PN-ABU-170
94426

Report Submitted to:
Susan Vernon-Gerstenfeld
Ecuador Project Center
By

Allan Concepción
Francisco Pereyó
Obadiah Plante

In Cooperation With
Daniel Tapia Falconi- Professor Earth Sciences
Escuela Superior Politecnica del Litoral- Guayaquil

URBAN WASTE MANAGEMENT IN GUAYAQUIL, ECUADOR

Dec. 2, 1993

This project report is submitted in partial fulfillment of the degree requirements of Worcester Polytechnic Institute. The views and opinions expressed herein are those of the authors and do not necessarily reflect the positions or opinions of ESPOL or Worcester Polytechnic Institute.

This report is the product of an education program, and is intended to serve as partial documentation for the evaluation of academic achievement. The report should not be construed as a working document by the reader.

Report Submitted to:
Susan Vernon-Gerstenfeld
Ecuador Project Center
By

Allan Concepción
Francisco Pereyó
Obadiah Plante

In Cooperation With
Daniel Tapia Falconi- Professor Earth Sciences
Escuela Superior Politecnica del Litoral- Guayaquil

URBAN WASTE MANAGEMENT IN GUAYAQUIL, ECUADOR

Dec. 2, 1993

This project report is submitted in partial fulfillment of the degree requirements of Worcester Polytechnic Institute. The views and opinions expressed herein are those of the authors and do not necessarily reflect the positions or opinions of ESPOL or Worcester Polytechnic Institute.

This report is the product of an education program, and is intended to serve as partial documentation for the evaluation of academic achievement. The report should not be construed as a working document by the reader.

Acknowledgments

We would like to thank USAID and WPI for providing us with the opportunity of attending the Ecuador project center; our parents for their financial aid and support without which we would have not been able to fulfill our task; Luis Torres, Walter Samaniego and Guillermo Castillo for their valuable information on which most of our report is based on; and Susan Vernon Gerstenfeld and Daniel Tapia for their helpful advice throughout the development of the project.

Executive Summary.

This project was made possible by the linkage between Worcester Polytechnic Institute and Escuela Superior Politecnica del Litoral. This linkage was funded by the United States Agency for International Development.

The major objective of this project was to investigate and propose alternatives to a sanitary landfill in Guayaquil, Ecuador, and to analyze the social implications of the proposed Las Iguanas project. A political chapter was included to document the decision making process concerning waste management in Guayaquil.

This project contains a thorough investigation of source and secondary separation, composting, incineration, landfill gas extraction, and recycling processes as alternatives to a sanitary landfill. These alternatives were researched mainly through literature, including the requirements for the implementation of processes in Guayaquil.

The social effects of the Las Iguanas proposal were gathered through the assistance of a representative from Fundación Madredolorosa. The most significant effect caused by the Las Iguanas project is that it leaves 3000 people without work. This and other repercussions of the Las Iguanas project are described in this report.

The politics of decision making in Guayaquil are also discussed in the project. The political information describes the relationship between ESPOL and the Municipalidad, as well as the motivation behind the Las Iguanas project. It is very important for the reader to understand the political nature of this project to fully understand the issues involved.

After extensive analysis of the data described above, the following conclusions were reached:

- The most feasible alternative to a sanitary landfill is a separation program to recover the recyclable materials from the waste stream.

- The success of a source separation program depends on the awareness of the citizens of Guayaquil concerning the separation of the waste.

- If the chamberos are allowed access to the new landfill, they will be assured of a future means of living and the companies that buy materials from them will be assured a continued supply of recyclable materials.

- If the municipality takes no action to assist the chamberos, they will be left unemployed and desperate for work.

- The proposed waste collection program for the Las Iguanas landfill does not account for the inspection of city zones. Therefore, some areas might be overlooked and become overrun with municipal waste.

Upon review of the above conclusions, the members of this group formulated the following recommendations:

- The implementation of a separation facility at the landfill site would prevent the loss of recyclable materials that will not be collected by the chamberos at the new landfill site.

- The municipality could encourage separation at home through the sponsorship of educational programs and media exposure.

- An incentive to a source separation program could be set by the municipality, proposing, for example, alternate collection days for organic and inorganic materials or for wet and dry waste.

- The municipality could ensure the cleanliness of the streets if the collection company was paid on a scale according to a combination of the amount of waste collected and the cleanliness of the streets. This strategy would provide for a more comprehensive coverage of the waste collection process.

- The municipality could prevent any conflict that might take place with the chamberos by negotiating with Fundación Madredolorosa and the chamberos themselves to attempt to meet the needs of the chamberos.

These recommendations are meant to serve as possible courses of action by the municipality of Guayaquil. The members of this group feel that the implementation of any or all of these recommendations would benefit the people of Guayaquil.

Authorship Page

Each member of our team contributed equally to the development of this project. As equal contributors, Allan Concepcion, Francisco Pereyo and Obadiah Plante take full responsibility as a group for this project in its entirety.

Table of Contents. **Page**

Acknowledgements	1
Executive Summary	2-4
Authorship Page	5
1.0 - Introduction	9-10
2.0 Methodology	11-13
3.0 - Information Analysis	14-63
3.1 Introduction to the Information Analysis	14-15
3.2 Technical Aspects of Urban Waste Management	16-53
3.2.1 Sorting and Separation	16-20
3.2.1.1 Sorting Techniques	18-20
3.2.1.2 Case Study	20
3.2.2 Recycling	21-28
3.2.2.1 Reuse	21
3.2.2.2 Solid Waste Reuse in Guayaquil	21-22
3.2.2.3 Recycling	22
3.2.2.4 History of Recycling	23
3.2.2.5 Importance of Recycling	23-24
3.2.2.6 Separation Methods for Recyclables	24
3.2.2.7 Recycling Glass Products	25
3.2.2.8 Recycling Metals	25-26
3.2.2.9 Recycling Plastics	26-27
3.2.2.10 Recycling Paper Products	27-28
3.2.2.11 Market for Recyclables	28
3.2.3 Composting	29-31
3.2.3.1 History of Composting	2-33

3.2.5 Fuel Burning Process 34-36

3.2.5.1 Introduction 34-35

3.2.5.2 Advantages and Disadvantages of Incineration 35-36

3.2.6 Gas Extraction 37-42

3.2.6.1 Introduction 37

3.2.6.2 Gas Extraction and Coilection 38-39

3.2.6.3 Landfill Gas Treatment 40-41

3.2.6.4 Estimation of Landfill Gas Potentials 41-42

3.2.7 Implementation of Processes in Guayaquil 43-53

3.2.7.1 Introduction to Implementation of processes 43-44

3.2.7.2 Sorting and Separation 44-46

3.2.7.3 RDF Option 46-50

3.2.7.4 The Gas Extraction Option 50-52

3.2.7.5 The Recycling Option 52-53

3.2.7.6 The Composting Option 53

3.3 Political Aspects of Las Iguanas Project 54-56

3.3.1 Introduction to Political Aspects 54

3.3.2 Recent History of Waste Management in Guayaquil 54-55

3.3.3 Las Iguanas Project 55-56

3.3.4 Political Reality in Guayaquil 56

3.4 Social Implications of Las Iguanas Project 57-63

3.4.1 Introduction to Social Aspects 57

3.4.2 Introduction to the Chamberos 57-58

3.4.3 Social Structure of the Chamberos 59

3.4.4 Social Impact of the Las Iguanas Project 59-61

3.4.5 Bogota Case Study 61-62

3.4.6 Medellin Case Study 62-63

4.0 Conclusions 64-65

5.0 Recommendations 66-67

Appendix A WPI/ESPOL/USAID Linkage 68

Appendix B Types of Size Reduction Machinery 69-73

Appendix C Chemical Composition of Landfill Gas Production 74-75

Appendix D Handout at ESPOL Presentation 76-79

Acronyms 80

Glossary 81

References 82-83

1.0 INTRODUCTION

Waste disposal is the disposal of waste products resulting from human activity. Once a routine action that required little concern, the disposal of waste has become a pressing problem in the twentieth century because of the growth of population and industry and the toxicity of many new industrial byproducts.

Most solid waste in the United States, such as municipal refuse, is deposited in open dumps. More sophisticated methods of disposal include the sanitary landfill, where waste is spread thin and separated by layers of tamped earth, and special incinerators that burn combustible waste while generating steam to run turbines, or use for heating. The recycling of non combustible products, such as glass and metals, like aluminum cans, is growing and offers long-range hope for disposal.

