WASTE-TO- ENERGY AS A KEY COMPONENT OF INTEGRATED SOLID WASTE MANAGEMENT FOR SANTIAGO, CHILE:
A COST- BENEFIT ANALYSIS

by

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Submitted in partial fulfillment of the requirements for the degree of

Master of Science in Earth Resources Engineering

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May 2006

EARTH ENGINEERING Center

Columbia University

Executive Summary

Santiago's current solid waste management system is in crisis and faces important political, geographical and environmental challenges that make it non-sustainable. Therefore, there is an urgent need to move towards an Integrated Solid Waste Management that includes modern alternatives, such as waste-to-energy (WTE). In a "sustainable development" approach, waste should be regarded as a resource for materials and energy recovery and not simply as a product for disposal.

The objective of this research is to examine what the city of Santiago is doing regarding its municipal solid waste (MSW) and to propose an Integrated Solid Waste Management for Santiago that focuses on the use of WTE as the key component. This report offers a Cost-Benefit Analysis of one WTE plant that will serve two municipalities of Santiago, La Florida and Puente Alto.

The mass-burn technology of the Martin Reverse-Acting Grate was selected for a WTE plant of capacity of 1000 metric tons/per day. This plant will provide 600 KWh/ton of MSW of net electricity output to utilities, equivalent to a saving of 50 gallons (190 liters) of fuel per ton. The facility will use a total land surface area of 6 hectares.

The cost-benefit analysis indicated that at the assumed gate fee (tipping fee) of USD14/ton the project has a positive Net Present Value (NPV) of $18 million at a 9% discount rate, therefore the project should be undertaken. The initial investment would be paid back in 17 years while the WTE plant would have a useful life of at least 30 years. It should be noted that the gate fee of USD14 is very low by modern standards since controlled landfilling is reported to cost USD30 to USD40 per ton. Thus, the sensitivity analysis showed that the WTE facility could charge a significantly lower fee than current landfills and still have a positive NPV. However, a very small increase or decrease in the electricity price or heating value can make a dramatic difference in profitability.

Before the construction of the plant, the none-quantifiable impacts such as the environmental, social and economic factors must be carefully examined. The perception of air pollution associated with the incinerators of the past and the location of the WTE plant are factors that could generate opposition from the host community. On the other hand, modern Waste-to-Energy plants have been shown to result in a dramatic decrease in air emissions in comparison to landfills. Also, their emissions are much below the EPA standards and lower than coal power plant emissions. In addition, the location of a WTE plant will be closer to the municipalities than the present landfills. This will reduce truck travel and diesel emissions to the atmosphere, and a significant reduction in generated smog. Overall, the non-quantifiable benefits seem to overweight the non-quantifiable costs, therefore supporting the construction of a WTE plant for Santiago. The community would have to be educated about these issues.

Considering that the current waste management situation in these two municipalities is almost identical to the rest of Santiago, the possibilities of WTE as a widespread solution for waste management are very promising.

Santiago's government should implement an integrated solid waste management system that would classify MSW under four categories: "recyclable", "combustible," "compostable," and "landfillable" waste. The government has already set a goal for recycling of 25% of the waste stream; in addition, the WTE plant proposed in this study for La Florida and Puente Alto could process an additional 14% of the waste stream of Santiago. Regarding "compostable waste", according to international standards, 5% of

Santiago's waste could be composted. Under this scenario, Santiago's waste to be disposed into landfills would be reduced by 44%. This would be a major step towards Integrated Solid Waste Management and the goals of sustainable development.

Positive experience with WTE and its widespread use in other countries should provide an encouraging prospect for Chile too. The Amsterdam WTE experience showed that part of its success was due to increasing the involvement of the citizens in the waste management process. This was achieved by means of educating to the community and convincing the public and other stakeholders of the benefits of combustion for treating the city's waste. This experience demonstrates what can be done with WTE and offers an excellent example of integrated solid waste management from which Santiago could derive similar benefits.

Acknowledgements

I extend my deepest gratitude to my advisor, Professor Nickolas Themelis, for proposing this project and for his support and guidance throughout. Without his vision this project would have not been possible.

I would also like to recognize my husband, Juan Somavia, for his invaluable insights, advice and support through the entire program, and the most important, for being the editor of this thesis.

I am very grateful to my family, for their economic support and encouragement throughout my graduate studies.

I would particularly like to thank Joost Meijer, from the National Environmental Commission of Chile (CONAMA), Andres Villalobos from La Florida Municipality, Manuel Jose Ossandon, the Mayor of Puente Alto Municipality, Leopoldo Perez from Puente Alto Municipality and Gerardo Rojas Silva from Vitacura Municipality. Their openness and willingness to share information and ideas was a key part of this project.

Finally, thanks to my colleges and friends from Columbia's Department of Earth and Environmental Engineering who have provide friendship and feedback which have been of great help, including: Priscilla Ulloa, Karsten Millrath, Kanako Okada, Georgina Columbus, Liliana Themelis and Kimberly Labor.

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1. Introduction

Chile has experienced tremendous economic growth in the last 15 years, vastly improving the standard of living of its population. This growth however has been coupled with the increase of significant and uncontrolled amounts of waste, creating countless environmental and social costs that need to be addressed. Presently, it is not compulsory to separate recyclables in Chile. As a consequence, there is little recycling consciousness among the citizens.

At present, 100% of municipal solid waste (MSW) collected in Santiago is deposited in authorized sanitary landfills that use about 1,400 hectares of land (1). Land in Santiago is scarce because of its high population, the increasing spread of urban areas, and its geographical location, trapped between Los Andes Mountain Range and the Coast Mountain Range, making it difficult to find space for new landfills. Current landfills will be filled within the next 20 to 40 years[1] (2).

Santiago is divided in 52 municipalities which are responsible for the collection, transport and final disposal of MSW. Municipalities are not satisfied with their actual waste disposal contracts. The current system is very expensive because of their lack of options, as each municipality in Santiago has only one landfill where it can dispose its wastes. Municipalities are willing to explore different alternatives for waste disposal.

As it is presented in this study, Santiago's current waste management system is unsustainable and in crisis, making it necessary to move towards an Integrated Solid Waste Management approach, in which a waste-to-energy plant could play a key role in guaranteeing its efficiency and sustainability.

In order to properly develop this proposal, this study will first present a brief description of what an Integrated Solid Waste Management System is. Then, an overview of Santiago's Municipal Solid Waste management will be presented, followed by an overview of Waste-to-Energy and by a Cost-Benefit Analysis of a WTE plant for Santiago.

The Cost-Benefit-Analyses chapter will begin with a description of the project including stakeholders. It will then delve into the project's environmental, economic and social impacts. Next, it will discuss the major assumptions and the monetization of costs and benefits associated with the project, to finally conclude with the analysis of results using the criteria of the Net Present Value. For the sensitivity analysis, a Montecarlo simulation was used.

As a support for this approach, some successful cases of WTE in the world will be presented at the end, followed by conclusions and recommendations of the author.

2. Integrated Solid Waste Management

2.1. Definition of Solid Waste

Solid Waste as defined under the Resource Conservation and Recovery Act (RCRA) is any solid, semi-solid, liquid, or contained gaseous materials discarded from industrial, commercial, mining, or agricultural operations, and from community activities. Solid waste includes garbage, construction debris, commercial refuse, hospital waste,

[1] Based on the author's calculations, landfills will reach their maximum capacity in 20 years from now.

sludge from water supply, waste treatment plants or air pollution control facilities, and other discarded materials.

Solid waste can be classified into different types depending on their source:

- *Household and commercial waste*: is generally classified as municipal waste
- *Industrial waste:* classified as hazardous waste
- *Biomedical or hospital waste*: classified as infectious waste.

In this study we are interested in municipal solid waste. MSW are household wastes that are set aside for curbside collection. MSW also includes other types of waste such as bulky household waste (eg appliances, furniture and residential garden waste), household hazardous waste, waste generated from local Council operations (eg waste from street sweeping, litter bins and parks), commercial and construction and demolition.

The composition of solid wastes varies significantly in each city and even in different seasons. It is a mix of wet materials (yard and food wastes) and dry materials (paper, cardboard, mixed plastics, textiles, rubber, leather and wood) in different percentages.

2.2. The Need of an Integrated Solid Waste Management

Solid waste management is in crisis in many of the world's largest urban areas as populations attracted to cities continue to grow. This growth is accompanied by economic development characterized by greater use of materials and generation of wastes. This has led to ever increasing quantities of domestic solid waste while space for disposal decreases.

In the US, the Environmental Protection Agency (EPA) has developed a national strategy for the management of solid waste, called the Integrated Solid Waste Management (ISWM) which is the combination of techniques and programs to efficiently manage the municipal waste streams, based on the fact that the 'waste' stream is made up of distinct components that should be dealt with separately in an sustainable manner.

The principles that lay at the foundation of this system are (3):

1) Protect public health and the environment
2) Lessen the borders of future generations
3) Conserve resources
4) Integrate multiples approaches
5) Combine best available technologies
6) Minimize cost

ISWM is a conceptual framework that aims to provide guidance on waste management and waste reduction. It proposes a waste management hierarchy that ranks waste management options in order of sustainability, from the most favored option to the least favored option (shown in Figure 1).

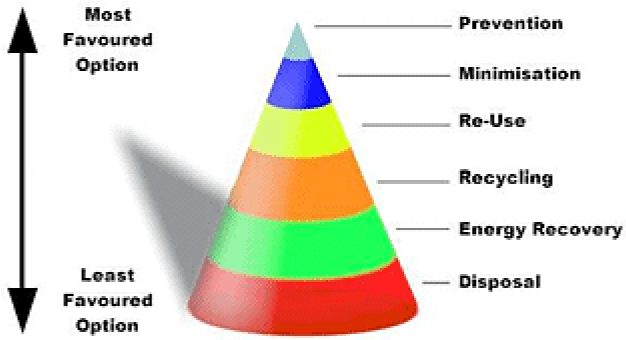

Figure 1: The Waste Management Hierarchy
(Source: www.greenstar.ie)

The first priority for a more sustainable waste management is **Prevention** and **Minimization**. Some wastes may be avoided completely, while in other cases they can be minimized. After reduction comes **reuse**, that is putting objects back into use so that entry into the waste stream is delayed or avoided. Examples include re-treading tyres or refilling bottles. The third level of the waste hierarchy is **recycling**, which means reprocessing materials back into new raw materials and products. Examples include re-pulping packaging to make cardboard, and manufacturing new glass bottles from old. **Energy recovery** means to gain value from waste products by converting them into energy, for instance Waste-to-Energy and Anaerobic/Aerobic digestion. Waste **disposal** comes at the bottom of the hierarchy and is the least desirable waste management option. One example is the popular use of Sanitary Landfills.

2.3. Components of an Integrated Solid Waste Management

As noted earlier, MSW consists of many materials with entirely different properties. Under ideal circumstances of sorting, processing, and recycling, these materials should go to different destinations. For example, metals and glass are not combustible or compostable; then, recycling would be the most appropriate course for such materials. Most of the collected paper and some plastics (e.g. PET and PE) should be sorted out and recycled. The non-recyclable paper, plastics and fibers contain useful energy; therefore they constitute a fuel that can be burnt in a properly designed combustion chamber to generate steam and then electric energy. Finally, the only materials to be landfilled should be inorganic compounds such as non-recyclable glass and ashes from Waste-to-Energy power plants (4).

Therefore, to accomplish an integrated solid waste management, MSW should be classified under four categories of “recyclable”, “combustible,” “compostable,” and “landfillable.”

Recycling: A key component of a recycle system is the Material Recover Facility (MRF), which is a specialized plant which separates, processes and stores recyclables (paper, cardboard, glass, metals, plastic containers, aluminum cans) which have been collected either separately from waste (a 'clean' MRF) or co-mingled with it (a 'dirty' MRF). These facilities separate, remove contamination, densify and ship recyclable materials to recyclers for processing. Any residual material not suitable for processing goes on for disposal.

Anaerobic/Aerobic digestion: The natural organic components of MSW (food and plant wastes) can be composted aerobically (i.e., in the presence of air) to generate carbon dioxide, water, and a compost product that can be used as soil conditioner. Anaerobic digestion consists of the degradation of organic material in the absence of oxygen. It produces mainly 55% of methane and 45% of carbon dioxide gas and a compost product suitable as a soil conditioner. The generated biogas in some cases produces electricity.

Waste-to-Energy: In a WTE plant, non recyclable MSW is combusted at high temperatures. The heat of combustion is used to produce steam that drives a turbine generator of electricity. In this process, a sophisticated air pollution control system is used to remove particulate and gaseous pollutants before the process gas is released into the atmosphere. Trash volume is reduced by 90% and the remaining residue is regularly tested and consistently meets strict Environmental Protection Agency (EPA) standards allowing beneficial use or disposal in landfills.

Landfilling: The last option is the final disposal into landfills. Landfill is a waste disposal site, usually hundreds of hectares, for the deposit of waste into land. The waste is spread and compacted and a cover of soil and/or liner is applied so that effects on the environment are minimized. Under current regulations, landfills are required to have treatment systems to prevent contamination of ground water and surface waters.

In an ideal situation, the fraction of MSW that cannot be subjected to recycling, composting or energy recovery, plus the residues from combustion (e.g. ash, non-usable glass, etc) must be disposed in properly design landfills.

