 600 kwh/metric tons x 33,500 metric tons per month = 20,100,000 Kwh/month. At a market price of US\$ 3.4 cents per kWh, the plant will have an income of **US\$ 683,400/month**.

3.4.2.2 Municipal Transfers

As stated earlier, the "Santiago Poniente" landfill will be replaced with a WTE facility. The average budget Municipalities allocate to the service of final disposal into landfills is approximately US\$10 per metric ton. We will assume that this same budget will be used to pay for the service of waste reduction through waste-to-energy. Therefore, the municipalities will pay to the WTE plant 33,500 metric tons per month x US\$10 = **US\$ 335,000 per month**

Total Cash Inflows: US\$ 1,018,400/month

3.4.2.3 Other uses

Due to climatic and economic reasons, industrial and domiciliary heating systems are not massively developed in Santiago. Most heating at residential level is through heating appliances and petrol heaters. At industry level, heating is mostly through petrol combustion. Therefore, for the purpose of this assessment, waste steam for district or other industrial heating was not considered as a reliable source of income.

3.5 Project evaluation

Having calculated the major cash flow components of the project -cash outflows (investment and operational costs) and cash inflows (energy output and municipal transfers)-, it is now possible to evaluate the project using the criteria of Net Present Value (NPV).

The net present value of an investment is the present (discounted) value of future cash inflows minus the present value of the investment and any associated future cash outflows (operational costs and taxes). What does it mean? It is the net result of a multiyear investment expressed in today's dollars.

For simplification purposes, several assumptions were made:

1. Discounted Payback of 30 years
2. Opportunity Cost of Capital: 7%/year (real discount rate). This is the available real interest rate in Chile for long term deposits, which could be considered as an adequate opportunity cost (12).
3. No inflation
4. Corporate tax rate of 35% (Foreign Investment Committee)
5. Plant investment will depreciate on a linear basis over 30 years. Basic depreciation was used to reduce taxable income, therefore reducing cash outflows and increasing the expected profitability of the project.
6. Investment decision is independent from the financing decision. The Analysis of the WTE Plant takes no notice of how the project will be financed. For now, we will treat the project as if it were all financed by stockholders. Financing recommendations will be made based on the results of the preliminary value of the project.

Table 3.2 shows cash flows associated with each inflow item (incomes) and outflow item (expenditures) for each period. Net Cash Flows were obtained after paying taxes of 35% over Pre-tax Profits.

$$\begin{aligned} \text{Pre Tax Cash Flow} &= \text{Cash Inflows} - \text{Cash Outflows} \\ &= (\text{Energy Sold} + \text{Municipal Transfers}) - (\text{Operational Costs}) \end{aligned}$$

$$\text{Pre Tax Profits} = \text{Pre Tax Cash Flow} - \text{Depreciation}$$

$$\text{Tax} = \text{Pre Tax Profits} \times 35\%$$

$$\text{Net Cash Flow} = \text{Pre Tax Cash Flow} - \text{Tax}$$

Based on the calculated cash flows of the project, the preliminary Net Present Value of the WTE Plant for Santiago, at a discount rate of 7%, is over US\$ 13 million.

$$\begin{aligned} \text{Net Present Value} &= \text{Present Value of Net Cash Flows} - \text{Initial Investment} \\ &\qquad\qquad\qquad (\text{Years 1 to 30}) \qquad\qquad\qquad (\text{Year 0}) \end{aligned}$$

$$\text{Net Present Value at 7\%} = \text{US\$ 92,354,289} - \text{US\$ 78,887,923}$$

$$\text{Net Present Value at 7\%} = \text{US\$ 13,466,366}$$

These preliminary calculations demonstrate that a WTE Plant for Santiago, with a capacity of 1,200 ton/day, would be able to generate enough income -through energy sold and current municipal transfers- to have a positive Net Present Value. In other words, the project generates more economic value than the cost of its investment.

This positive result has several implications in term of its financing:

1. The project is viable without requiring any substantial additional government support beyond the current municipal transfers of US\$10/ton.
2. The project could be financed through a bank loan with an annual interest rate of up to 8.5%. At a discount rate of 8.5% the project still has a positive NPV of US\$ 1.1 million.

3. If the Central Government were to fully finance the investment costs of the Plant, it is possible to even consider reducing the Municipal Transfers to US\$ 6/ton and the project would still have a positive NPV. Therefore, it ends up being a cheaper alternative for Municipalities than landfills.

In terms of its Discounted Payback, the number of periods in which the project pays its initial investment is 21 years (See table 3.2).

4. Conclusions

This preliminary assessment indicates that Waste-to-Energy could be an environmental and economic solution to Municipal Solid Waste disposal in Santiago.

Waste-to-energy facilities produce clean and renewable energy through the combustion of municipal solid waste in specially designed power plants which are equipped with state-of-the-art pollution control technologies. EPA has pointed out that after the implementation of Maximum Available Control Technology, waste-to-energy plants produce electricity “with less environmental impact than almost any other source of electricity.” In addition to the generation of electricity, WTE plants allow for the recovery of ferrous and non-ferrous metals that are then recycled.

On the other hand, the use of potential greenfield sites for landfilling combustible materials, as is practiced in Santiago, represents a non-sustainable use of land because little can be done with this land after the landfill is closed. At present, the three authorized landfills in Santiago use a land space of over 1000 hectares; meanwhile, the WTE facility that is proposed for Santiago will use a total space of 9 hectares. A WTE plant saves valuable landfill space and uses waste as a renewable source of energy.

The project evaluation demonstrates that a WTE Plant for Santiago, with a capacity of 1,200 metric tons/day, would be able to generate enough income to have a positive Net Present Value. In other words, the project generates more economic value than the cost of its investment. With a 7%/year real discount rate the net

income would be US\$ 13 million. The project is viable without requiring any substantial additional government support beyond the current municipal transfers. If the Central Government were to fully finance the investment costs of the Plant, the WTE plant would end up being a cheaper alternative for Municipalities than landfills.

In conclusion, Santiago's current MSW management is based on short-term solutions that are not sustainable. In the coming decades Santiago is going to run out of landfill space. The author firmly believes that Waste to Energy is a viable answer to address Santiago's long term solid waste management needs.

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