A growing concern for many communities is the problem of waste management. A coordinated program for handling refuse is necessary for any community to safely dispose of urban waste, while also avoiding the problem of dwindling space available for waste disposal. Options for waste management include recycling, landfilling, and energy production through the incineration of combustible waste.

In developing countries, the problem of waste disposal is often compounded by lack of infrastructure; lack of funds; lack of technology; corruption; at times, the vicissitudes of politics; and social issues such as the disposition of the workers who handle the waste.

The purpose of this paper is to suggest waste management alternatives for the city of Guayaquil, while taking into account the available technology, the available funds, the political situation, and the social issues that affect the situation. It is meant to fulfill the requirements of an Interactive Qualifying Project, which is designed to investigate the

impact of technology on society, and to recommend solutions if there is a negative impact. In the case of Guayaquil, it is to investigate how the increasing amount of waste that comes with development is impacting society and what can be done to lessen that impact.

2.0 METHODOLOGY

Given the growing problem of solid waste management for Guayaquil, Ecuador, we have investigated alternatives to a sanitary landfill as well as the social issues involved in the waste management system currently in place. We also examined the political aspects involved in the management of the current and proposed systems as discussed in section 3.3.

In investigating these topics a five phase approach was utilized:

I- A preparative phase.

II- A fact finding phase.

III- A data review phase.

IV- A strategy generation phase.

V- A strategy recommendation phase.

Phase I, which took place during the term previous to traveling to Ecuador, consisted of reviewing literature on possible waste management alternatives for the city of Guayaquil. The focus of the project was to suggest alternatives to a sanitary landfill, and to document how the implementation of a landfill would affect society. Because of this, we did not devote a lot of time to reviewing what information was available on the current social and political situation of the city. From the information gathered a preliminary proposal was formulated for review by the sponsor and advisor of the project.

Phase II began upon arrival in Ecuador. It was during this phase that the focus changed. An interview with engineer Guillermo Castillo informed us that the government had already developed a sanitary landfill design as an alternative to the present waste management program. We then decided to shift the focus of our project. We would still suggest alternatives to a sanitary landfill, but we would devote our

efforts towards investigating the social and political issues surrounding the landfill project.

A number of interviews were scheduled to gather information on the three areas of investigation: waste management alternatives, social issues, and the political situation. A visit to the San Eduardo landfill site was scheduled in order to view firsthand the present situation.

Waste Management alternatives

Utilizing the information gathered during phase I, interviews were scheduled with Guillermo Castillo and Walter Samaniego. Guillermo Castillo, who is head of planning for the Department of Aseo Urbano, wrote the technical proposal for the Las Iguanas landfill. He was able to give us information on the technical aspects of the landfill such as the composition of the waste stream, current feasible technologies, landfill management practices, landfill strategies, and landfill costs.

Our interview with Walter Samaniego, who is a sociologist who works with the chamberos, the workers at the current landfill, gave us information on economic factors such as markets for recycled materials, energy, and compost.

Social Issues

Another set of interviews was aimed at determining the magnitude of the social impacts of the new landfill and possible implementations of waste management alternatives to the landfill. Information was also gathered on the effects of closing the old landfill at San Eduardo.

Interviews were scheduled with Guillermo Castillo, Luis Torres, and Walter Samaniego. From Guillermo Castillo we learned what plans the municipality has for the old landfill and what social planning went into the new landfill. Luis Torres, an economist who works with small organizations who are

seeking financial aid, gave us a picture of the chamberos' way of life and culture. Our interview with Walter Samaniego gave us an idea of the economic situation of the chamberos such as their monthly income, what they buy, and so forth.

Political Situation

A last interview was scheduled with Guillermo Castillo. Since he is involved with the municipality, he was able to give us a view of how politics was affecting the current waste management system and how it would affect the decision on the new landfill or other waste management alternatives.

Phase III, which took place during the week of Nov. 15-19, consisted of a period during which the data was reviewed and consolidated to give a picture of the technical, social, and political aspects of the solid waste management program affecting Guayaquil.

Phase IV, which was the strategy development phase, took place during the first half of the week of Nov. 22-26. This phase was devoted to applying the waste management options to the waste management problem as seen in phase III.

Phase V consisted of reviewing the strategies developed in phase IV and deciding upon the strategy to recommend.

3.0 INFORMATION ANALYSIS

3.1 Introduction to the information analysis.

The information analysis is the researcher's attempt at sifting through and making sense of all of the information that pertains to a problem. Data is first collected through literature, interviews, and other sources and then reviewed. When all of the information has been collected and reviewed, then there should be a sufficient base of knowledge from which to draw conclusions and make recommendations.

In the case of Guayaquil, the problem is one of urban waste management. In order to analyze this problem accurately, we have chosen a three element analysis. These elements are the technical, social, and political aspects of urban waste management.

As resources around the world are being consumed at even greater rates, people are becoming more concerned about materials and energy resources. New ways are being developed to conserve these natural resources, such as practicing energy conservation, and using renewable resources. A sensible alternative is to reuse the resources that we have already used. The waste that is thrown away every day contains recyclable materials and also is a potential fuel. An added benefit of reusing waste is that it reduces the volume of waste that must be landfilled.

It is much more economical to reuse a recyclable material such as aluminum, than to mine the ore, refine it, and form it. There is a great deal more energy used in the production of virgin materials than is used in recycling used materials.

Waste can be used as a fuel, both processed and unprocessed. The combustible materials within mixed waste represent stored energy that is lost if thrown away. The energy derived from waste can be used to generate electricity, at a cheaper cost than

coal or oil.

In order for a community to implement the recovery processes for either energy production or recycling, a study of the composition, quantities, and characteristics of the waste is necessary. From this study a sorting and separation program can be developed to prepare the waste for either process.

The optimum treatment for Municipal Solid Waste, hereafter referred to as MSW, is determined while taking into account a number of criteria for the area being studied. The treatment procedures being considered in this study include:

- sanitary landfilling,
- recycling,
- composting,
- incineration, and
- landfill gas extraction,

When choosing a treatment plan, the following parameters should be taken into consideration:

- amount and characteristics of MSW produced,
- availability of landfill space,
- transport or exchange distances,
- recyclables/Reusables and energy market availability,
- environmental impact,
- socioeconomic impact, and
- economical investment in desired plan,

3.2 TECHNICAL ASPECTS OF URBAN WASTE MANAGEMENT

3.2.1 Sorting and Separation

One of the most important elements of an effective waste management program is waste sorting and separation (Barton,1979, p. 30). All other facets of managing waste depend on the identification and separation of waste. Neither recycling nor energy production can be performed properly if the wrong materials are used (Barton,1979, p. 18).

Sorting involves the identification of the various components that comprise the waste. Efficient classification techniques prevent reactive materials from coming in contact with each other. They also indicate whether the material should be recycled, burned for energy, or landfilled. Data can be collected on the composition of waste, and used to plan strategies for further waste management. For example, a large concentration of metals would indicate that recycling would be feasible, while a large amount of combustibles would lend itself to energy production.

Separation is the division of solid waste into its component forms. Once the waste has been identified, it is separated into certain groups such as paper products, yard waste, glass, metals and plastics. These materials are then shipped to a materials recycling facility, a waste incineration or cogeneration plant, or a landfill. Where these components are shipped depends on whether they are suitable for recycling, combustion, or neither.

Sorting and separation may be done by manual, mechanical, or chemical means (Barton,1979, p. 30). Manual labor, in which workers sort the waste by hand, is the primary method by which waste is sorted. It is not as efficient as mechanical sorting and separation, but if the community is involved in supporting a materials recovery facility, it provides a cost-effective way to sort solid waste. Machines that sort and

separate refuse are more efficient because they combine the steps of identification and separation. They utilize the physical characteristics of the waste to both identify and separate waste. Chemical separation is required when materials have multiple chemical components, such as toxic waste. In developing countries, chemical separation is often impractical because it requires large investments of energy, chemicals and technology (Barton, 1979, p. 18).

Manual sorting and separation usually involves workers standing alongside a conveyor belt. Each worker is assigned the task of looking for a certain category of trash. When the worker finds a piece of trash that fits his or her category then he or she puts that piece in a bin beside them. Workers try to sort the waste as carefully as possible, however, they are still subject to human error.

Manual sorting and separation can also include programs such as that in Mexico. Pepenadores, squatters who occupied landfills and made a living rooting through trash, recycled their finds and sold them. In order to give them a better standard of living the government has taken over the pepenadores. Housing, schools, and recreational services are being provided to the pepenadores, and in return the pepenadores continue sorting the waste in the landfill (Waste Age, April 1992, p. 150-154).