3. Overview of Santiago's Municipal Solid Waste Management

3.1. History

Until 1990, all the MSW produced in Santiago was disposed in uncontrolled "garbage dumps." In 1994, the Framework Environmental Law (Ley de Bases del Medio Ambiente) was passed establishing that MSW must be disposed in Sanitary Landfills. This led, 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.

Consequently, 100% of MSW collected in Santiago is now deposited in authorized sanitary landfills. However, none[2] of this waste is separated at its origin, prior to collection, or at the landfills. The rest of the waste that is not collected is either recycled in an informal way (see point 3.8) or deposited in: 1) "vertedero" (which is a "pseudo-legal" dump); 2) illegal garbage dumps; or 3) dumped indiscriminately. According to the National Environmental Commission (CONAMA) estimates, there are still 66 illegal "garbage dumps" in Santiago (3).

[2] There are some municipalities that have pilot projects that separate recyclables from trash at residences or offices

A big step in the framework of solid waste management in Chile was the recent promulgation of the “Policy for an Integrated Solid Waste Management” (Politica de Gestion Integral de Residuos Solidos, January 17 2005). In addition to establishing a regulatory framework, this legislation declared that in 2006 the “Sanitary Landfills Regulations” (Reglamento de Rellenos Sanitarios) and “Norms for emissions from Incineration” (Norma de Emision para Incineracion y co-incineracion) will be promulgated.

3.2. Institutional Framework

Santiago is divided in 52 municipalities which are responsible for the collection, transport and final disposal of municipal solid waste. The Environmental Health Department of Santiago (SESMA) is responsible for overseeing and inspecting the operation and management of all the facilities used 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 for setting environmental standards and norms and enforcing their implementation. Based on an environmental assessment, CONAMA decides on the approval of landfills or other industrial projects regarding the final disposal of MSW. CONAMA is also responsible for the imposition of penalties for noncompliance with environmental regulations. Finally, the Santiago Regional Government (Intendencia Metropolitana) acts as coordinator, facilitator and, if required, a mediator between these bodies. Municipalities in Chile are completely autonomous by Law, but are supervised by the Comptroller General of Chile on their administrative operations.

3.3. Rate of MSW Generation

According to the most recent census, Santiago Metropolitan Region (SMR) with 6 million inhabitants represents nearly 40% of the Chilean population (5). The city produces 1.1 kg of garbage per capita daily. As shown in Table 1, the annual amount of MSW produced in Santiago in 2003 was about 2.43 million metric tons[3]. On a year-to-year basis, volume is growing at an average of 3.5%. It is expected that by the year 2011 the annual amount of MSW generated in SMR will reach 3.20 million metric tons (6).

[3] All tonnages in this paper are reported in metric tons (1.1 short tons = 1 metric tons)

Table 1: Rate of MSW Generation in Santiago

Year	Metric tons/year
2001	2,267,743
2002	2,347,114
2003	2,429,263
2004*	2,514,287
2005*	2,602, 287
2006*	2,693,367
2007*	2,787,635
2008*	2,885,202
2009*	2,986,185
2010*	3,090,701
2011*	3,198,876

*Projected by CONAMA (National Environmental Commission). www.conama.cl (The National Environmental Commission does not have the amounts generated for this years).

3.4. Characterization

About half of all residential solid waste generated in Santiago is organic (54%), while paper accounts for 13.3%, plastic 10.4% and textiles 2.1%. Metals and glass make up a smaller percentage, 1.6% and 3.5% respectively. (Figure 2) (7).

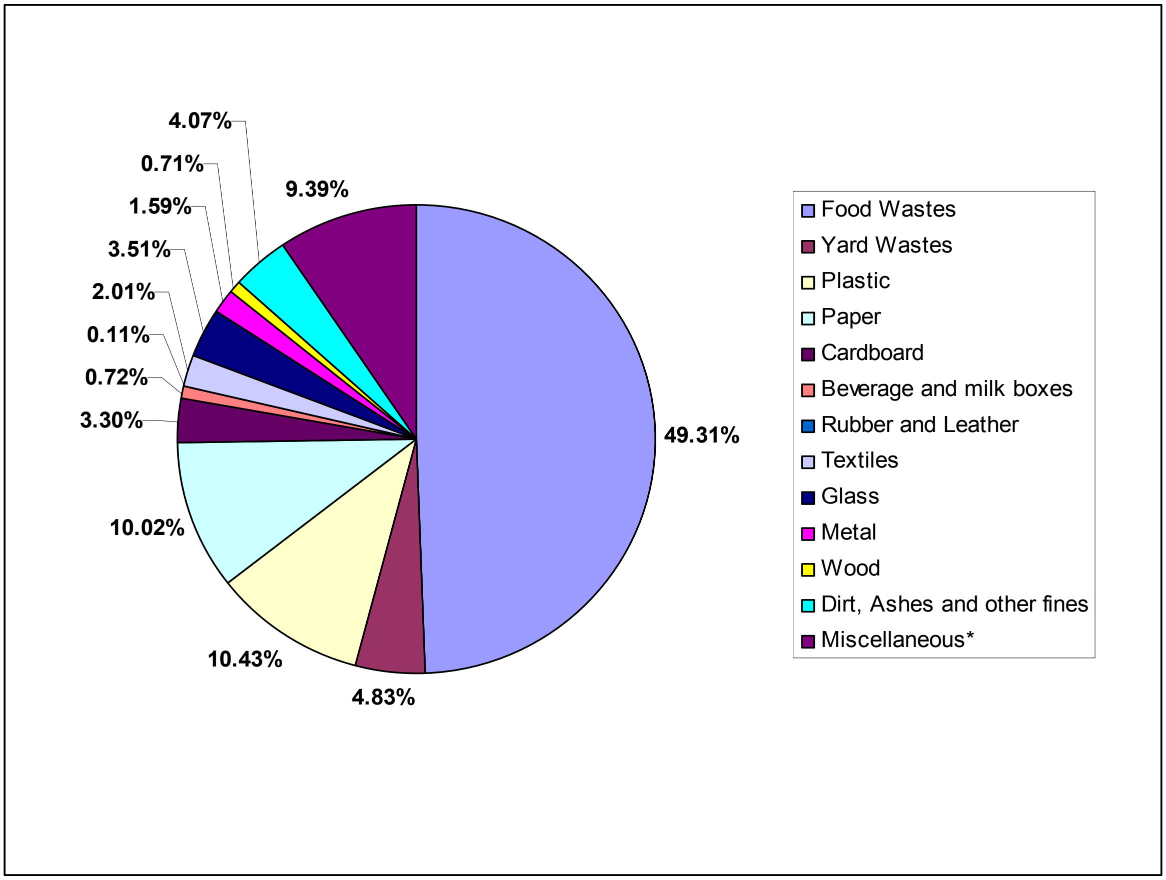

Figure 2: Composition of the Santiago MSW

* Batteries, styrofoam, diapers
Source: Estudio de caracterización de Residuos Sólidos Domiciliarios en la Región Metropolitana-Informe Final-Conama RM- Ingeniería en Construcción – Centro de Asistencia Técnica Pontificia Universidad Católica de Valparaíso (December 2005).

3.5. Responsibility for Waste Management in Santiago

Although the 52 municipalities of Santiago are in charge of MSW management, they contract all waste management services out to the private sector by bidding openly for the collection and disposal service.

The current regulation is dispersed and incomplete, resulting in judicial uncertainty lack of coordination, and no incentives to create new market driven solutions. The absence of clarity and transparency regarding the responsibilities of the municipalities results in inadequate municipal policing, that responds mostly to users' complaints, and in the proliferation of numerous clandestine dumping sites. Furthermore, each municipality acts independently from the others.

In addition, cost recovery continues to be a problem. Municipalities have a huge debt because there is a high non-payment rate from domestic users. An important share of municipal budgets (between 20% and 50%) is spent on the administration and management of solid waste services. The essential problem is that the collection and disposal waste costs are integrated in the "property tax", which depends on the property value and some households below a certain level of property value are exempted from property taxes.

Consequently, there are enormous differences between low income and high income municipalities. In the high income municipalities, the money needed for waste management is collected. For example, in the municipality of Vitacura, almost no one is exempted from paying property tax, so the budget allocated to waste management is entirely collected from residents (8). In the low income municipalities, most of the properties are below the threshold level and residents do not pay property tax, so they are supposed to pay their waste collection and disposal bills directly to the municipality. However, a large fraction of these payments are not collected. For example, in Puente Alto municipality, an estimated 99% of the population is exempted of payment of property tax so the municipality has to cover most of the cost for waste management (9); in La Florida municipality, 75% of the users are exempted from paying waste collection and disposal fees (10).

Low income municipalities claim that they cannot deny waste collection to anyone because it is part of their obligation as local government. In Puente Alto they are more than 300,000 debtors. "What shall we do, put them all in jail?" claimed the Mayor when he was interviewed by the author in the course of this study.

It is clear that municipalities are confronting a budget problem for waste management and that the current situation is not working. Maybe a simple method for increasing recovery is to add this charge to the bill of some other utility, like r electricity, as is done in Greece (11). As another example, in Brazil, initiatives to incorporate this charge in other public services bills have helped to improve waste collection and disposal significantly (12).

Another problem faced by the municipalities is that each municipality in Santiago has only one landfill where it can dispose its wastes. This monopolistic generates a lack of transparency in the awarding of some contracts and creates a wide distribution of prices for the same services.

3.6. Collection, Transport and Final Disposal of MSW

3.6.1. MSW Flow

The MSW flow in Santiago from origin to final disposal is as follows:

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

Collection: The waste is collected three 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 transport the waste to the landfill.

Final disposal: The only final disposal is by landfilling.

The above describes the waste flow in about 90% of the municipalities. In the other 10%, they have started recycling programs in their communities. In their case, a fourth collection is added each week: The recyclable materials (paper, cardboard, aluminum cans, glass and plastic containers) are collected in one stream and are transported to a materials recovery center. The separated products are transported to the recycling companies.

3.6.2. Landfills

There are only three operating authorized sanitary landfills in Santiago (Figure 3), all of which compete, at some level, for the reception of wastes:

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

Lomas Los Colorados and Santa Marta have their associated transfer station: at Quilicura and Puerta Sur, respectively. (Figure 3).

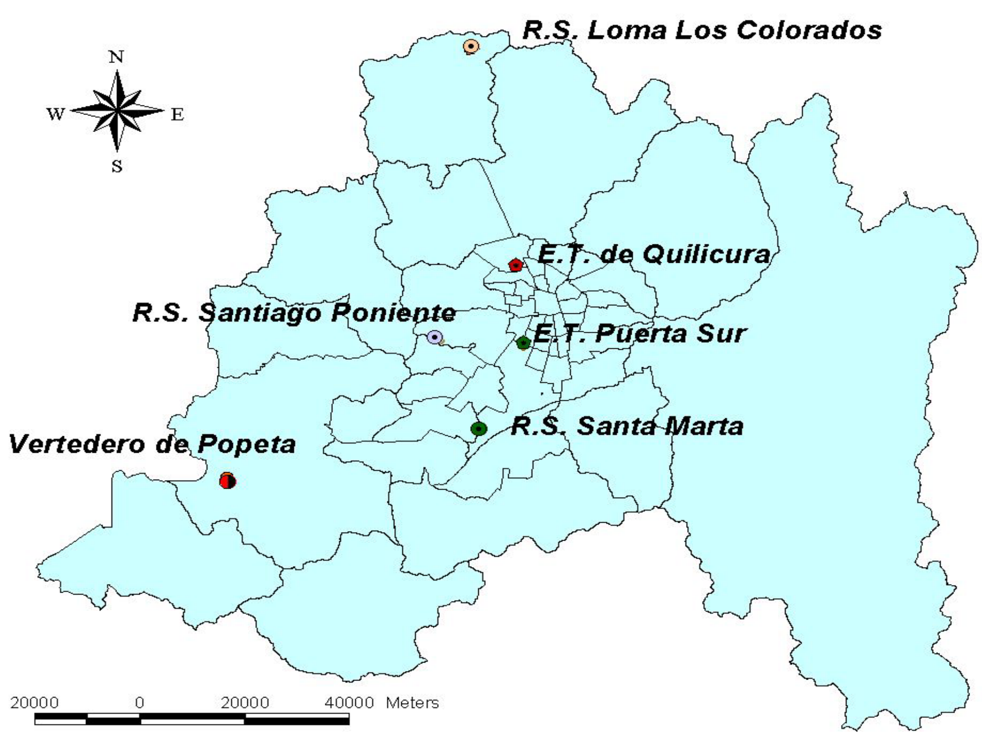

Figure 3: Locations of landfills in Santiago
(Source: SESMA, www.sesma.cl)

3.6.2.1. Loma Los Colorados

This landfill, managed by KDM S.A, is located in the Municipality of Til-Til (73 km north of Santiago). It is in operation since March 1996, covers an area of 800 hectares (240 hectares is used for the deposition of waste) and is expected to reach final official capacity in 2046[4]. 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 (i.e., it receives 60% of the total generation). The transfer station associated with this landfill, Quilicura, is also managed by KDM. In the transfer station the waste is compacted to a density of 0.55-0.60 ton/m^3 and then loaded in containers of 30-ton capacity to be transported by train to the landfill. The municipalities providing waste to Loma Los Colorados are: Cerro Navia, Colina, Conchalí, Curacaví, Huechuraba, Independencia, Isla de Maipo, La Cisterna, La Reina, Lampa, Las Condes, Lo Barnechea, Lo Prado, Maipu, Ñuñoa, Penalolen, Providencia, Pudahuel, Quilicura, Quinta Normal, Recoleta, Renca, San Bernardo, San Joaquín, San Miguel, Santiago, Til Til, Talagante, and Vitacura (1).

3.6.2.2. Santa Marta

This landfill, managed by Consorcio Santa Marta, 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 (77 hectares is used for the deposition of waste) and it is expected to reach final capacity in 2022. The transfer station serving this landfill, Puerta del Sur, is also managed by Consorcio Santa Marta. 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, Pirque, Lo Espejo, San Jose de Maipo, La Granja (1).

3.6.2.3. Santiago Poniente

This landfill, managed by COINCA, is located in “Fundo la Ovejería de Rinconada”, Municipality of Maipu. It started operations in October 2002 and is designed to receive 45,000 tons of MSW per month. This landfill covers an area of 300 hectares (77 hectares is used for the deposition of waste) and it is expected to reach final capacity in 2022, serving a population of 1,349,834 from the eastern central Municipalities of Santiago*:* Cerrillos, Estación Central, Pedro Aguirre Cerda, El Bosque, San Bernardo, Paine, Padre Hurtado, Peñaflor, Isla de Maipo (1).

3.7. Current MSW Management Costs

The service of collection, transport and final disposal of MSW is contracted out 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.

Relatively to Chile’s standard of living, the current MSW management costs are considered to be high. Since each municipality acts independently and negotiates its own price there is not a fixed price for this service, thus having a big range for the collection and disposal. For the collection, the cost varies between USD 10/ton and USD 25/ton and for the disposal of waste varies between USD 10/ton and USD 20/ton. The average cost

[4] According to the authors calculation it will reach full capacity by 2031. See section 4.3.

used, in further analysis, is for collection is USD 15 per metric ton and the average cost used for disposal USD15 per metric ton for (5), (7), (8), and (9).

Santiago has a tariff system that is independent of the amount of waste generated. Each person, as said before, has to pay through the property tax bill and this price is fixed and does not depend in the amount of waste generated. Therefore this system does not encourage generating less waste or even recycling.

3.8. Status of Recycling

Presently, it is not obligatory to separate recyclables from trash in Chile. As a consequence, there is little recycling consciousness among the citizens. 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).

Whatever sorting of recyclable materials is done 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 resells it to a handful of recycling companies (2). There is not a Materials Recovery Facility (MRF) where all the recycling materials are processed together.

Table 2 shows recycling statistics in the Metropolitan Region in metric-tons. It can be seen that from the year 2000 on, recycling rates have increased. Recycling of containers and plastic materials began only a few years ago.

Table 2: Recycling Statistics in The Metropolitan Region (metric-tons)

Year	Glass	Cans	Paper	Plastic	Containers (Tetra-Pack)	Household Scrap	Organics	Total Recycling	% Recycled
1995	891	-	2,000	-	-	-	-	2,891	0
1996	2,520	-	2,500	-	-	-	-	5,020	0
1997	3,600	770	3,200	-	-	10,896	-	18,466	1
1998	5,400	945	53,127	-	-	12,515	1,800	73,787	3
1999	7,851	1,050	61,673	-	-	16,362	7,112	94,048	4
2000	10,261	1,120	83,589	1,950	-	29,442	13,566	139,928	5
2001	11,869	1,120	132,579	1,620	200	31,153	17,432	195,973	8
2002	13,583	1,068	128,291	1,733	378	35,970	24,909	205,932	8
2003	13,341	1,029	131,453	12,890	392	42,152	28,111	229,368	9

Source: Induambiente Magazine, Vol 75, 2005

The government goal is that by 2020 recycling should account for 25% of the MSW generated (6). However, to reach that number, recycling must be mandatory and there should be an appropriate framework and regulations. Also, the public should be educated since, as mentioned above, there is not a recycling consciousness among citizens.

A study by the National Environmental Commission showed that the cost of recycling in Chile is less than the cost of final disposal into landfills, which should encourage further recycling (13).

Also, there are small pilot projects promoted by the National Environmental Commission, but volumes are insignificant. Still, some government authorities are trying to raise recycling consciousness through the use of collecting containers and household compost projects, encouraging recycling in public offices and universities, educational programs in schools, and training courses.

Three important recycling projects among big waste producers have been sponsored by the National Environmental Commission (6):

- Metropolitan Park: There are 35 recycling stations identified with different colors where cans, plastics and glass are collected.
- Public Offices: There are 60 public offices that are part of this project where it is estimated that in a year these institutions recover 160,000 kg of paper.
- Vega Central Market: This project consists in the separation and collection of all the organics products generated in near 1,000 locals in this fresh market. These organic products are a stock in an assigned place where it is later transported to a compost plant called “Catetito” in San Bernardo province.

As we noted above, the existing recycling is done by individual collectors. In some cases, municipalities have organized these collectors, trying to formalize their collection activities and improve their living conditions. One example of success is in La Reina Municipality.

<u>Case Study: La Reina Municipality </u>(12)

The municipality of La Reina, in Santiago, Chile, faced a significant social problem in the early nineties, related to the activity of some 1,500 informal waste collectors (cartoneros). At the same time this Municipality, which contains the city’s largest park area, had significant clean-up expenditures. To mitigate these elements, the municipality, together with a company in the waste management sector, took the initiative of organizing a system for the collection, separation and resale of recyclable products, especially paper, cardboard, glass and plastic. They decided to organize and “formalize” waste collectors, so that they could contribute in a better way to the collection and separation of recyclables.

The initiative consisted of organizing the activity by means of granting a permit to a company to install a collection center, providing the collectors (cartoneros) with a uniform and a container, and training them in the process of waste separation. The company signed an agreement with each cartonero establishing the price to be paid, fixed for a certain commodity but adjusted for inflation, by weight and type of waste received.

Thirty-three percent of the municipality’s families (24,000) participated in the recycling program, with an average collection of 84 metric-ton/months of marketed products. The greatest recovery rates were for plastic and paper, reaching nearly 40% of the total generated waste. Taking into account that about 40,050 metric-tons are disposed of yearly in the municipality of La Reina, the rate of recycled wastes reached on average about 2% of this total.

This is an example of a successful case study which other municipalities should follow.

3.9. Current and Future Policies and Strategies

As noted earlier, in Chile there is not a Solid Waste General Law (Ley General de Residuos). Only recently the “Policy for an Integrated Solid Waste Management” was published (January 2005), which recommends the development of a comprehensive solid waste management law.

This is needed because there is a legal vacuum, and therefore a lack of clarity in the responsibilities of each party involved in the waste management process and this generates juridical insecurity and lack of creation of new alternatives for waste management. It is suggested that there is an urgent need to legislate this area.

The Policy for an Integrated Solid Waste Management (PISWM) proposes the following seven objectives:

1. Minimize sanitary risks and environmental impact produced by the wrong disposal of wastes.
2. Generate and promote a quality and cost effective public service of municipal solid waste management at the municipality level.
3. Encourage a regional vision of municipal solid waste management.
4. Promote a waste minimization culture by developing an efficient and dynamic market for waste management
5. Encourage environmental education of citizens and generate a waste consciousness among them.
6. Build and carry out a solid waste information system.
7. Generate an efficient and modern institutional framework to oversee and coordinate solid waste management, for which a special executive office will be created.

For the fulfillment of these objectives the PISWM sets up lines of action and strategies to promulgate new norms as the following ones:

1. Landfill Norm
2. Sewage Sludge Norm
3. Waste Hospital Norm
4. Norm that regulates the cost of collection and final disposal of waste
5. Clarify the “Regulatory Plan for Santiago Metropolitan Region”, in the point that specifies the location of waste treatment plants.
6. Promote a Solid Waste General Law
7. Incineration Norm

Until now (May 2006) none of these norms have been promulgated.

The PISWM establishes a basic strategy that focuses on the following priority objectives regarding MSW: a) prevent MSW creation; b)minimize its creation; c) MSW treatment (presumably materials and energy recovery); and d) disposal of MSW that cannot be treated.

The PISWM also set the following guiding principles:

- 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.
- 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.
- Make an effort to reduce solid waste at its origin (industries, house holds, hospitals)
- As much 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.

4. Waste-to-Energy

4.1. Overview

Worldwide, over 130 million tons of MSW are combusted annually in over 600 WTE facilities that produce electricity and steam for district heating, recover metals for recycling, and substantially reduce the volume of waste that is finally disposed (14).

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 1.43 barrels (190 liters) of fuel oil per ton. In this process a sophisticated air pollution control system is used to remove particulate and gaseous pollutants before the process gas is released into the atmosphere (14).

Trash volume is reduced by 90% and the remaining residue is regularly tested and consistently meets strict Environmental Protection Agency (EPA) standards allowing reuse or disposal in landfills. The combined bottom and fly ashes amount to 20-25% of the weight of the original MSW (15).

A typical WTE plant comprises the unit functions and processes shown in Figure 4. The components of the unit functions and process are briefly described as follows:

- *storage pit* for storing and sorting the incoming refuse
- *crane* for charging the combustion box

- *furnace* or *combustion chamber* consisting of bottom grates on which the combustion occurs
- *heat recovery system* of pipes in which water is turned to steam
- *ash handling system*
- *air pollution control system (APC)*: electrostatic precipitators or baghouse filters for physical removal of dust and some heavy metals; additional chemical flue gas cleaning in dry/semidry scrubbers followed by fabric filters or wet scrubbers for washing/spraying the flue gas (16).

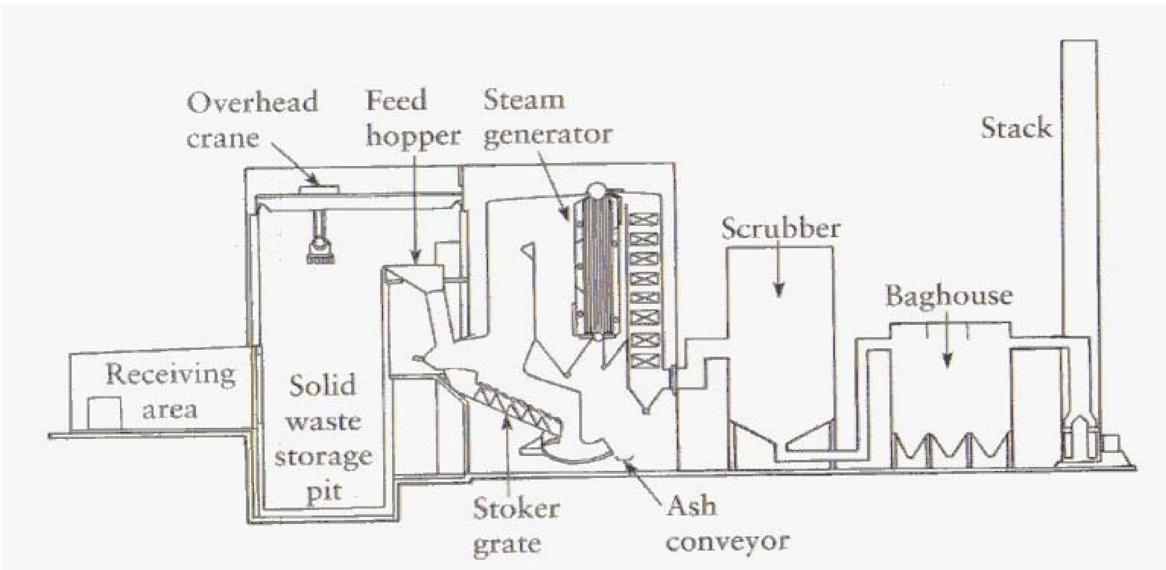

Figure 4: A typical Waste-To-Energy Combustor

The heart of the WTE process is the combustion chamber in which the MSW is introduced and reacted with oxygen at high temperatures. In most units the refuse is moved through the combustion chamber on a moving grate. The function of the grate is to move the refuse through the combustion chamber while an air stream (underfire air) is introduced through the slowly moving bed through openings in the grates. The underfire air both assists in the combustion as well as cools the grates. The control of underfire air is also the most important variable in maintaining a desired operating temperature in the combustion chamber. Most WTE plants operate in the range of 980 to 1090 °C, which ensures good combustion and elimination of odors, and is still sufficiently low to protect the refractory materials lining the combustion chamber. The temperature within the combustion chamber is critical for successful operation. If it is too low, then combustion may be incomplete.. Above 1090 °C, the refractories in the furnace will have a short life. Thus the window for effective operation is not large, close control needs to be kept on the charge to the combustion chamber and the amount of underfire and overfire (secondary) air (15).

4.2. Waste-to-Energy as a Renewable Source of Energy

Waste-to-energy has been recognized by the U.S. Environmental Protection Agency (EPA) as a clean, reliable, renewable source of energy (17). In addition, the combustion of municipal solid wastes for generating electricity has been recognized by several US states as a renewable source of energy. The search for renewable energy sources is motivated by the desire to reduce use of fossil fuels.

In the traditional sense, renewable sources of energy are those that nature can replenish, such as waterpower, windpower, solar radiation and biomass (wood and plant waste). However, MSW contain a large fraction of paper, food wastes, cotton and leather, all of which are renewable materials under proper stewardship of the Earth.