A further step in the direction of hand sorting is to involve households and businesses. They can be encouraged to sort their refuse as they produce it. Keeping refuse components separate would diminish the need for separating mixed refuse, although it would not end it. The most difficult problem with this approach is that it is hard to produce a behavioral change in a populace until a crisis situation occurs. Sorting trash is considered too much of an inconvenience, and people will not change their attitudes toward sorting trash until they are personally affected (Letcher, 1986 p. 218.).

3.2.1.1 Sorting Techniques

Mechanical sorting involves the use of machines designed to exploit the physical properties of the various components in waste. There are many physical properties that may be used to identify and separate waste. These properties include magnetic and electrical properties, color, density, phase, elasticity, weight, melting point, and malleability (Barton, 1979, p. 30).

Magnetic properties are widely used to sort ferromagnetic materials from non-magnetic materials. The most common approach is to use a revolving drum that contains the electromagnet. A chute or conveyor belt carries mixed waste to the drum. Ferromagnetics are attracted to the drum long enough to fall into a different bin than the one in which the nonferromagnetics fall. A technique called ferrohydrodynamics utilizes the fact that a suspended solution of ferromagnetic material experiences varying density and viscosity when subjected to a magnetic field which varies in strength. Magnetic fields may be used to separate nonferrous metals from non conducting materials by inducing an electrical current in the metals. The electrical current causes them to be attracted to a collector to be held for separation (Barton, 1979, p. 32-35).

Electrical properties may be used to sort waste by many methods. Electrical conductivity can be measured directly by an electrical probe to direct a mechanical separator to sort material. Electrostatic precipitation involves the inducing of an electric charge in waste materials such as plastic and aluminum. The electric charge causes the materials to be attracted to a collector which is oppositely charged. The materials are then collected and shipped to a recycling facility. Electromagnetic radiation may be used to identify materials. Visible radiation is used by machines which can identify waste by color. Other machines have infrared sensors that can identify waste by the intensity of the reflected infrared radiation (Barton, 1979, p. 35-

39).

Phase properties involve the exploitation of the different phases of matter, solids, liquids, and gases, to separate waste. Solids may be separated from liquids by filtration and screening. Filtration requires a material that has holes of a sufficient size to allow the liquid molecules through while trapping solid particles at relatively high pressures. Screening is essentially the same process, involving larger holes and lower pressures than does filtration (Barton, 1979, p. 39-41).

Density differences can be used to separate waste. Hydraulic separation relies on differing densities between the solid wastes that must be separated, and the liquids used. Separation occurs when the different densities of the waste components cause them to either sink or float. Water classification uses a rising current to carry lighter particles upward while materials that are more dense fall downard. Oscillating stratification involves drawing a material dissolved in a liquid through a gravel bed where it is stratified according to density. Centrifuges accelerate materials in a circular path so that waste products separate according to weight. Pneumatic separation separates objects with low density and high drag from objects that are denser and have little drag (Barton, 1979, p. 41-50).

Elasticity refers to the rebounding characteristics of a material. A separation technique that utilizes this characteristic has a conveyor belt that effectively throws a piece of material at another conveyor belt. That conveyor belt is angled so that if the material is very elastic, it will bounce off into a sorting bin. If the material is not elastic enough, then it stays on the conveyor belt and is carried to the other bin. A variation on this method throws the material at the conveyor belt, but instead of bouncing, the material can either slide off the conveyor belt into the bin, or stay on the conveyor belt until it gets dropped in the other bin (Barton, 1979, p. 52-54).

Selective melting can be used to separate metals. A furnace outfitted with a

sloping hearth facilitates the collection of the molten fraction. Molten salt baths are now used, because they produce purer metals (Barton, 1979, p. 60-61).

Cryogenic embrittlement makes use of the fact that below certain temperatures, materials can become brittle. This method is frequently used to strip the insulation off wires, because the plastic surrounding the metal wire becomes brittle while the metal remains ductile. Because the plastic becomes hard and shatters easily, while the metal remains soft and flexible, the wire can be bent or hammered, and the plastic will break off of the wire, leaving the wire intact. This technique may also be used with plastics and aluminum cans (Barton, 1979, p. 62-63).

3.2.1.2 Case Study

Brazil began testing a relatively new recycling system called accelerated fermentation in 1992. A study of the waste that entered Rio de Janeiro's landfills found that over 50 percent of the waste was organic. The Brazilian government decided upon a process that was developed by Novergie of France, in which three composting towers ferment the organic waste into compost. This compost is sold as fertilizer to city gardeners, and the rest is shipped off to farms around the country. The recyclable materials are removed from the remaining waste by various mechanical or manual means, and are shipped to recycling plants. What remains is waste such as rubber, leather, and textiles for which there is no local recycling market. These wastes are transported to the nearest landfill, because Rio de Janeiro has run out of landfill space (Waste Age, September 1992, p. 51-56).

The situation in Rio de Janeiro is similar to the one in Guayaquil. Over 50% of the waste in Guayaquil is also organic. Guayaquil also has limited landfill space, although the government is planning a new landfill. This process could be applied by the city of Guayaquil.

3.2.2 Recycling

3.2.2.1 Reuse

The reuse of products is a very important practice for reducing the volume of solid waste in the waste stream. Consumers can contribute to this process by purchasing refillable containers and other reusable products. Also, buying products in bulk reduces the ratio of packaging to product, thus reducing the amount of packaging waste that would enter the waste stream if the same products were purchased individually or in smaller quantities.

In Guayaquil, reusing materials is a way of life. The poor people use every available resource for sustenance. Also, nations with few natural resources reuse much of their waste in order to save the limited resources they have.

In contrast, nations with abundant natural resources do not reuse nearly as much waste as those with few natural resources. The United States, for example, is associated with the term "disposable society". In the United States, there are many single use products that could be replaced by long term use products.

3.2.2.2 Solid Waste Reuse in Guayaquil.

The reuse of recyclable materials provides an incentive to industries and certain economic activities. Articles obtained from the solid waste stream enter the commercial cycle destined to be reused by industries or non-controlled activities such as: making kabob sticks, plastic caps and bottles, unlicensed liquor, tomato paste and jam bottling. Although the variety in recycling products is extensive, the greatest amounts recycled are of plastics, paper, cardboard, and glass.

The plastics used the most by the industries of Guayaquil are: polyethylene, polypropylene, polyvinyl chloride, and polystyrene. Plastics are recovered from the

landfill site and other waste stacks around the city. They are then sold to intermediaries who sell them to the industries that can reuse them. The industries that buy these plastics usually buy new plastics from other countries for use in their products. Since these imported plastics are more expensive than the plastics that they buy from the intermediaries, there is always a market for recovered plastics. In 1990, 3,658 tons of plastics were recovered, taking the place of $4,912,536 in imported plastics.

One third of the materials used by paper and cardboard companies is recycled paper and cardboard. Companies receive the paper after it has been separated into the reusable groups. The chamberos separate the paper into different groups consisting of: newspaper, bond paper, Kraft wrapping paper, and mixed cardboard. In 1990, from REIPA Cia. Ltda., 14,412 tons of paper were recovered, substituting for $3,305,773 that would have been spent on prime wood pulp. These reusable materials were recovered from malls, stores, and other institutions.

The reuse of glass in Guayaquil is practiced in many small businesses. This is done by the production of reusable bottles which require a deposit by the store owner purchasing the merchandise. Non-reusable bottles are still produced, though most of these bottles end up in the waste stream, and are recycled by the chamberos. The recovered glass is then sold to companies that can reuse them. One of the largest glass companies, CRIDESA, has announced that 30% of the materials they use is recycled glass (Oyala, 1991, pp. 25-26).

3.2.2.3 Recycling

Recycling plays a major role in any solid waste management system. Recycling is defined as any process where waste materials are collected, manufactured into new materials, and used or sold again in the form of new products or raw materials

(Powelson, 1992, p.9).

3.2.2.4 History of Recycling

In pre-revolutionary war America, recycling scraps of metals and textiles was common practice. The agrarian economy required settlers to make the best use of the few resources available. Along with the industrial revolution of the 1800's came rapid population growth. These large scale transformations required the use of many natural resources as well as recycling of existing products. Into the twentieth century and through World War II, recycling continued to be of necessity for many families. The tremendous strains faced by much of the United States during the two world wars and the Great Depression forced people to recycle whenever possible. After World War II, the American public did not feel the need to recycle and recycling became "unfashionable". It has taken quite some time for recycling to become fashionable again. Only recently, with the twentieth anniversary of Earth Day in 1990, has recycling been in the spotlight. Through media exposure, solid waste has been focused on as a problem. Recycling is more important now than ever before as a solution to minimize the amount of solid waste disposed of in landfills and to ease the solid waste crisis.

3.2.2.5 Importance of Recycling

The benefits from recycling are numerous. Recycling contributes environmentally by slowing deforestation. Also, less energy is consumed by producing recyclable materials. When this energy reduction is in the form of fossil fuels, there is less environmental damage from less acid rain and the decrease in the greenhouse effect (Powelson, 1992, p.4). Recycling also extends the life of landfills by decreasing the volume of the waste stream. In addition, recycling programs require a large work

force to take part in collection, sorting and processing recyclables, which generates jobs and income. The areas documented above give a complete picture of the importance of recycling.

3.2.2.6 Separation Methods for Recyclables

There are two methods by which recyclables are collected and separated. Those methods are source separation and secondary separation. Each method requires its own organization as is shown below.

Source separation involves separating the material to be recycled at the source, namely: in the home or in the workplace. In a source separation program, metals, plastics, glass and paper are separated into bins. These materials are then picked up by a curbside collection service or dropped off at the nearest recycling center. Because the materials are separated before entering the waste stream, there is very little contamination from outside elements, unlike in secondary separation methods.

Secondary separation methods involve separating recyclables from all other waste once it is already in the waste stream. This separation takes place at the landfill itself and requires mechanical or manual labor. Secondary separation produces materials that are contaminated much more than in source separation methods because the desired materials are mixed with all other waste in the waste stream.

In general, source separation involves considerable planning at the household, workplace, and collection levels; it also yields less contaminated products. Secondary separation requires no planning in the household and workplace, but instead, requires an organized separation program at the landfill. Secondary separation methods yield more contaminated products than source separation methods. Both of these methods can be used to recycle glass, metals, plastics and paper.

3.2.2.7 Recycling Glass Products

Glass can be divided into four categories: flint or clear, amber, green and mixed. Flint glass is the most abundant glass in the waste stream, and is therefore, the most commonly recycled. All of these glasses must be separated by color, crushed into glass cullet, and cleaned of any impurities in the recycling process. Contamination is very troublesome in glass recycling. All types of glass must be ninety-nine percent free of any outside contaminants such as metals and plastics (Powelson, 1992, p.84). The general specifications for the maximum amount of color contamination are as follows (Powelson, 1992, p.85):

TABLE 2.1

COLOR CONTAMINATION ALLOWANCE

	Allowed Additives			
Glass Recycled /	*% Flint*	*% Amber*	*% Green*	*% Other*
Flint	95-100	0-5	0-1	0-5
Amber	0-5	90-100	0-10	0-5
Green	0-10	0-15	80-100	0-10

Glass recycling is economical for the manufacturing industry but it is not a self-supporting process. A subsidy must come from one or more of the following sources in order to encourage glass recycling: government, glass producers, consumers, scrap dealers and processors or the beverage industry (Powelson, 1992, p.80). Without help from one of the above sectors, glass recycling is not an economical alternative.

3.2.2.8 Recycling Metals

All types of metals can be recycled. The most commonly recycled are aluminum and steel because they are the most abundant metals in the waste stream. As in glass recycling methods, the metals to be recycled must be separated first by type of metal and then by grade of metal. Aluminum, for example, can be divided into more than thirteen grades which must be separated prior to purification (Powelson, 1992, p.112).

Metal recycling significantly reduces pollution which would be generated by extraction of virgin ore. For example, steel produced from scrap, as compared to virgin ore, reduces air pollution by 85 percent, cuts water pollution by 76 percent and eliminates mining wastes altogether (Brown, 1991, p.65). The resources saved in steel recycling are iron ore, coal and limestone (Powelson, 1992, p.140).

3.2.2.9 Recycling Plastics

In general, there are two different types of plastics: thermoplastics and thermosets. Both types consist of polymeric chains; however, the molecules in thermoplastics are not bonded to one another. In thermosets, polymer molecules are bonded together or cross linked (Powelson, 1992, p.129). Macroscopically this means that thermoplastics can be reheated and cooled and formed into rigid objects; however, thermosets cannot be reheated and cooled because they will decompose. Thermoplastics, therefore, offer a wider range of recycling options than thermosets (Powelson, 1992, p.129).

Plastics must be separated just as any other recyclable material must be separated. All types of plastic must be kept separate from one another. There can be no contamination from other plastics in order to yield a homogeneous product.

Due to the tremendous variety of plastic products and their specialized recycling processes, only two types of plastics are commonly recycled. Polyethylene terephthalate and high-density polyethylene are currently the only economically

attractive plastics in recycling. PET, polyethylene terephthalate, is the plastic used in beverage bottles and bottles for cooking oils. HDPE, high-density polyethylene, is most commonly used in milk bottles and detergent containers. As mentioned above, these two plastics must be kept separate in the recycling process.

Plastic recycling methods offer an 88 percent energy use reduction when compared to using virgin materials (Powelson, 1992, p.127). Also, plastic recycling conserves petroleum, a valuable resource, and saves landfill space.

3.2.2.10 Recycling Paper Products

There are four broad areas into which paper is grouped: high grade, newspaper, corrugated and mixed paper. The grade of paper depends on the length, smoothness and strength of the paper fibers. High grade paper is subdivided into two groups: pulp substitute grades and deinking grades (Powelson, 1992, p.115). Pulp substitute grades contain paper which is bright enough and strong enough to be substituted for wood pulp. Deinking grades must have the ink removed from the paper in order to yield the desired products (Powelson, 1992, p.115). Newspaper can also be recycled to yield boxboard, chip board, and other low grade paper products. Corrugated paper can be downgraded into the same products as newspaper or can be recycled into more corrugated paper. Mixed paper is the lowest grade of paper and contains any type of paper. Mixed paper is most commonly made into boxboard products (Powelson, 1992, p.114).

Each individual grade of paper must be separated accurately in order to yield the desired products. The strictness of accurate separation decreases with the decreasing grade of paper. High grade paper requires the most attention in separation while mixed paper requires virtually none. Separation not only from different types of paper, but, from other products in the waste stream is also necessary. Sun-damaged paper must

also be separated and cannot be recycled into any paper products because the fibers are too weak and brittle to be reused (Powelson, 1992, p.111).

Paper recycling is an economic choice for paper manufacturers. In many cases, recycled paper can be substituted for virgin materials. By using recycled paper products, air pollution is reduced 74 percent and water pollution is reduced by 35 percent in comparison to using virgin materials (Powelson, 1992, p.108). Also, 7000 gallons of water and 17 small t rees are saved per ton of paper recycled (Powelson, 1992, p.108).

3.2.2.11 Market for Recyclables

In order to have a successful recycling program, there must be some sort of market for the recyclables and the products of recycling processes. The most obvious market for recyclables is the industry which produces similar products from virgin materials. Glass, metal, plastic and paper can all be recycled and used in their respective industries. Many of the products produced from recycled materials are identical to those produced by virgin materials. Because of the increase in public awareness concerning the environment, recycled products are being demanded by the consumer. The public demand for recycled products is a powerful force in creating a broader market for recycling.

3.2.3 Composting

Composting is a useful method in an efficient solid waste management system. Composting is "the biological decomposition of the organic constituents of wastes under controlled conditions" (Golueke, 1989, p.2). This method of waste reduction contributes to the protection of public health, conservation of natural resources, safe disposal of wastes, and the reduction of environmental stress (Golueke, 1989, p.1). Economics also plays a major role in composting as an alternative.

3.2.3.1 History of Composting

Composting has been part of agriculture for many years. Native Americans composted organics long before Columbus reached the "New World." Settlers of the Americas used composting to bolster their gardens in which they grew all of their food. Throughout the eighteenth century, composting continued to be used primarily on a small scale in agriculture. Composting first became widely used in the early 1900's with a focus on protecting public health and conserving natural resources. In the mid 1900's, waste disposal was the primary concern of composters. The rapid increase in population coincided with an increase in solid waste and composting became a valuable alternative to landfilling. A return to the idea of resource conservation increased composting activity in the 1970's in the United States (Golueke, 1989, p.1). Today, in the 1990's, the crisis involving solid waste and rising cost of landfill space are forcing governments to seriously look at composting on a large scale.

3.2.3.2 Large-scale Composting Methods

Compost systems can be separated into three general areas on the basis of oxygen usage, temperature and technological approach (Golueke, 1989, p. 2). Systems

dependent on oxygen usage are divided into aerobic and anaerobic decomposition. Those dependent on temperature are divided into mesophilic and thermophilic. Using technology as the basis, compost systems are divided into static pile, windrow and closed vessel composting (Powelson, 1992, p. 273). The following is a description of the terms used to classify compost systems.