At this time, the US Department of Energy (DOE) categorizes WTE as one type of biomass, as shown in the following definition: *The term biomass means any plant derived organic matter available on a renewable basis, including dedicated energy crops and trees, agricultural food and feed crops, agricultural crop wastes and residues, wood wastes and residues, aquatic plants, animal wastes, municipal wastes and other waste materials.*

The objective of renewable status legislation is to provide an economic incentive that encourages the development of alternative energy resources in order to reduce the environmental impacts resulting from the extraction and combustion of fossil fuels. WTE provides this environmental advantage, because, on the average, the combustion of one ton of MSW produces electricity equivalent to 0.3 tons of coal or one barrel of oil.

4.3. Waste-to-Energy for Santiago

WTE is the only renewable energy source to offer an additional environmental advantage: the avoidance of the environmental impacts of landfilling of MSW.

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 and confronted public demonstrations that have affected their normal operations. New landfill developments are likely to face greater challenges. On top of this, the increasing spread of urban areas and its geographical location makes land in Santiago scarce (Figures 5 and 6). As a consequence, there will be not enough space for more landfills around the city in the coming decades. It is expected that the present landfills will be filled within the next 20 to 40 years (2).

Figure 5: Map of Santiago, Chile

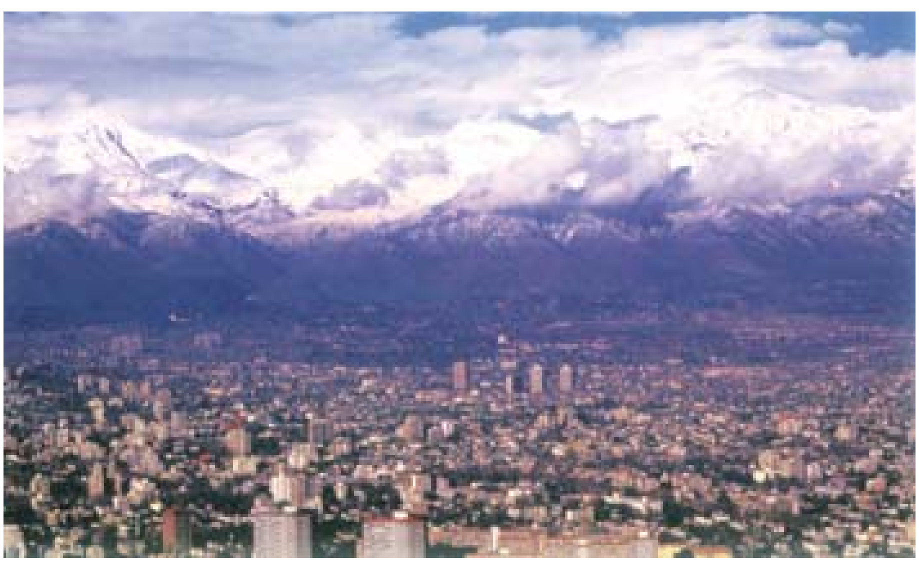

Figure 6: A View of Santiago with The Snowed Andes in the Background

According to the author's calculations, at the current rate of waste growth (average of 3.5%), using a density for waste of 0.7 tonne/m^3 and assuming that the landfill will be filled to the average height of 45 meters (maximum achievable for sanitation landfills), Lomas Los Colorados, Santiago's largest landfill (240 hectares for waste disposal), will reach full capacity by the year 2031, 15 years earlier than expected. See figure XX. Based on the same calculations, Santa Marta and Santiago Poniente landfills will reach full capacity by years 2026 and 2022 respectively, very close to their stated useful life. Where will Santiago's waste be disposed in 20 years from now?

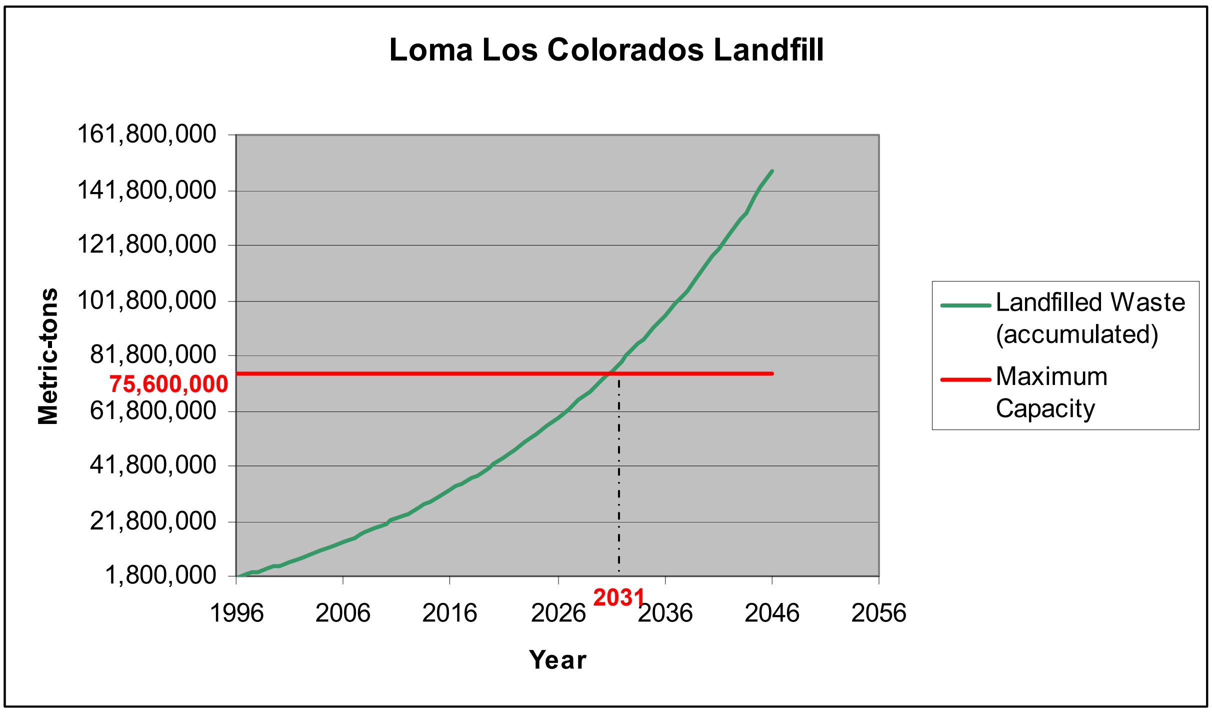

Figure 7: Year in Which Landfill Loma Los Colorados Will Reach Maximum Capacity.

In terms of environmental impacts, for every ton of MSW landfilled, greenhouse gas emissions of carbon dioxide increase by an estimated 1.2 tons (14). Also, 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.

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. In consequence, accumulation of such a large volume of waste for long time is dangerous for the environment. Therefore, there is an urgent need to investigate new waste management technologies such as Waste-to-Energy.

5. Cost-Benefit Analysis of a Waste-to-Energy Plant for La Florida and Puente Alto Municipalities

5.1. Description of The Project

In view of the demonstrated advantages of WTE over landfilling in other nations, it is worthwhile to examine the economics of the first WTE in Chile. It will be assumed that the most suitable location for the first Chilean WTE is at a site where it will serve the municipalities of La Florida (400.000 inhabitants) and Puente Alto (600.000 inhabitants) in Santiago, Chile. These two municipalities were chosen for several reasons: They are the most populous in Santiago and consequently they are the ones that produce more waste, currently generating a total of 24.000 tons per month. Both of them dispose their MSW at the same landfill, Santa Marta, located in Talagante (12 kilometers from the center of Santiago), and they are situated next to each other in the southern part of Santiago. Nearly 74% of the population of these municipalities consists of middle income families; low income families represent 20% (8), (9). Figure 5.1 shows the location of these municipalities in Santiago Metropolitan Area.

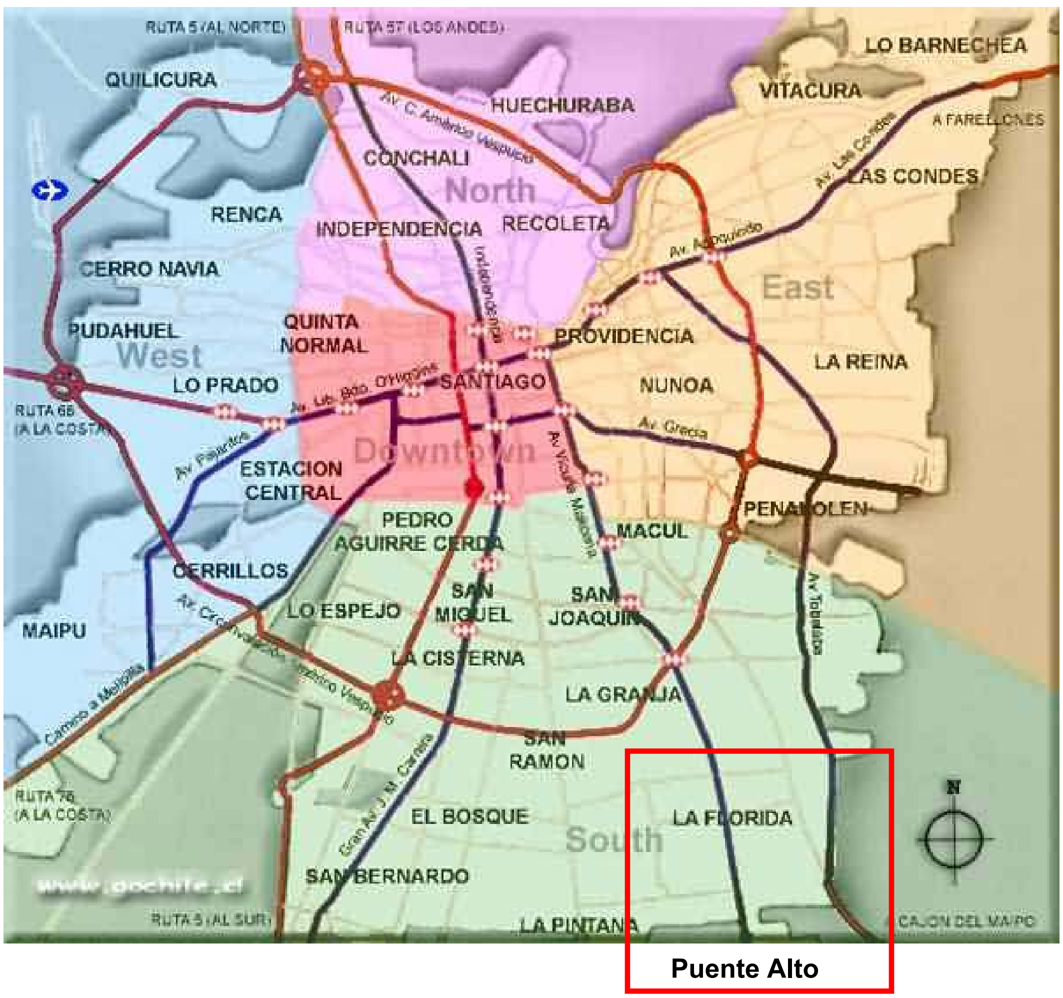

Figure 8: Santiago Metropolitan Region Area
Rectangle shows the location of La Florida and Puente Alto boroughs.

In January 2006 the author interviewed the Directors of the Department of Sanitation of both municipalities, concluding that both municipalities are experiencing severe waste disposal problems. They are not satisfied with their present waste disposal contracts, and the monopolistic condition of their current waste disposal arrangements. Both municipalities are spending a large fraction of their budgets on waste disposal and both are willing to explore other options. Therefore, there is an opportunity to look at new alternatives for waste disposal. A WTE plant offers the possibility to efficiently address these problems for these communities and eventually for the surrounding municipalities.

The tool to be used to assess the economics of a WTE plant for these two municipalities is a Cost-Benefit Analysis (CBA). CBA is a standard method of comparing the social cost and benefits of alternative investments projects. Costs and benefits are measured and then weighed up against each other in order to generate criteria for decision-making. Typically one or more of three decision criteria are used:

- Net Present Value (NPV)
- Internal Rate of Return (IRR)
- Benefit-Cost Ratio (BCR)

A project is deemed to be acceptable if the NPV is positive, or if the IRR exceeds the applicable discount rate, or if the BCR exceeds one.

In making this analysis, it is necessary to analyze the impact on possible stakeholders, and then delve into the non-quantifiable impacts and the opportunity costs on the basis of certain assumptions. Next, it is essential to d monetize the costs and benefits associated with the project, and conclude with a formal cost-benefit analysis including the selection of the discount rate. The final section of this chapter describes the results of a sensitivity analysis on the effect of changes in some important parameters.

5.2. Stakeholders and Secondary Market Effects

When considering the construction of a WTE plant, there will be different stakeholders affected by the change made to the current waste management system. The relevant stakeholders are the government, authorities, the waste sector, community groups, and the energy sector. The possible stakeholders and interest groups are shown in Table 3.

Table 3: Stakeholders for Construction of a WTE Plant in Santiago

Stakeholder	Stakeholder interest	Possible stakeholder influence
National Environmental Commission	The project requires an environmental impact assessment	Termination, delay, or change of the project
Environmental Health Department	The waste is managed properly (odors, noise, etc) and air emissions of the plant meet the emissions regulations	Termination, delay, or change of the project
La Florida Municipality	Have an economically competitive alternative to waste disposal	Supply waste to the plant and payment for waste disposal
Puente Alto Municipality	Have an economically competitive alternative to waste disposal	Supply waste to the plant and payment for waste disposal
Ministry of Energy	Look for new alternative energy options and regulate the energy price	Regulate energy price – Incentives for clean energy
Santiago Government	Social Health Benefit	Approve or disapprove the project
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	Project may lead to work opportunities. Negative impacts: traffic, odor, visual impact, etc.	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 companies	Wish to maintain or expand their business	New requirements for sorting, containers and vehicles
Energy Producers	Current energy producers prefer few energy suppliers and higher energy prices	Energy production at lower prices than the ones offered by WTE plant may crowd out energy demand, leaving no buyers for energy output
Buyers of electricity generated by WTE	More energy available at the lowest possible price	Provide income stream to offset costs of investment
Waste disposal facilities (Landfills in Santiago)	Wish to receive more waste	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

Secondary Market Effects

The introduction of a WTE plant will produce an increase in the supply of waste disposal capacity, measured in metric tons/year, thereby affecting the market equilibrium of waste disposal.

The demand for waste disposal (D) could be considered highly inelastic, because all produced waste (q_1) has to be disposed, even at very high prices. In this scenario, the lesser the supply of waste disposal options, the higher the price. This is the current situation in the market of waste disposal in Santiago, due to the lack of other options, for these two municipalities, than the current Santa Marta landfill, which in fact acts as a quasi monopoly.

Figure 9 shows that the increased supply (supply shifts to the right, from curve S_1 to S_2) will create a new equilibrium point at a lower price level (P_2). The extent of the price change will depend on the elasticity of the supply curve, which was not estimated for this analysis. The demand curve remains the same for the purpose of this exercise (eventually demand for waste disposal grows over time as population grows). The new equilibrium point is total waste disposed (q_1) at the new price of P_2.

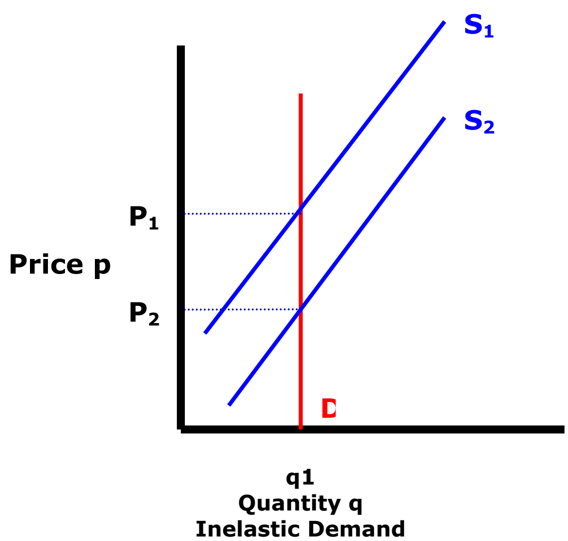

Figure 9: Secondary Market Effects of Introducing a WTE Plant

5.3. Non-Quantifiable Impacts

The cost benefit analysis of any project would not be complete without understanding the socio-cultural and environmental impacts of the project, though small and unquantifiable they may be. WTE is a waste management facility that is considered a renewable energy technology. Any means of energy production and waste management impacts the environment in some way, and WTE is no different. The magnitudes of many of these impacts are very subjective and depend on the specific tests employed. The following sections describe some of these environmental, social, and economic impacts.

5.3.1. Environmental Impacts

Odor

The combustion process destroys all odor-emitting substances in the waste, and the slag and fly ash are sterile and odorless after cooling. WTE plant odor is thus emitted mainly from handling and storing waste before combustion. The main sources are the unloading activities and the waste storage pit. To avoid emitting foul air into the environment, the tipping floor, where trucks drive in to discharge their load into the waste pit, and the feed hopper of the combustion unit are totally enclosed and the entire building is under draft (negative pressure) so that no air can escape to the outside atmosphere, even when the doors through which the trucks drive into the tipping floor are open. The air drawn by the draft fans is used as the combustion air in the WTE unit. Because of this inherent feature of the process, there are no odors escaping the WTE building, such as one encounter in the transfer stations of Santiago or near landfills. The odor in WTE plants is not an issue (19).

Noise

Truck traffic in and out of the WTE is the greatest source of noise pollution resulting from WTE plant operations. Well maintained and responsibly operated trucks will help minimize this problem. Local ordinances may restrict truck traffic to certain hours of the day and to specified truck corridors. Under these conditions, noise pollution should not be a significant factor. Equipment inside the plant generates some noise but due to the fact that all equipment is fully enclosed in the WTE building, visitors cannot hear it when they are outside the building.

Reducing the Waste Up To 90%

An environmental benefit of the WTE is the reduction of the waste by 90 % of the volume, therefore only 10% of the volume needs to be landfilled in the form of ash (13).

Air Pollution

The most contentious issue regarding energy recovery from solid wastes is that of emissions to the atmosphere due to the combustion process. Emissions of Particular Matter (PM), mercury, hydrochloric acid, and dioxins have been the most worrisome problems in the past. However by the end of 20^{th} century, emissions in modern WTEs were reduced to extremely low levels by means of reduction of precursors in the feed (e.g. mercury containing products), better combustion practices, and greatly improved gas control systems that include dry-scrubbing, activated carbon injection and filter bag collection system (20). For example, Table 4 compares air emissions of a typical WTE facility with the current EPA standards (2).

Table 4: Comparison of 1999 Emissions from SEMASS No. 3 Unit with EPA Standards

Emission	EPA standard[1]	SEMASS[2]
Particulate (gr/dscf)	0.010	0.002
Sulfur Dioxide*	30	16.06
Hydrogen Chloride*	25	3.6
Nitrogen Oxides*	150	141
Carbon Monoxide*	150	56.3
Cadmium**	20	1.24
Lead**	200	30.03
Mercury**	80	5.09
Dioxins/Furans (ng/dscm)	30	0.86

gr/dscf: grains/dry standard cubic foot; *ppmdv:parts per million dry volume; **μ/dscm: microgram per dry standard cubic meter; ng: nanogram
[1]The standards and data are reported fot 7% 0_2, dry basis, and standard conditions.
[2]Average of 1994-1998. Boiler N^{0}3.

Diesel Emission Reduction

Since WTE plants require little space, relatively to landfills, and do not emit odors, they can be located close to the municipalities they serve. This will certainly reduce truck travel which in turn will decrease diesel emissions to the atmosphere. Diesel engines contribute to a substantial portion of the Nitrogen Oxides (NO_x), PM, and hydrocarbons (HC) emissions from mobile sources. NO_x reacts with HC and sunlight to form ground-level ozone (smog). With the reduction of diesel truck travel, threshold be a significant reduction in generated smog.

Clean Energy Production

Considering the overdependence on fossil fuel based energy, Chilean government at all levels have encouraged diversification of the energy supply. WTE as explained in Section 4.2 is considered a renewable source of energy. WTE, in alliance with other renewable energy sources, can play an important role in developing a portfolio of clean energy production for Chile.

5.3.2. Economic Impacts

Real Estate Values

Historically in Chile, traditional waste disposal facilities have faced opposition by local neighbors and residents due to the negative impact such facilities have on the price of real state. However, a WTE plant could be used as a way to improve the host area and increase rather than decrease its land value. In selecting the site for the new WTE plant, it is advised to select a site that was an old industrial plant or transfer station, or what is known in the US as a "brownfiled". The objective of the designers of the WTE should be to find such a brownfield and then design the plant, architecturally and environmentally, to better the previous conditions.

Employment

Any new construction of an industrial plant will generate employment in the construction process and further in the operation of the plant. Permanent employees will be around 60 and temporary employees (construction process) will the in the order of 200.

5.3.3. Social Impacts

Land Use

The "not in my yard expression," is commonly used for communities affronting a possible construction of a waste disposal facility. The location of a WTE plant will certainly produce protests of the community near by. Because a WTE will be located within Santiago, there would be no need for the waste transfer station that serves the current landfill. In fact, as mentioned, the new WTE may be located on the site of an old brownfield and improve the neighborhood.

Aesthetic Value

Negative aesthetic impacts can be prevented or minimized by proper site landscaping and building design. However, site selection and innovative design can change perceptions. Figure 10 and figure 11: Brescia, Italy WTE facility (before and after the construction of the plant) shows how a WTE plant can be used to improve the aesthetic value of a community. Visible steam or vapor plumes can be emitted by some facilities and this is also a negative aesthetic value impact for the community living near.

Figure 10: WTE Site before Construction

Figure 11: WTE Facility in Brescia after Construction

Traffic

As was noted in the "noise impact" point, a WTE facility will increase the traffic truck in the surrounding area of its location. Local government should plan an organized transport system in order to minimize the surrounding traffic and may restrict truck traffic to certain hours of the day and to specified truck corridors.

Table 5 and 6 summarize the environmental, social and economic impacts that need to be taken into consideration in any WTE project assessment and that could not be monetized for this analysis. Nevertheless, their magnitude has been scored based on subjective analysis and literature review.

Table 5: Non-Quantifiable Costs

Kinds of costs/impact	**Nature of costs**	**Major stakeholders**	**Scores**
Environmental	Odor	Neighborhood	**--**
	Air pollution	Environmental Health Department	**----**
	Noise	Neighborhood	**--**
Social	Land Use	Community groups, neighbors, Environmental NGOs	**----**
	Aesthetic value	Community groups and nearby citizens	**-**
	Traffic	Neighborhood	--
Economic	Real estate value	Neighborhood	--

Key: Significant cost ---- Some cost -- Insignificant cost -

Table 6: Non-Quantifiable Benefits

Kinds of benefit	Nature of Benefits	Major stakeholders	Scores
Environmental	Reducing the waste up to 90%	National Environmental Commission	+ +++
	Clean Energy Production	Ministry of Energy	++
	Diesel Emission reduction	Environmental Health Department	+ +++
Social	Aesthetic value	Community groups and nearby citizens	+
Economic	Employment	Manufacturers of wind turbines, people seeking employment, Government	+ +

Key: Significant benefit ++++ Some benefit ++ Insignificant Benefit +

5.4. Assumptions

5.4.1. Technology

5.4.1.1. Available Technologies

Municipal Solid Waste Combustion systems are mostly characterized as either Mass Burn units or Refuse-Derived Fuel (RDF) units. A third technology is Fluid Bed units.

i. Mass Burn Technology

A mass burn unit does not pre-process the solid waste prior to feeding into the combustion unit. Trucks carrying MSW empty their load into a large totally enclosed chamber. An overhead “claw” crane scoops material and deposits it at the feed end of a moving metal grate that moves the waste material slowly through the combustion chamber. Many WTE operators favor this technology process because it does not require pre-processing of the feed and is relatively simple operation. However, the rates of heat, mass transfer, and combustion of the large bags deposited on the grate are relatively low and a large combustion chamber is required. The temperatures generated in the combustion chamber are in the order of 900°C (16).

This is the most common and dominant WTE technology in the US, and other developed countries. The most widespread grate technology is developed by Martin GmbH (Munich, Germany) and 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 (13).

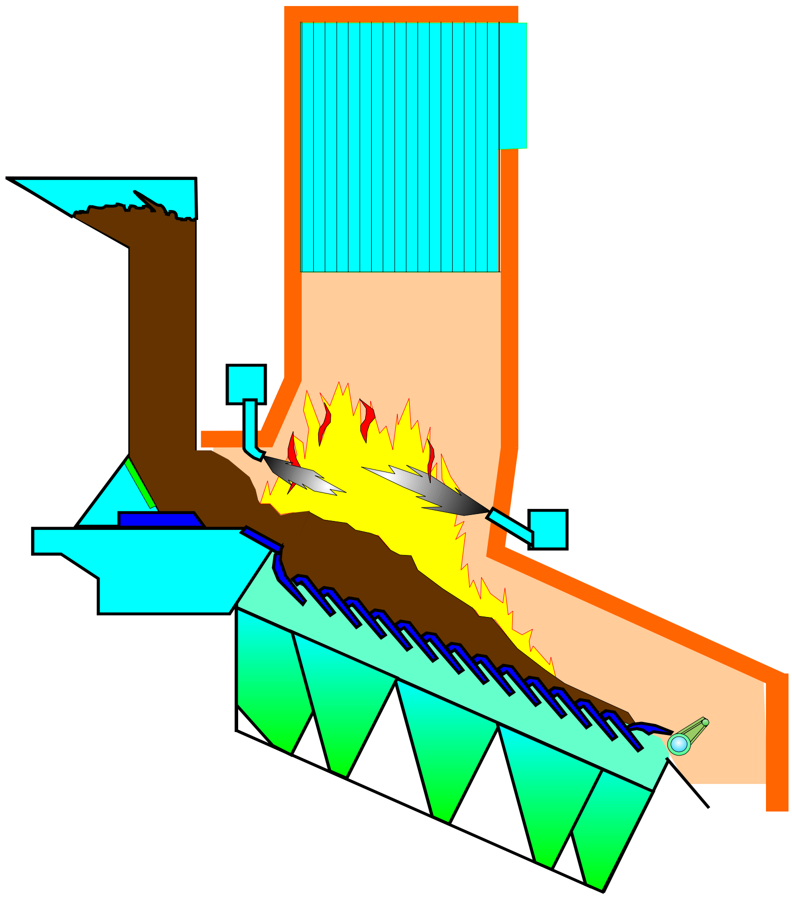

Figure 12: Schematic Diagram of the Mass Burn Technology

ii. Refuse Derived Fuel (RDF) Technology

In a RDF system, the solid waste is processed prior to combustion to remove non-combustible items and to reduce the size of the combustible fraction, thus producing a more uniform fuel at a higher heat value. The processing generally entails separation of inert materials, size reduction, and densifying (e.g. pelletizing). This allows for the removal of both recyclables and hazardous materials. The RDF is fed through a rotary feeder and injected into the combustion unit above the grate. Some combustion takes place above the grate with the remaining combustion occurring in the grate (16).