Aerobic composting requires oxygen to fuel the aerobic bacteria responsible for decomposition. Anaerobic composting, on the other hand, requires an oxygen free atmosphere for anaerobic bacteria to function in (Golueke, 1989, p. 2). The differences between aerobic and anaerobic composting go further that just oxygen dependence. Aerobic systems are characterized by high temperatures, the absence of foul odors, and generally operate more rapidly that anaerobic systems. Anaerobic composting processes take place at low temperatures, produce an odorous intermediate, and proceed slower than aerobic processes. From these differences, it is clear that aerobic composting is the method of choice. Most large-scale compost facilities implement an aerobic method of decomposition (Golueke, 1989, p. 2).

In mesophilic composting the temperature is held within the range of fifteen to forty degrees Celsius. Thermophilic composting takes place at higher temperatures than mesophilic, generally between forty-five and sixty-five degrees Celsius. It should be noted that most composting processes include both temperature ranges.

The closed vessel method of composting places the material to be composted into an enclosed vessel. This method requires carefully controlled addition of water and air to the compost. Often, the vessel containing the waste is mechanized to stir the compost as it decomposes (Powelson, 1992, p. 274).

The static pile method requires no mixing of the compost during decomposition. Air is pumped into the compost through perforated pipes embedded in the compost. By forcing air into the piles, the compost can remain stationary for the

entire process (Powelson, 1992, p. 273).

In the windrow method, material to be composted is placed in long rows of specific height and width. The piles are aerated using specialized windrow machinery that turns the rows (Powelson, 1992, p. 274). Other than occasional mixing, piles in the windrow method are allowed to decompose naturally, which may take up to twenty-four months.

Large-scale composting is a very capital intensive process. It requires a reliable and proven process as well as a well established organization. A composting facility needs proper management and funding to succeed. Among the problems with composting facilities are odor and leachate control which pose health risks if not controlled (Powelson, 1992, p. 274).

3.2.4 Size Reduction

Recovery of valuable materials from solid waste can be accomplished by processing it to release, separate and remove the desired components. To do this effectively, the materials in the waste require size reduction for the following reasons:

-Plastic bags, bottles and cans must be broken to release their contents.

-Textiles, wood and other miscellaneous large objects must be cut to smaller sizes for further processing.

-Size reduction reduces the tendency of materials to tangle.

-Storage and retrieval of waste derived materials become more efficient after size reduction.

-Magnets cannot effectively remove large pieces of metal from a mixture of other large objects.

-Air classifiers are not effective in separating objects that are large in proportion to the cross sectional areas, objects that can tangle and clumped materials. Size reduction expands the refuse and creates aerodynamic shapes.

-Combustion is slow when objects are large and dense and inefficient when some objects are large and others small (Hasselriis, 1984, p. 84).

Size reduction can be accomplished by different methods. Impact, like dropping, smashing and crushing, is effective in breaking brittle materials, such as stone, wood and glass, and in opening cans and breaking metal objects. Shearing, such as cutting and tearing, is effective in reducing the volume of paper, cardboard, plastics, light materials and wire. Attrition, such as wearing down and grinding, is effective in reducing materials to lint and powder by surface abrasion. Densification improves storage, retrieval and burning properties of refuse fuel by pelletizing the waste.

The devices capable of reducing the volume of the materials from municipal

solid waste range from automobile shredders, which can handle anything, to granulators that can only handle material that will not damage the sharp knives and will pass through the discharge holes without plugging them. The basic types are shown in Appendix B.

3.2.5 Fuel Burning Process

3.2.5.1 Introduction

Once processed, Refuse Derived Fuels, hereafter referred to as RDF, can be stored or burned right away. RDF burning properties vary with respect to atmospheric humidity at the moment of incineration. For this reason, storage may be more efficient in order to extract the greatest amount of energy available from the fuel during optimal atmospheric conditions. RDF may sometimes be burned along with wood chips in order to maximize heat extraction from the burning process. This also varies with the amount of paper contained in the processed RDF.

The fuel is fed into a boiler where it is burned, producing steam in a series of pipes which run water along the incinerator. The steam may be used for different purposes. It may run a steam powered turbine producing electric power, or it may be used for heating. Considering the location of the proposed project, the use of the produced steam for heating may be discarded. Steam may also be used for the production of hot and chilled water.

The burning process consists of two phases. Primary incineration produces high-pressure steam which is used for energy production. Primary incineration decomposes most of the burning waste. Secondary incineration consumes the waste totally while also burning any combustible gases that may have formed during the incineration process. Secondary incineration produces low-pressure steam which is used for heating purposes, because it does not have enough thermal value for energy production. Secondary incineration also reduces the amount of air pollution produced by the incineration process.

Energy production may be done in the same facilities and sold to the local electric companies, or the plant may sell the vapor to the electric company directly

from the boilers via piping to a nearby electric production facility.

Residues from the burning process are small. Incineration plants can reduce the volume of waste by up to 90 percent and ashes from the boilers are collected and landfilled (Williams, 1991). Ashes from the incineration process usually contain concentrated heavy metals, polyaromatic hydrocarbons and dioxins, for this reason residual ash should be sent to a dedicated ash landfill or be classified and landfilled as hazardous waste.

The United States Environmental Protection Agency has developed a test-The Toxic Characteristic Leaching Procedure that identifies levels of 25 organic chemicals in addition to the eight metals and six pesticides and herbicides that may be present in the ash (Williams, 1991). Presently waste-to-energy developers are trying to develop methods of producing products with ash, such as offshore reefs, roadbase material and asphalt.

3.2.5.2 Advantages and Disadvantages of Incineration

Although Recycle Energy Systems are an expensive way of disposing of trash, they are a reliable source of energy for the future. Not depending on importing or producing any type of fuel, such as coal, oil, or natural gas, RDF are an inexpensive fuel source which depends only on production costs. Production costs for RDF processing are small compared to the rising prices of oil and coal, but the fact still remains that the production of RDF involves the use of expensive machinery and personnel. Some processes may be carried out using different methods. Sorting, for example, may be done manually or with the aid of machinery. Size reduction on the other hand, may not be properly done by any other methods than with the use of special machinery.

A mass-burn system incinerates municipal solid waste with little processing.

Mass-burn facilities consist of very simple operating systems and the personnel requires less training than in a RDF facility. For this reasons mass-burn facilities are easier and less expensive to operate. The incineration process in mass-burn facilities produces less energy per ton of waste burned because of the thermal value of the fuel utilized. Mass-burn facilities often use other types of fuel to maximize the burning process.

RDF processing is comparably more expensive but the processing of waste prior to the burning process gives a higher thermal value while lowering the potential air pollutants by the extraction of ferrous materials prior to incineration. The higher energy revenue from RDF methods help counteract the costly waste processing.

3.2.6 Gas Extraction

3.2.6.1 Introduction

As waste is deposited in sanitary landfills and covered, an anaerobic process of decomposition produces combustible gases from organic matter. These gases were first vented to prevent lateral migration or explosions due to uncontrolled escapes into the atmosphere. Later the gases were collected and flared. Now landfill gas can be exploited for the production of energy.

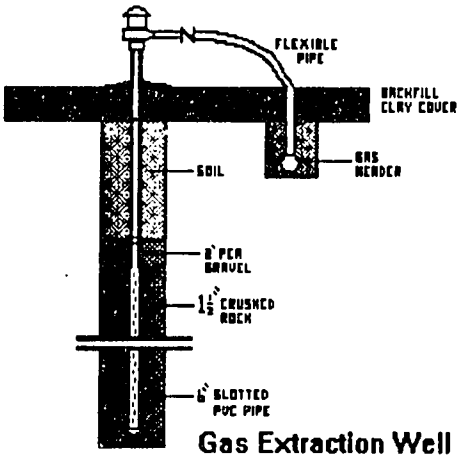
Landfill gas is a product of the decomposition under anaerobic conditions of organic products present in MSW (please refer to Appendix C for chemical processes). In theory, the biological decomposition of 1 ton of refuse can produce about 400 m^3 of landfill gas containing 55 percent methane and having a calorific value of at least 19750 kJoules per m^3. Landfill gas contains mainly methane and carbon dioxide. Some of the carbon dioxide is removed in aqueous solutions; consequently, landfill gas contains more methane than CO_2, which is about 45 percent of the usable gas. Some of the volatile organic compounds present in the gas are formed during the decomposition process while others are already present in the waste. The contents of these compounds varies greatly depending on the contents of the refuse and the landfill operating procedures. These gases are produced under anaerobic conditions under the top filling in sanitary landfills; therefore the amount of gases produced in open dumps varies. The decomposition process is carried out by a number of fermenting bacteria that transform organic matter into intermediary metabolites, which are in turn transformed to methane. The production of methane by this process is affected by a number of factors that include temperature, pH, oxygen presence, humidity, and others. The optimal temperature for the process is not known, but it is assumed that the typical temperatures ranging in landfills provide for a favorable process.