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 13 (13).

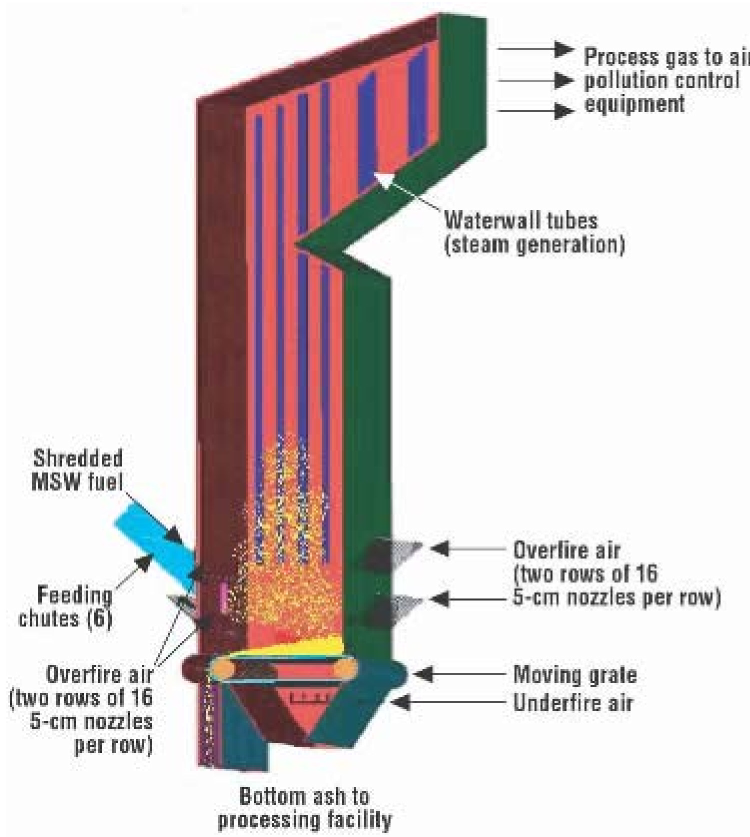

Figure 13: Schematic Diagram of the SEMASS Process at Rochester, Massachusetts, USA

The advantage of an RDF plant is that the heat value of the fuel is more uniform and thus the amount of the excess air required for combustion is reduced. The amount of combustion air used is important because if there is insufficient oxygen in the combustion chamber, a reducing atmosphere is created which leads to corrosion problems. For RDF systems the excess air is about 50%, while in mass burn plants, because of the large variation in fuel value between items, about 100% excess air is needed. While there appear to be several theoretical advantages of RDF over mass burn plant, they have had their share of operating problems. Processing of solid waste is not easy, and RDF plants have encountered corrosion and erosion problems (15).

iii. Fluidized-Bed WTE Plants

Combustion of MSW in fluidized bed reactors is used extensively in Japan. This method requires shredding (to -5cm) and removing inert materials like glass and metals from the feed to the fluid bed reactor. The remainder is fed on top of a fluidized bed of sand or limestone. Combustion under these conditions is very efficient and results in even temperatures and higher energy recover, lower amounts of non-oxidized materials leaving the combustion chamber, and less excess air than mass burn plants. Fluidized-bed combustors operate at temperatures in the range of 830°C - 910°C and can use additional fuel as required so that they can burn materials with very high moisture content. Because of the lower uniform temperatures, “slagging” and corrosion problems in the furnace are kept to a minimum. On the other hand lower temperatures result in the high NO_x levels and thus an additional dry scrubber is required in addition to the limestone fed into the bed (19).

A main disadvantage of the fluidized bed is that it requires pre-treating of the waste before the fluidized bed so that it meets the rather stringent requirements for size, calorific value, ash content, and so forth. Because of the heterogeneous composition of MSW, it can be difficult to produce a fuel that meets the requirements at any given point (16).

5.4.1.2. Selecting the Appropriate Technology

As mentioned in section 3.8, Santiago lacks a regulated system of trash separation at its origin. The WTE facility will receive black bags without preprocessing of solid waste. For this reason, the most appropriate technology for Santiago is the mass burn plant since no pre-processing is necessary apart from the removal of bulky items like “white goods” (large appliances). Also mass burn plants are easier to operate and install than RDF (with RDF facilities, operators generally have more difficulties). This is something to consider since the WTE plant for Santiago will be the first one in South America. 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. At the moment there is a huge problem with the treatment of sewage sludge residues in Santiago, so this WTE plant could also be a solution for that subject. Furthermore, 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.

Within the mass-burn category, the Martin Reverse-Acting Grate technology was selected with a capacity of 1000 metric tons/per day (330,000 metric tons/per year). The capacity was chosen to receive all of the residential and commercial waste generated in La Florida and Puente Alto Municipalities plus a 20% additional capacity.

Figure 14 is 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.

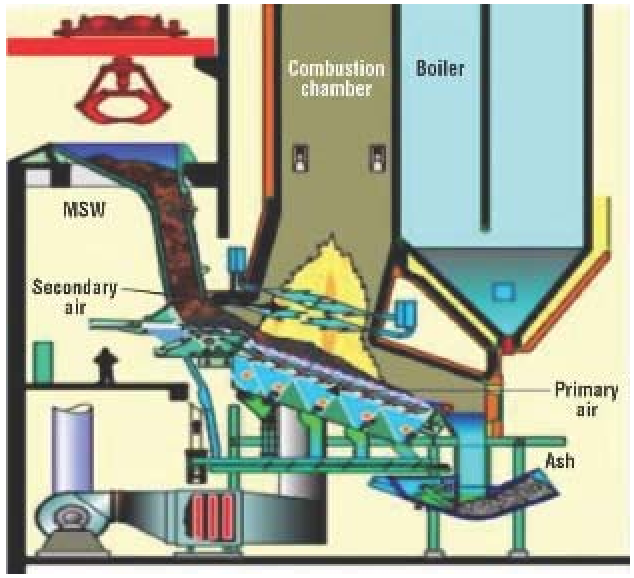

Figure 14: The Martin Grate Combustion System

5.4.2. Location

Land is one of the most vital resources used for any kind of enterprise, including WTE. Finding a site is one of the most difficult assumptions in this CBA since any new project involving a Waste Treatment Facility (WTF) could generate some protests from the community near by. Prior to considering a site it is necessary to educate the community to let them know that WTE is not a landfill and that a WTE plant will be comparable to a medium to heavy industry in its environmental impact, potential public nuisances, transport network requirements, and other infrastructure needs.

The legal norm for sitting a WTE plant is called “Regulatory Plan for Santiago Metropolitan Region”, August 2005 (Plan Regulador Metropolitano de Santiago). The purpose of this document is to regulate and organize the territorial use and design plan of the city and to promote the development of it. In this regulation, Article 7.2.3.3 on Thermal Treatment Plants establishes:

- A WTE facility is considered an industrial type of plant.
- Can be located inside or outside the Santiago Metropolitan Region.
- The location should be in land uses dedicated for medium or heavy industry and/ or exclusive zones for manufacturing activities.
- The facility should be at least 40m from residential zones from the outside perimeter of the plant.

Another important input for sitting the plant is that, as noted before, at the present time both Municipalities transport their waste to the Santa Marta’s transfer station “Puerta del Sur” that is located 23 kilometers from the market square in Puente Alto and 14 kilometers from the center of La Florida Municipality. Therefore these are set as the limits of the area within the WTE should be located. The plant should not be further away than the existing transfer station.

Since there are no WTE plants in Santiago, there is not a specific norm for them. There is a new Norm for Incineration (2006) but does not state anything regarding the location of future plants and basically refers to combustion of wood (biomass).

The current legal Regulatory Norm is vague and insufficient with regard to locating a Waste Treatment Facility. As discussed in Section 3.9, one of the future norms to be promulgated will concern the location of Waste Treatment facilities.

5.4.3. Energy Generation

The potential energy production and income from energy sales depend heavily on the energy content (net calorific value) of the waste. The amount of energy or heat value in an unknown fuel can be estimated by ultimate analysis, compositional analysis, proximate analysis and calorimetry. In this study, for the calculation of the calorific value, after reviewing all the methods it was estimated that for the case of Santiago the "compositional analysis" was the best method to be used. It is not part of this study review each of these methods. For more information please look at references. This method was used because the exact composition of solid waste was known.

Moisture in MSW decreases the available heat for combustion in WTE plants that produce electricity. For example food wastes contain about 70% moisture and their calorific value is only 4,647 kJ/kg Table 7 shows the average percent composition of the MSW in Santiago and the heat value of each component.

On the basis of these data, the estimated heating value for Santiago's MSW is 9,500 kJ/kg.

Table 7: Heating Value of MSW in Santiago

Material	Composition %	Heat value (kJ/kg)
Food Wastes	49.31	4,647
Yard Wastes	4.83	6,506
Plastic	10.43	32,531
Paper	10.02	16,730
Cardboard	3.3	16,266
Beverage and milk boxes	0.72	15,800
Rubber and Leather	0.11	21,387
Textiles	2.01	17,445
Glass	3.51	0
Metal	1.59	0
Wood	0.71	18,590
Dirt, Ashes and other fines	4.07	6970
Miscellaneous*	9.39	4000
Calculated heating value of Santiago MSW	**100**	**9,490**

*Batteries, styrofoam, diapers, dross

Source: Solid Waste Engineering, P. Vesilind, W. Worrell, D. Reinhart

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 that the Martin Grate WTE will produce 720 kwh/metric ton of MSW. Out of this energy output, 600 Kwh/metric ton will be sold commercially, and the rest will be used internally for the plant operation (20).

The minimum calorific value required for a WTE plant to operate without additional fuel is 7,000 kJ/kg. The average calorific value found in Europe and North America is in the range of 9,000 to 13,000 kj/kg (18).

5.4.4. Subsidies and Incentives for Producing Clean Energy

There are some government subsidies and grants for research and development of clean energy technologies. In July 2005, the National Commission of Energy (CNE) and The Chilean Economic Development Agency (CORFO) provided basic subsidies for the research and development of projects for the generation of clean energy electricity. In April 2006 a second announcement was made for the bidding of funds to co-finance Pre-Investment Studies or specialized consulting for the pre-investment stage. These subsidies could amount up to USD 50.000.

However, for the purposes of this study, the basic scenario analysis will not take into account subsidies from the government.

5.5. Monetizing Costs and Benefits

5.5.1. Monetized Costs

5.5.1.1. Investment

The capital cost of the project 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.

i. Building Costs

Calculating the investment cost was a difficult task. As noted before there are no modern WTE plants in South America. The general contractors of Martin Grate technology for the US and Mexico is Covanta Energy Corporation and as for today there is not a representation for South America. Consequently, the following assumptions were made:

1. A cost of construction in the U.S. of US$150,000 per daily short tons of capacity of MSW (15).
2. 70% of the costs of equipment and building construction are procured at Chilean costs and 30% at U.S.' costs (20).
3. The plant operates 330 days per year (20).
4. 1 USD = 530 Chilean pesos (CHP)

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

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

The cost of building an industrial plant in Santiago, in steel structure, is US$165/ m2 (22). The cost of building an equivalent industrial plant in Washington (US) is USD 579/m2. (23)

Chilean cost : US $ 165/m2

US cost : US $ 527/m2

Conversion factor: Chilean Cost / U.S. cost = 0.3131

Therefore, the cost of equipment and construction of a Waste-to-energy plant in Santiago is:

- 0.7 x USD150,000 per daily ton of capacity x 0.3131 = USD32,876
- 0.3 x USD150,000 per daily ton of capacity = USD45,000

=> USD 77,876 per daily ton of capacity (short tons)

Consequently, the cost of construction a WTE plant in Santiago is approximately US$85,664/per daily metric ton of capacity. Therefore, for the required capacity of 1000 metric ton/day, the estimated capital cost is USD 85.7 million.

This is a preliminary calculation of the building costs and in the case of a real project a more detailed cost study is needed.

ii. Land

The Martin Grate WTE is projected to be located in an industrial area near the Municipality of La Florida and Puente Alto. The plant will be placed in an area of 15 acres = 60,703 m2 = 6 hectares.

The Cost of 1 m2 in the industrial area in Puente Alto is 1.1 UF[5] (23) = CHP 17, 924.92 = USD 33.82.

Total Land Cost = 60,703 m2 x USD 33.82 = USD 2,053,012

5.5.1.2. Operational Costs

The components of the operational costs are: labor, material supplies, maintenance and ash disposal.

i. Labor

The plant will have as permanent workers the following:

[5] UF is an inflation adjusted unit of money used mainly in business and formal financial transactions that involve large sums and was created at a time when inflation was high. It is frequently used with rental contracts and buying and selling homes or businesses. The rate of the UF varies daily according to the monthly inflation rate of the previous month.