3.2.6.2 Gas Extraction and Collection

Landfill gas migration control is the key to a successful gas recovery system. Landfill gas is produced under pressure and tends to move to areas of less concentration. The prevention of this migration is usually succeeded by the installation of physical barriers that trap gas in concealed areas. Gas migration can be controlled by the placement of material that creates a zone of high gas permeability, thus facilitating the flow to that zone, from which the gas can be collected. The material commonly used for this purpose is commercial grade gravel.

More sophisticated systems involve an array of venting pipes that collect gas through the landfill. Vertical wells are installed consisting of slotted pipes at an average of 50 meter intervals drilled all the way to the bottom of the landfill. All vertical pipes are interconnected by a horizontal pipe network.

FIGURE 3.1



Gas Extraction Well

A vertical landfill gas recovery well consists of a plastic pipe, of 12 to 25 cm in diameter, placed in a hole in the ground extending through the refuse. The bottom 3 to 5 meters of the pipe are perforated with slots of 3 to 6 mm width. The well is between

0.6 and 1.2 meters wide and extends at most 7 meters, covering from 50 to 90 percent of the landfill depth. The area around the pipe in the well is filled with gravel to allow for gas flow and prevent waste to enter the pipe. In order to keep air out and the gas from escaping, the top half meter of the well is filled with concrete or any impervious material (Commission of the European Communities, 1992).

The wells may be placed when the landfill is completed or the whole network, including the horizontal wells, may be placed while the landfill is in use. Active areas, areas being landfilled, are ideal for the placement of the horizontal pipes, since no excavation will have to be done once the landfill is finished. Vertical wells are easier to put in place, and the installment process does not present a potential gas escape.

The installation of a pipe network on a recently filled landfill requires a series of safety measures to prevent failure. Land settlement must be accounted for when placing the pipes in the ground, allowing for movement of the network during the years. Longevity of the pipes is determined by their placement. Pipes placed above ground are usually high-density polyethylene (HDPE) because of the resistance of such material to ultraviolet rays. For underground piping Polyvinyl chloride (PVC) pipes is preferred because HDPE is more fragile.

Landfill gas contains a high humidity level, so as the gas goes above ground and the pipes get colder, water condenses along the pipes and restrains the gas flow. For this reason, condensate traps must be placed along the collection line at intervals between 50 and 200 meters. The pipes must slope downwards towards a condensate drain. Once the collection line is designed accounting for pipe placement to get the optimal extraction rate from the landfill, engineering criteria, such as head loss along the pipes and gas flow rate, must be examined.

3.2.6.3 Landfill Gas Treatment

Landfill gas contains around 55 percent methane, although the percentage may vary according to local conditions. In order to extract a usable product, the gas must undergo a treatment process. Since landfill gas is water-saturated, it is necessary to dry it. This is usually done by lowering the gas temperature to below freezing in order to trap the condensed water. Water from landfill gas is corrosive; therefore special pipes must be used to collect the water. Then, after the gas is filtered for dust particles, it can be used in burners adapted for the use of methane.

Apart from CO_2, landfill gas contains a number of compounds that can be removed for increased fuel quality. Hydrogen Sulfide, when present in landfill gas, can be removed by several processes. First, it can be removed from landfill gas by pressure-swing water scrubbing. This method is mainly used when carbon dioxide is removed jointly. Secondly, hydrogen sulfide can be removed by pressure swing and/or temperature-swing adsorption on activated carbon. Alternatively, hydrogen sulfide on activated carbon can be made to react with oxygen to produce sulfur and water. Thirdly, hydrogen sulfide can be removed by chemical reaction with iron oxides. Regeneration occurs with oxygen. In addition, the end-use equipment is modified so as to avoid contact of copper-based components with the gas.

Landfill gas can be upgraded to natural gas quality by lowering its carbon dioxide content, for example, to below 3 percent volume, by removing moisture and by reducing its hydrogen sulfide, H_2S, content, for another example, to below 3.5 mg per m^3. The upgrading treatment processes include gas absorption into a liquid, chemical or physical absorption in a solid; membrane separation; or biological removal processes. Ad/absorption processes often occur by the pressure-swing technique. In this technique, gaseous compounds to be removed are ad/absorbed at high pressure. The ad/absorbent medium is regenerated by gas release at lower pressure. Upgraded

landfill gas can be injected in the public grid, whenever local utilities allow it, used as a vehicle fuel or, eventually as a chemical feed stock: namely for the synthesis of methanol, CH_3OH (Commission of the European Communities, 1992).

Landfill gas has a lower burning value than natural gas, mainly because of its carbon dioxide content. For the previous and other reasons, burners and other energy production machinery using landfill gas must be modified. Because of its dry nature, landfill gas has no lubricating property. Valves and valve seats require wear resistant materials in order to last. Also, spark ignition engines require the addition of a gas carburetor, which provides a stoichiometric air-landfill gas mixture to the combustion chamber. Diesel engines need to be adapted to allow the compressed gas-air mixture to be ignited by injection of pilot diesel fuel. Because of the fluctuating concentrations of methane in landfill gas, constant carburetor and igniter adjustments are required. This problem can be avoided by analysis and control of the gas upstream from the burners.

Gas turbines can also be used for energy production. Landfill gas must be upgraded to a minimum heating value of 11300 kJoules per m^3, and gas production from the wells must be at least a thousand m^3. The carbon dioxide contents in the gas give the turbine a greater volumetric flow therefore increasing the power output from the turbine.

3.2.6.4 Estimation of Landfill Gas Potentials

The estimation of landfill gas potential requires three sets of data. It is necessary to know the amount of waste and the amount of organic matter in it. It is necessary to know how much of that waste is landfilled. Lastly, it is necessary to know how much gas can be produced from a certain amount of waste.

Once the amount of waste is estimated for the location, it is necessary to exclude its moisture content for potential evaluation. Then, once the amount of dry

waste is known, it is necessary to exclude the relative proportion of inert and non fermentable materials contained in the waste. When doing this evaluation, paper, cardboard and textiles are considered as biodegradable. Wood and plastics are considered as non biodegradable, although some plastics are biodegradable. Whenever the amount of biodegradable is not known, the average value of 75 weight percent of organic degradable matter in dry waste is taken as the best approximation.

The amount of gas recovered depends on how much of the waste actually decomposes, in reality, between a fourth and a half; and how much of the produced gas is collected, which in a well managed site is usually about 70 percent (Commission of the European Communities, 1992). Atmospheric conditions do not tend to influence much the production of gas, which is mostly ruled by local landfill conditions. Landfills decompose organic matter for periods ranging on the order of about 20 years, with an average gas generation rate of 5 m^3 per ton filled refuse per year. However these results may vary.

3.2.7 Implementation of Processes in Guayaquil

3.2.7.1 Introduction to implementation of processes

The implementation of the processes that will be proposed in this paper will maximize the amount of energy and materials recycled from the municipal waste in Guayaquil, as well as reduce the amount of waste needed to be landfilled. The composition of the waste produced in Guayaquil and its vicinities inhibits the implementation of a single resource recovery process.

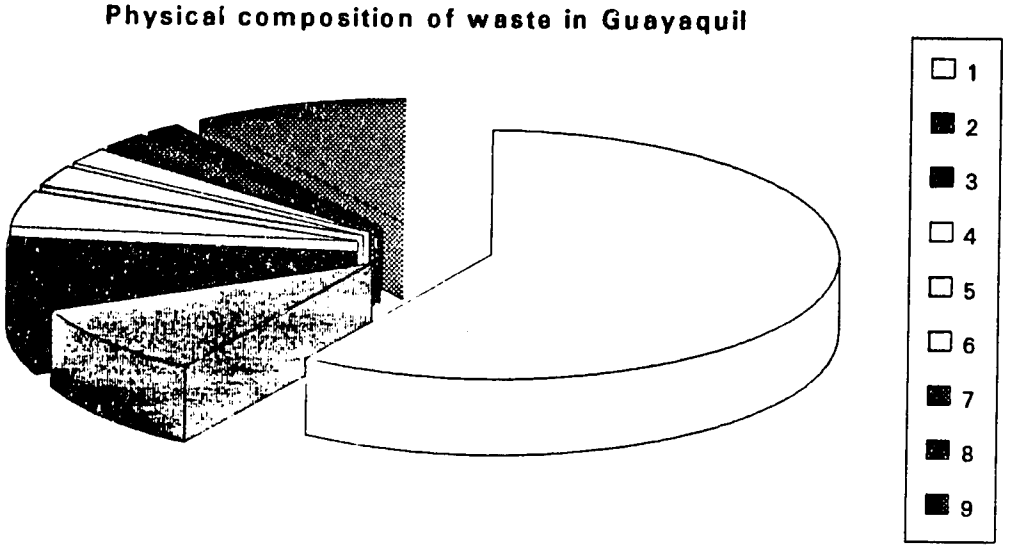


FIGURE 3.2

Decomposable material	*1*	*58.9%*
Paper and cardboard	*2*	*9.7%*
Plastics	*3*	*8.0%*
Wood	*4*	*4.7%*
Metals	*5*	*2.6%*
Glass	*6*	*2.4%*
Textiles	*7*	*2.2%*
Garden Wastes	*8*	*1.7%*
Other	*9*	*9.8%*

MSW has many properties that affect the processing and production of energy as well as materials recovery. Properties of interest in MSW are: components of MSW, combustibility, chemical composition, biodegradability and moisture content (Hasselriis, 1984, p.7).

It is important to understand the components of MSW to be able to determine the most effective process. Once a process has been chosen, knowledge of the composition of the waste enables customization of the process for greater efficiency.

The combustibility, or lack thereof, is also an important property. Combustible and non-combustible materials require identification prior to process selection.

It is important to identify the chemical composition of the MSW in order to determine heat and recycling values of the waste, as well as determining possible toxicity of the waste.

The moisture content is also an important property of MSW. Moisture content influences processing, handling and use of MSW. Very moist waste is best for composting, while dry waste can be incinerated.

Finally, the biodegradability of waste needs to be known. This affects not only whether the waste can be composted or not, but also determines how much gas will be produced if the waste is landfilled without processing.

When considering solid waste, there are mechanical properties which must be analyzed. Properties such as: tensile strain, compressive strain, yield points, stretching energy and compression energy are useful when researching mechanical processes (Hasselriis, 1984, P.7). Also particle size and particle size distribution are important properties to determine in MSW.

3.2.7.2 Sorting and Separation

Waste can be sorted by manual or mechanical means. Both sorting options offer

benefits. Manual sorting and separation does not require large investments in equipment and technology. However, the costs of sorting depend upon labor costs, which can vary. Mechanical separation requires large investments in both equipment and technology, and also maintenance, which will become more costly with time. However, labor costs are low since only a few people are needed to operate the machinery, and the machines tend to pay for themselves over time.

In the case of manual sorting and separation, a building is required to house the necessary equipment, which includes some type of conveyor belt, storage bins for the storage of the different types of waste, and sorting bins for the workers to put things in. Workers are assigned the task of separating a certain kind of refuse, such as newspaper, from the rest of the waste, and putting it in their sorting bin. As the bins fill up with that type of waste, the sorting bin is emptied into the storage bin, where it waits to be shipped to a facility which will either recycle, incinerate, compost or landfill the material.

Mechanical separation of wet and dry wastes is limited to magnetic, electrical or physical separation, since other techniques rely on using water to aid in separation, which would render the combustible waste useless unless dried. Electrical and magnetic processes can be used if there is sufficient material which will be affected by these processes. Because metals make up a small percentage of the waste in Guayaquil, this is not a suitable process for implementation. Using the physical properties of weight and density are the only viable alternatives.

One process that utilizes these properties is centrifuging. Since this technique cannot process waste at reasonable rates, it is an unfeasible alternative. The other process, pneumatic or air separation, also uses the properties of weight and density to separate waste. It also has the capability to process refuse at high rates, making it the only viable alternative for sorting waste without the use of an alternative.

Machines that sort and separate waste by pneumatic separation are called air

classifiers. The wet and dry wastes can be processed after being separated by an air classifier. The wet wastes can be sent on to a composting facility, or to a landfill. The dry wastes can be processed for fuel.

The sorting and separation process of air classifiers is not perfect. There are many types of waste that cannot be sorted efficiently into their appropriate categories. For instance, newspapers, which are compact and have high fuel value, can fall into the same bin as the wet waste, while an aluminum can, which is relatively light and has no thermal value, might be carried into the dry bin. Because of these problems, size reduction machinery is used to break up the waste into small particles. This lessens the effect of drag such as in the case of the can. There will still be contamination in each component separation due to particles of differing materials sticking to each other.

3.2.7.3 The RDF Option

Most of the waste coming into Guayaquil's waste stream is humid waste, which is mixed together with the rest of the waste (Refer to Figure 3.2). This decomposable material must be separated from the rest of the waste before implementing an incineration process. From the separated "dry" waste, recyclable materials can be recovered by separation before or after the incineration process takes place. Depending on the composition of the dry waste and its potentially harmful contents, resource recovery before the incineration might be chosen. For example, lead content must be determined beforehand because of the potential of lead to melt or even evaporate in the incineration chamber, polluting the atmosphere and causing harmful effects on humans and animals. However, recovery after the burning process is easier and more cost effective because metals and glass will not burn in the process, and can easily be retrieved from the remaining ashes. In order to separate metals and glass form the less dense and combustible materials before the incineration process takes place, complicated and

expensive processing is necessary. Metals can be separated by means of magnetic separation. Other recyclable materials can be separated by density separation.

Some combustibles need to be identified in the separation process. Textiles, for instance, are not easily shredded and pose problems for machinery involving rotating parts which the textiles tangle on. Also, combustibles include solvents which may cause explosions upon incineration. Dirt, glass, and sand are non-combustibles which have negative effects on mechanical processes. Non-combustibles clog machine parts and act as abrasives on gears (Hasselriis, 1984, p.7).

The ash produced from combustible materials presents another problem. Ash contains traces of vaporized metals and other products which cause complicated reactions once landfilled. The ash poses health and environmental problems as well (Hasselriis, 1984, p.7).

The moisture content can affect the burning of the waste. The moisture content of food and yard waste can reach 86 percent, while for paper it is anywhere from four to fifteen percent of the average (Hasselriis, 1984, p.8).

The common method for determining the weight fraction of moisture involves heating a sample of solid material to evaporate all of the water and then attribute the weight loss to the loss of water vapor. It should be noted, however, that some materials are not readily relieved of water, such as paper, food and yard waste.

The time required to dry materials depends on several factors. Among these factors are: the relative humidity of the atmosphere, temperature difference between substance and surroundings, and velocity of gases above solid surface (Hasselriis, 1984, p.9). Also, the thickness of material has a significant effect of the time needed to sufficiently dry the material.

In order to dehydrate products such as wood or foods, the material must be heated to a temperature sufficient to rupture the cellular material. For this reason, it takes a

significant and variable amount of time to dehydrate cellular materials (Hasselriis, 1984, p.9).

A proven method for determining the time and temperature required to dry a material is to heat the material and periodically measure the weight loss. From the weight loss data, the optimum conditions for drying can be determined depending on the accuracy desired.

In addition to the release of water upon heating, some volatile liquids may also be released. At temperatures above 110 degrees Celsius, many volatile liquids will be driven off. This expulsion of volatile liquids adds another dimension to the degree of error associated with weight fraction measurements (Hasselriis, 1984, p.9).

Dry waste can still contain metals and glass. If there is a market for these materials, then they can be recovered either through further processing, or by separation from the ashes after incineration. Whether these materials are separated or not , the waste is now suitable for burning.

Refuse derived fuels incineration processes are implemented for waste streams containing a paper content of 5.7 percent or higher. Guayaquil's waste stream contains a paper and cardboard content of 9.7 percent, an acceptable parameter for RDF preparation. The problem concerning fuel production involves the amount of humid waste in the waste stream. Combustible materials, including wood, paper and cardboard, plastics, garden wastes and textiles, make up 26.3 percent, but these are all combined with the rest of the waste, including all organic matter, making 90 percent of the MSW "wet" (Collazo, 1992).

The separation of the dry combustible materials from the wet organic matter presents the opportunity of implementing RDF processing while the organic matter remains intact to be used either in the composting process or to be landfilled for gas extraction. Both RDF production and materials recovery rely heavily on materials size

reduction and separation, presenting a costly waste management process option.