- 1 General Manager
- 4 Managers
- 2 Electricians
- 4 Mechanics
- 8 Plant Operators
- 5 Shift supervisors
- 30 General Workers

- General Manager CHP 5,000,000/month = USD 9,434 per month (24)
- Managers CHP 3,500,000/month = USD 6,604/ month

  : 4 x USD 6,604 = USD 26,416/month (24)
- Electricians CHP 1,500,000 = USD 2,830/ month

  :2 x USD 2,830 = USD 5,660/month (24)
- Mechanics CHP 1,000,000/month = USD 1,887/month

  :4 x USD 1,887 = USD 7,548/month (24)
- Shift Supervisors CHP 1,000,000/month = USD 1,887 / month

  :5 x USD 1,887 = USD 9,435/month (24)
- Plant Operators CHP 800,000/ month = USD 1,509 / month

  :8 x USD 1,509 = USD 12,072/month (24)
- General Workers CHP 400,000/month = US $ 755/month

  :30 x USD 755 = US$ 22,650 per month (24)

Total Labor Cost = US$ 93,215 per month = USD 1,118,580/year

ii. Material supplies

The cost of material supplies will be USD 4/daily metric ton (19).

1,000 metric tons x USD 4 x 330 days = US $1,320,000/year

iii. Maintenance

The maintenance cost comprises machinery and building maintenance. The maintenance cost will be 2% of the investment cost per year (19).

USD 85,664,000 x 0.02 = USD 1,713,280/year

iv. 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 (15). Approximately 10% of this ash is fly ash and this has to be disposed because of its toxic components; however bottom ash can be reused as road base material, cement blocks, asphalt or concrete applications. To dispose fly ash into sanitary landfills it has to be mixed with bottom ash in order to lower the toxicity in it. In this project evaluation it will be assumed that 70% of the ashes produced will be disposed into landfill, the rest being reused. Therefore ash disposal will be considered as a net cost.

For this project evaluation it is assumed that the plant will have an ash residue of 15%. As was discussed in point 3.7, the cost of discharge MSW into landfills is USD 30 per metric ton, which includes collection, transport and final disposal. The plant will process an approximate amount of 330,000 metric tons of waste per year (1,000 metric tons/day x 330 days).

- 0.15 x .70 x 330,000 metric tons per year = 34,650 metric tons of ash per year

The cost of landfilling this ash is: 34,650 metric tons x USD 30 per metric ton = USD 1,039,500/year.

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

Total Operational Cost: USD 5,191,480/year

5.5.2 Monetized Benefits

The cash inflows of the project are the electricity generation and the tipping fee paid by the municipalities.

5.5.2.1. Electricity Generation

As seen in point 5.4.4 the plant will produce 600 Kwh/metric ton to be sold commercially.

The price at which the net electricity is sold for to Santiago's Electric Distribution System is CHP 39.955 per kWh = USD 7.54 cents per kWh (25) (at an exchange rate of CHP 530 per USD). 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.

As mentioned, the plant will generate a net of 600 kwh/metric ton. Receiving 1,000 metric tons of MSW a day it will process 330,000 metric tons a year (1 year = 330 working days of the plant). Therefore, the plant will produce 600 kwh/metric tons x 330,000 metric tons per year = 198,000,000 Kwh/year. At a market price of USD 7.54 cents per kWh, the plant will have an income of **USD 14,929,200/year.**

5.5.2.2. Tipping Fees

For this CBA, it was assumed that the tipping fees that municipalities are paying now for the service of waste disposal is the cap that could be allocated to an alternative Waste-to-Energy disposal option. Table 8 shows the budget the municipality of Puente Alto and La Florida allocate to the service of final disposal into landfills.

Table 8: Cost of Collection and Final Disposal for The Municipalities Of La Florida And Puente Alto

Municipalities	MSW Generated (Ton/month)	Collection/Transport Cost		Final Disposal Cost (Landfill)		Total Cost	
		CHP/Ton	USD/Ton	CHP/Ton	USD/Ton	CHP/Ton	USD/Ton
La Florida	11.000	10,750	20.1	7,552	14.1	18,302	34.3
Puente Alto	13.000	7,871	14.7	8,300	15.5	16,171	30.3

(Source: La Florida and Puente Alto Municipality, January, 2006)

It will be considered only the final disposal (not the collection cost that will remain the same, even though the WTE plant will be nearest). The tipping fee used for this project is 7,420 CHP/ton = USD 14 per ton. Therefore, the municipalities will pay to the WTE plant 330,000 metric tons per year x USD14 = **USD 4,620,000 per year**

Total Benefits: USD 19,549,200 /year

5.5.2.3. 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.

5.6. Discount Rate

Calculating the discount rate is the key part in every CBA, therefore the discount rate will be used as a variable in the sensitivity analysis. There are two possible scenarios; one, is that the project is fully funded by private investment in Chilean pesos and a second scenario is that the project is entirely financed in US Dollars.

Case 1: The project is entirely financed by private investment in Chilean pesos. In this case the discount rate represents the opportunity cost of alternative private sector investment. The discount rate is equal to 9% (26), which is the available real interest rate in Chile for long term deposits in Chilean UF[6].

[6] UF is an inflation adjusted unit of money used mainly in business and formal financial transactions that involve large sums and was created at a time when inflation was high. It is frequently used with rental

Case 2: The project is fully funded by private foreign investment in dollars, then the discount rate is the current US discount rate of 7% (27) plus the Chilean premium risk that is currently 2% (28). Therefore the discount rate will be 7% + 2% = 9%.

Since both cases showed a discount rate of 9% that is the one chose for this project as the basic scenario.

5.7. Results

Having calculated the major cash flow components of the project -cash outflows (investment and operational costs) and cash inflows (energy generation and tipping fee), 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.

Several assumptions where made:

1. No inflation. All prices are expressed in US Dollars.
2. Corporate tax rate of 35% (29).
3. 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.

Table 9 shows cash flows, for a WTE plant for Santiago, associated with each inflow item (income) and outflow item (expenditures) for each period. 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 9%, is over USD 18 million.

Net Present Value = Present Value of Net Cash Flows – Initial Investment

(Years 1 to 30) (Year 0)

Net Present Value at 9% = USD 106,146,688 – USD 87,717,012

Net Present Value at 9% = USD 18,429,676

contracts and buying and selling homes or businesses. The rate of the UF varies daily according to the monthly inflation rate of the previous month.

Table 9 : CASH FLOW OF A WASTE-TO-ENERGY PLANT IN SANTIAGO, CHILE

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Cash Inflows														
Energy Sold		$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200
Tipping fee		$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000
Total Income **(2+3)**		$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200
Cash Outflows														
Investment														
Land	($2,053,012)													
Capital Investment	($85,664,000)													
Operational Costs														
Labor		($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)
Maintance		($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)
Material Supplies		($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)
Ash disposal		($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)
Total Expenditures **(4+5+6+7+8+9+10+11)**	($87,717,012)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)
Pre Tax Cash Flow **(3-12)**	($87,717,012)	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720
Depreciation		($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)
Pre Tax Profits **(13-14)**		$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253
Tax (35%)		($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)
After Tax Cash Flow **(13-16)**		$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931
Present Value	at 9%	$106,146,688												
Net Present Value at 9% (17-5-6)	**$18,429,676**													
Discount rate	9.0%													
Accumulated Present Value		$9,478,836	$18,175,016	$26,153,163	$33,472,563	$40,187,610	$46,348,203	$52,000,123	$57,185,371	$61,942,479	$66,306,799	$70,310,761	$73,984,122	$77,354,177
Discounted Payback Time	**17 years**	$9,478,836	$18,175,016	$26,153,163	$33,472,563	$40,187,610	$46,348,203	$52,000,123	$57,185,371	$61,942,479	$66,306,799	$70,310,761	$73,984,122	$77,354,177

14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200	$14,929,200
$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000	$4,620,000
$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200	$19,549,200
($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)	($1,118,700)
($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)	($1,713,280)
($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)	($1,320,000)
($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)	($1,039,500)
($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)	($5,191,480)
$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720	$14,357,720
($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)	($2,855,467)
$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253	$11,502,253
($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)	($4,025,789)
$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931	$10,331,931
$80,445,971	$83,282,479	$85,884,780	$88,272,213	$90,462,517	$92,471,971	$94,315,507	$96,006,824	$97,558,491	$98,982,039	$100,288,046	$101,486,218	$102,585,458	$103,593,935	$104,519,144	$105,367,959	$106,146,688
$80,445,971	$83,282,479	$85,884,780	$88,272,213	$90,462,517	$92,471,971	$94,315,507	$96,006,824									

These preliminary calculations demonstrate that a WTE Plant for Santiago, with a capacity of 1,000 metric ton/day, would be able to generate enough income -through energy sold and tipping fee- to have a positive Net Present Value. This indicates that the project should be done; the project generates more economic value than its investment and operational costs. The Internal Rate of Return is 11.3%.

In terms of its discounted payback, the number of periods in which the project pays its initial investment is 17 years.

5.8. Sensitivity Analysis

For the sensitivity analysis the tool used was "Crystal Ball." Crystal Ball is a software that performs Monte Carlo simulations in excel spreadsheets. Crystal Ball automatically calculates thousands of different "what if" cases, saving the inputs and results of each calculation as individual scenarios. Analysis of these scenarios reveals the range of possible outcomes, their probability of occurring and which input has the most effect on the model.

Four key variables were tested:

- Calorific value of the waste: As mentioned in point 5.4.4, the heating value of municipal solid waste varies a lot from season to season and even from different income levels. Different heating values have different electricity outputs. For the basic scenario 9,500 kJ/kg was used as calorific value. The sensitivity analysis was tested with the values seen in Table 10.

Table 10: Heating Value with Respective Energy Output

Heat value (kJ/kg)	**Net electricity output* (Kwh/ton)**
7,000	350
8,000	450
9,000	550
10,000	650
11,000	750

* This is considering the net electricity to be sold commercially
Source: Municipal Solid Waste Incineration, *Requirements for a Successful Project*, T. Ramd, J. Haukohl, U. Marxen, The World Bank, 2000.

- Discount rate: Since this rate is not exact and could fluctuate, a sensitivity analysis was made for different cases, in a range from 7% to 13%. The base scenario is 9%.
- Tipping fee: It was interesting to evaluate the option of charging less than the actual landfill or in the worst situation charging more. A sensitivity analysis was made from a range of USD 8 to USD 20. The base scenario is USD 14.

- Electricity price: Electricity prices in Santiago, which are closely tied to trends in natural gas cuts and wet or dry years[7], have increased by more than one-third since 2004 (30). Prices could continue to trend upward, particularly if there are continued natural gas cuts from Argentina. However, it is foreseen that Chile's majors utilities plan to build several hydroelectric plants and diversify its electricity generation sources so, may be in the future, electricity prices will drop again. Therefore it was evaluated the effect of both price increases and decreases, in the range of 5 ¢/Kwh and 12 ¢/Kwh. The base scenario is 7.54 ¢/Kwh.

Figure 15 shows the effect on the NPV of changes in any one of these variables, holding the rest constant at the base values. The chart shows that the project breaks even under almost every scenario.

The most surprising factor is the effect of tipping fee. The WTE facility could be cheaper than current landfills and the project still has a positive NPV.

With a higher discount rate of up to 11.3% we still have a positive present value.

Another important factor to considerer is the heating value of the waste. The sensitivity analysis showed that this variable is very susceptible to small changes in it in the NPV. The minimum heating value for the project to be positive is 8,500 kJ/kg (500 Khw/metric-ton as electricity generation) and this is not far away from the basic scenario 9,500 kJ/kg. As said before this value can vary a lot so this is something to take into consideration.

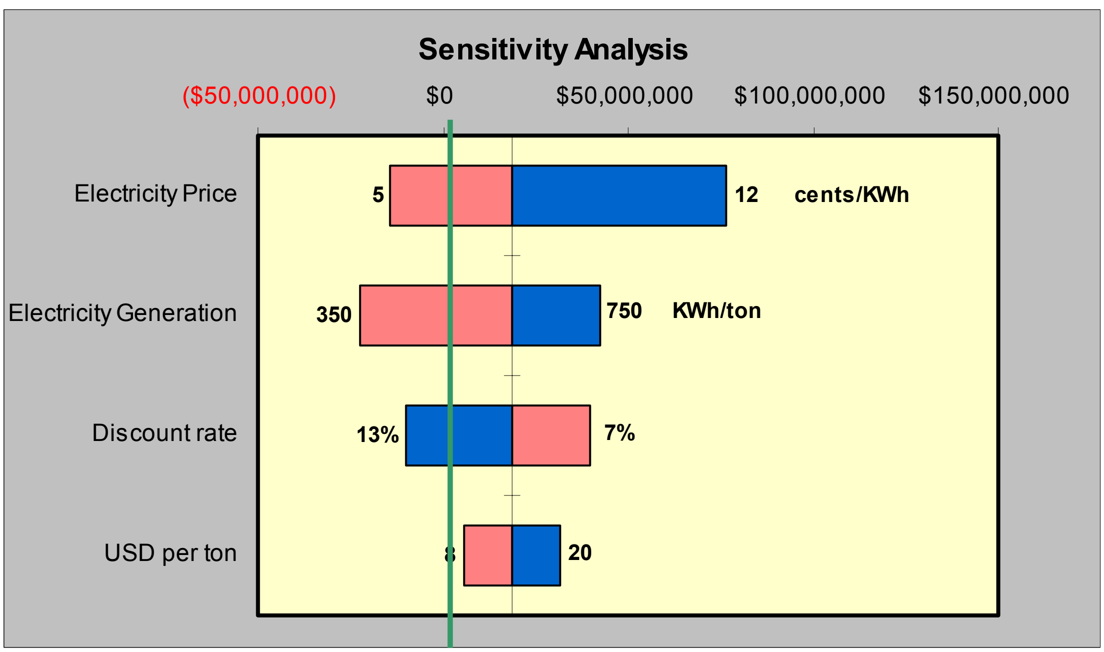

Figure 15: Results of Monte Carlo Simulation

[7] Electricity generation in Central Grid (Santiago Metropolitan Region) comes basically from hydroelectric 59% and Natural Gas 22%, coal is only 12%.

Figure 16 shows how predominant the variables are in the project. The most important factors determining project's viability are electricity price, heating value outputs (electricity generation) and the discount rate.

A very small increase or decrease in the electricity price or heating value can make a dramatic difference in profitability. Monte Carlo analysis on electricity price shows that variations in it account for 49.2.5% of the variation in the NPV, on electricity generation accounts for 32.5% and in discount rate for 15.9%. Surprisingly, tipping fee has an almost negligible influence in the project NPV outcome

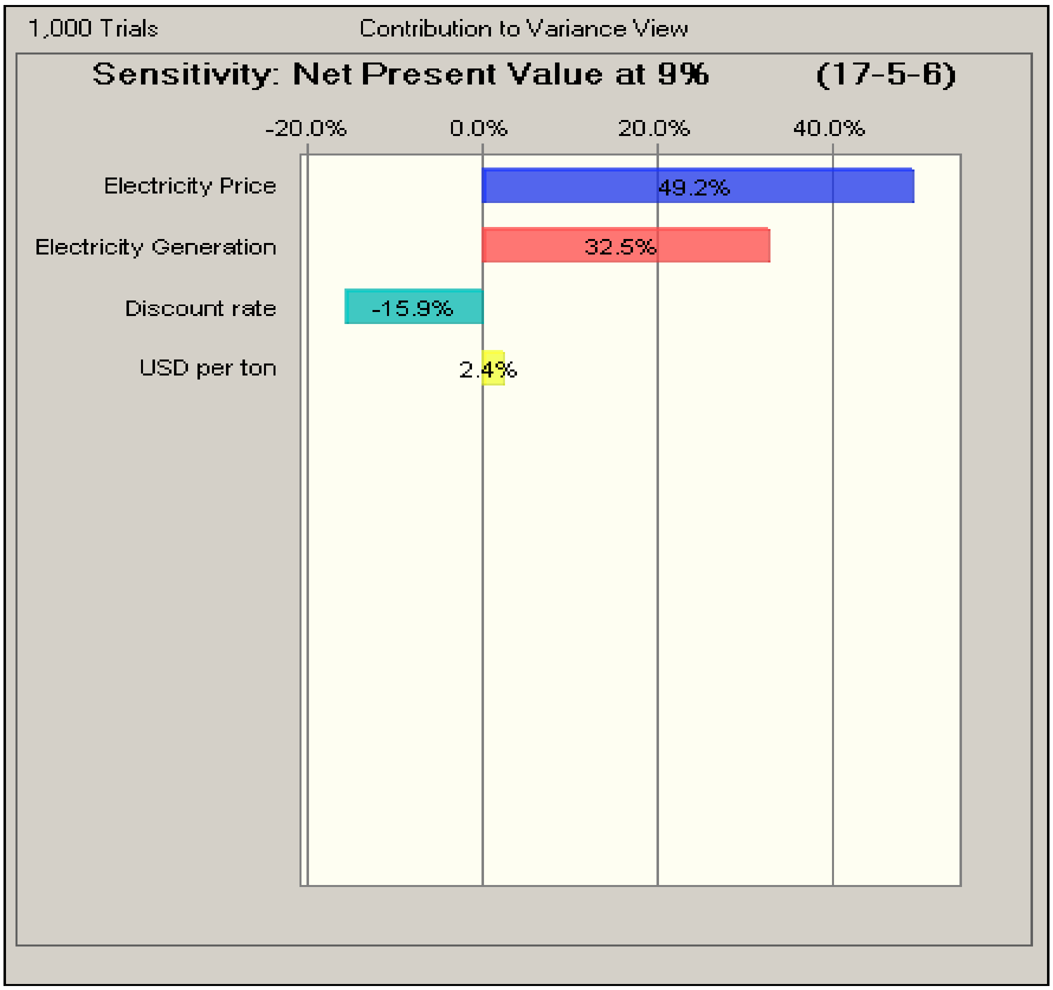

Figure 16: Importance of Variables in the Project

5.9. Cost-Benefit Analysis Conclusions

The result of the Cost-Benefit Analysis of a Waste-to-Energy Plant for the municipalities of La Florida and Puente Alto indicates that the project should be undertaken because it has a positive NPV, thus generating more economic benefits than costs in almost every scenario.

However, there is some further analysis that remains to be done in the estimation of the heating value variable, as several studies indicates that Santiago's heating value could be lower than the one calculated here. However, these studies were made in the nineties and Santiago's waste composition has changed significantly, decreasing its organic composition from 70% to 50% in a few years.

Overall, the non-quantifiable benefits seem to outweigh the non-quantifiable costs, therefore supporting the construction of a WTE plant for Santiago. The community would have to be educated about these issues.

The approach being taken in this research could be subject to some criticism with regard to some of the assumptions made. However, it is intended to give some useful insights to decision makers by providing a clear picture of the project and the key variables involved. The project is promising as the benefits of power generation and environmentally better waste treatment are expected to be large.

6. Successful Cases of Waste-to-Energy in The World

6.1. Brescia WTE Facility in Italy

This is an example of a successful project with cogeneration of electricity and heat. On March 1998, two and a half years after the beginning of construction, the WTE plant of the city of Brescia (3 x 33 ton/hounr of waste) started its operation.

In 2004, 721,000 tons (L.H.V 8.37 MJ/Kg) of waste (including 258,000 of biomass) were processed, while producing 475 GWh of electricity and 395 GWh of heat for the district heating network of Brescia, which serves a population of more than 130,000. The plant (the greatest in Italy) processes all the non recyclable Municipal Solid Waste generated in the province of Brescia (population of more than 1 million) and provides the city of Brescia (200,000 inhabitants) with one third of its electricity and heat demand. No MSW are any longer landfilled in the province of Brescia.

The WTE plant of Brescia is part of the "sustainable development" strategy of the city and also of the "Brescia Integrated Waste Management System" (BIWMS), which has been implemented by the City Council since 1992, with a great involvement of citizens. The aim of BIWMS is the maximum recovery of materials (from separate collection of the recyclable waste; in 2004, 40% of MSW were recycled and a new goal of 50% was defined) and energy (from the remaining waste).

Much attention has been paid to the protection of the environment and to the efficiency of the energy generation which amounts to 27% as electricity, 55% as heat, and 82% overall. As a result, on the bases of electricity and heat generated, the emissions to the air are lower than those produced by coal, oil, and gas fueled power plants. In year 2004, the equivalent savings in fossil fuels are 150,000 tons of oil and emissions of more than 300,000 tons of CO_2 were avoided, compared with landfill disposal of waste and energy generation with fossil fuels.

One of the innovations of the Brescia plant is the recirculation of flue gas that results in higher oxygen utilizations and lower process gas volume per ton of MSW processed.

Nine years of operation experience with progressive improvements, have shown that, within BIWMS, it is possible to increase the recovery of MSW and to produce cleaner energy, giving a concrete contribution to the sustainable development in a typical densely populated urban area. (31)

6.2. The Amsterdam Experience

The successful community relations strategy followed by the operator of Amsterdam's WTE plant has convinced the public and other stakeholders of the benefits of combustion for treating the city's waste.

In 1992, the city of Amsterdam created Afval Energie Bedrijf (AEB), a WTE enterprise that operates as a self-contained entity but is owned by the City. AEB's mission is to recover as much energy and materials as possible from MSW while protecting the environment.

In 1993, AEB began operating a large WTE plant on a site at the western end of the city in the area known as Westpoort. After 12 years of operation, it can be confidently said that it has been an important success. While treating more than 800,000 metric tons per year, the installation has produced 580,000 MWh of electrical energy, 102,000 Gj of heat and 180,000 metric ton of construction materials from bottom ash – all this with minimal air pollution and with a positive reaction from the population.

This year, AEB will start operating a 66% expansion of the WTE facilities. At the same time, an adjoining new sewage treatment plant serving one million inhabitants will start operating. The two installations will take advantage of several positive interactions, including utilization of the biogas produced from the sewage sludge digestion. This expansion will create the world's largest municipal waste treatment centre. It has been granted all the relevant permits without any public opposition and with support from non-governmental organizations (NGOs).

Part of the success is that early on AEB adopted a deliberate strategy and program of communications with national authorities, city officials responsible for funding the projects, regulatory officials, NGOs and the general public. This strategy can be described in two words: total transparency.

In these discussions, AEB recognized that political leaders, regulatory officials, environmental NGOs, consumer groups, waste management industries, other societal groups and the media all have a definitive sense of their role and responsibilities in the community. These had to be acknowledged and treated with respect.

AEB continues to publish annual reports giving full details of the financial, technical, social and environmental aspects of its operations.

A principal objective of the AEB program has always been to increase the involvement of the citizens of Amsterdam in the waste management process, in making the inhabitants of Amsterdam aware of the subsequent process and to be involved in the discussion and decisions regarding the treatment of their waste.

The AEB experience not only demonstrates what can be done with WTE. It is an excellent example of integrated waste management from which other urban centers in the world could derive similar benefits. The immediate results of AEB's achievements are the direct benefits to its community. (32)

7. Conclusions

As presented in this study, it is clear that Santiago's current waste management system is in crisis and faces important political, geographical and environmental challenges that make this management unsustainable. Unfortunately, most of Chileans have only a vague notion of what happen to the waste they produced after it is picked up from their doorstep.

In the coming decades Santiago is going to run out of landfill space and little can be done with this land after the landfill is closed. Based on the author's calculations, landfills will reach their maximum capacity in 20 years from now.

Therefore, there is an urgent need to educate the population and to move towards an integrated solid waste management approach, in which a WTE plant could play a key role to efficiently address these problems, as was presented in this report. In a "sustainable development" approach waste should be regarded as a resource for materials and energy recovery and not simply as a product for disposal. It is necessary to create public awareness of the real cost of solid waste management, the importance of waste minimization and what happens to the waste after the waste is disposed.

The result of the Cost-Benefit Analysis of a Waste-to-Energy Plant for the municipalities of La Florida and Puente Alto indicates that the project should be undertaken because it has a positive Net Present Value (NPV) of USD 18 million under the base scenario, based on a discount rate of 9%. The project will pay its initial investment in 17 years and have a useful life of at least 30 years. In addition, the WTE facility would save valuable space, as the WTE plant proposed for Santiago will use a total space of 6 hectares.

The WTE facility could charge a significantly lower fee than current landfills and the project still has a positive NPV. There would still be a positive NPV with a higher discount rate of up to 11.3%. However, a very small increase or decrease in the electricity price or heating value can make a dramatic difference in profitability.

In WTE plants it is also possible to co-fire other fuels such as waste tires or sewage sludge residues from waste water treatment plants. At the moment, waste volume, energy shortages, land scarcity, and disposal of sewage sludge, are all serious problems in Santiago. This WTE plant could be part of a comprehensive solution for these issues.

Before the construction of the plant, the none-quantifiable impacts such as the environmental, social and economic factors have to be carefully examined and considered. Potential air pollution and the location of the WTE plant are the factors that could have more weight in creating opposition from the community near by. On the other hand, it is important to acknowledge that Waste-to-Energy plants produce dramatic decreases in air emissions, in comparison to landfills, and their emissions, are way below the EPA standards and lower than coal power plants emissions. In addition, the location of a WTE plant will be closer to the municipalities than the actual landfills. This certainly will reduce truck travel and diesel emissions to the atmosphere; consequently, there would be a significant reduction in generated smog. A WTE plant should be located in a site of an old industrial zone or old transfer station and improve the host area. Overall, the non-quantifiable benefits seem to overweight the non-quantifiable costs, therefore supporting the construction of a WTE plant for Santiago. The community would have to be educated about these issues.

Considering that the current waste management situation in these two municipalities is almost identical to the rest of Santiago, the possibilities of WTE as a widespread solution for waste management are very promising.

Santiago's Government should implement an integrated solid waste management system that would classify MSW under four categories: "recyclable", "combustible," "compostable," and "landfillable" waste. The government has already set a goal for recycling of 25% of the waste stream; in addition, the WTE plant proposed in this study for La Florida and Puente Alto could process an additional 14% of the waste stream of Santiago. Regarding "compostable waste", according to international standards, 5% of Santiago's waste could be composted. Under this scenario, Santiago's waste to be disposed into landfills would be reduced in 44%. This could be a major contribution to a solid waste sustainable management and would represent an integrated solid waste management approach.

To reach these targets there should be an appropriate framework and regulations. Today, norms that regulate waste management in Santiago are dispersed among many legal bodies, with duplications and contradictions. A multiplicity of entities has responsibilities in the sector, a situation that creates coordination problems. Furthermore, there is a lack of information systems to allow the monitoring and comprehensive evaluation of solid waste services. It is suggested that there is an urgent need to legislate this area.

Positive experiences with WTE and its widespread use in other countries should provide an encouraging prospect for Chile too. The Amsterdam WTE experience showed that part of its success was to increase the involvement of the citizens in the waste management process. This was achieved by means of educating to the community and convincing the public and other stakeholders of the benefits of combustion for treating the city's waste. This experience not only demonstrates what can be done with WTE, it is an excellent example of integrated solid waste management from which Santiago could derive similar benefits.

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