Determination of heating values for MSW and RDF production can be determined by chemical analysis or laboratory analysis by means of a calorimeter. Both methods require special laboratory equipment and techniques for the determination of the thermal energy released from the samples. Lab analysis of some of the constituents of MSW and their calorific values are given in table 3.2.

TABLE 3.2

MOISTURE AND HEATING VALUE

Constituents	*% Moisture Content*	*Heating Value* (Btu/lb.)
Textiles	13.2	7403
Wood	16.6	7108
Yard Waste	75.2	1970
Plastics	0.0	15910
Paper	18.9	6455

Data from Porteus, 1981

Given that combustible "dry" materials are separated from "wet" organic materials and assuming the moisture content of these combustible materials are within those from the theoretical values, the calorific values for MSW in Guayaquil are shown in table 3.3.

TABLE 3.3

Constituents	*% in MSW**	*Btu/lb.*	*% C.V.(x100)*
Paper and Cardboard	36.8	6455	2375.44
Plastics	30.4	15910	4836.64
Wood	17.9	7108	1272.332
Textiles	8.4	7403	621.852
Yard Waste	6.4	1970	126.08
"Dry" Combustible Materials	26.3	Total C.V. of MSW	9232.344

* (% Based on Weight)

A 9232.344 Btu/lb. calorific value for the "dry" combustible waste is a fairly high value compared to United Kingdom and United States produced RDF (refer to Table B1, Appendix B). This value is calculated from percent of constituents, for specific percent moisture content, after metals and glass have been taken off the waste stream using the Btu values from theoretical data. These values may be subject to change depending on actual percent moisture, weight distribution by percent of dry waste and efficiency of separation procedures.

3.2.7.4 The Gas Extraction Option

Because of the amount of putrescible matter found in Guayaquil's waste stream the potential for gas extraction from the decomposition of the organic matter yields a high energy recovery from MSW. Organic matter makes up 58.9 percent of Guayaquil's waste, but the implementation of a separation process would mean that the amount of waste landfilled would include residual ashes from the incineration process, organic matter and other materials not incinerated or recycled instead of the waste composition presented in figure 3.2. Table 3.4 gives the percent composition of waste landfilled after all resource recovery processes are implemented.

TABLE 3.4

PHYSICAL COMPOSITION OF LANDFILLED WASTE

Constituent	*% of Landfilled Waste*
Organic Matter*	77.16
Ashes	3.45
Metal & Glass	6.55
Other[a]	12.84

[a] Other: Includes construction waste and soil and small quantities of leathers and rubber.

* It is necessary to exclude the moisture content for proper lfg potential evaluation. The exact moisture content of the considered waste is not often known. Whenever unknown, a moisture content of 35% is taken as the best approximation.

The quantitative output of landfill gas varies from landfill to landfill because methane producing bacteria are very sensitive to a number of environmental factors. In theory, the biological decomposition of 1 ton of refuse can produce about 400 m^3 of landfill gas containing 55 percent methane and having a calorific value of at least 19750 kJoules/m^3.

In practice, however, conditions in landfills are not ideal for organic matter decomposition, so that only about one fourth to one half of the organic portion of the tipped waste decomposes. Furthermore, even in well designed and managed sanitary landfills, only 70 percent of the landfill gas, hereafter referred to as lfg, generated by the biological decomposition of organic matter in the landfill is abstracted through the extraction wells. In poorly managed sanitary landfills, the recovery of landfill gas can be as low as 25 percent. So that an average value of 100 m^3 of lfg containing 55 percent methane, per ton refuse appears as an acceptable value for the practical evaluation of the potential of lfg (LFG, from Environment to Energy, 1992).

Evaluation of lfg potential need thus take into account the mass of waste landfilled, its age and the prospective for the future. In landfills managed in steady-state conditions, namely with regular tipping over the years, the yearly potential can be approximated simply by the yearly mass of waste tipped, times the conversion yield of waste to lfg.

Table 3.5 presents waste production for a period of 10 years, the average lfg production estimated for those years and the total lfg production through the period.

TABLE 3.5

Year	*Waste Production** (tons/year)	*LFG Production* (m^3/ton)	*Total LFG Produced* (m^3)
1992	535.820	53582.0	53582.0
1993	556.625	55662.5	109244.5
1994	578.525	57852.5	167097.0
1995	601.155	60115.5	227212.5
1996	624.515	62451.5	289664.0
1997	649.700	64970.0	354634.0
1998	674.885	67488.5	422122.5
1999	701.895	70189.5	492312.0
2000	728.905	72890.5	565202.5
2001	757.740	75774.0	640976.5
2002	788.035	78803.5	719780.0
		Total LFG in 10 years	719780.0
		Lower C.V. for Total LFG (kJoules)	1.4215655^{10}

** Data from Operations and Maintenance Manual for Las Iguanas Sanitary Landfill, Hector Collazo, 1992.*

For the 1992-2002 period in lfg production, the average power output would be 45.0775 KWatt/hour using the theoretical data for gas production in the city of Guayaquil, Ecuador.

3.2.7.5 The Recycling option

There is already an extensive recycling operation in place in Guayaquil. In the current system, the chamberos sort the trash manually, and sell it to intermediaries. The intermediaries then transport trash to factories, and factories buy the recovered materials instead of using virgin materials. This system depends upon the operation of the San Eduardo landfill. When that landfill closes, the chamberos will lose the source of materials that they make a living off of, and industry will lose a source of inexpensive material that can be substituted for expensive imported materials.

Because construction for the Las Iguanas landfill has not been completed,

implementing a separation and recycling process is still a viable option. Materials could be either separated at the source, where the waste is produced, or it could be separated prior to being landfilled. Once waste is separated at the source, or as described above in the introduction section, separated materials could be sold to the markets that already make use of them.

3.2.7.6 The Composting Option

Composting could present a viable option for the city of Guayaquil. The composition of the waste favors this option. Over 50 percent of the waste generated by Guayaquil is organic. If composting were the only option implemented, the volume of waste needed to be landfilled would be reduced by one half, effectively doubling the operating life of the new landfill. The compost derived from the process could be sold as inexpensive fertilizer, and help pay for the cost of implementing this option.

The main obstacle towards implementing this process is that the market for compost is small. The main reason for this is that, according to Engineer Guillermo Castillo, the public believes that compost is unclean, and not nearly as efficient as production quality fertilizer.

3.3 POLITICAL ASPECTS OF LAS IGUANAS PROJECT

3.3.1 Introduction to Political Aspects

This section is designed to give the reader an understanding of the political structure and municipality operating procedures in Guayaquil. This information, in combination with Appendix A, provides a firm description of the political environment surrounding this project. The majority of the following information was provided by Engineer Guillermo Castillo, who works with both ESPOL and the municipality of Guayaquil.

3.3.2 Recent History of Waste Management in Guayaquil

In early 1992, the city of Guayaquil was engulfed in a crisis concerning waste collection. Only 40 percent of the municipal solid waste was being collected. The other 60 percent lay in huge piles in the streets in nearly every part of the city. The public protested about the waste problem, and in April of 1992, the government of Ecuador took action to help Guayaquil.

The government removed all of the officials from the Department of Aseo Urbano, the department responsible for waste collection. The government cited corruption in the Department of Aseo Urbano as the reason for action.

The decision to completely privatize waste collection was made and two companies were selected to run the collection process, namely: Bande and Ecualimpia. These companies are still in operation at this point and will continue until the new landfill is opened. The companies have divided the city into sectors which are treated separately when awarding the companies for the work. The municipality pays the companies by "clean sectors". The Department of Aseo Urbano employs a team of 19 supervisors, led by Andres Intriago, who inspect the sectors to insure that the collectors are doing their

job. There are formal guidelines for penalizing a company if they do not fulfill their obligations. The penalties are 75 percent, 50 percent, or 0 percent pay depending on the success or failure of the collection company. The municipality has had problems with collection companies that pick up the waste from their sectors but do not bring the waste to the landfill site; instead, the waste is dumped along the side of the road. For this reason, a different collection system will be implemented in the new landfill.

3.3.3 Las Iguanas Project

The Las Iguanas Project was contracted by the municipality and the design was completed by ESPOL in August of 1992. The study was undertaken to find a solution to the crisis documented above. The technical part of the ESPOL proposal was headed by Guillermo Castillo, while the Socio-Economic Impact Assessment was headed by Luis Torres.

The ESPOL proposal cited Las Iguanas as the most acceptable site for a sanitary landfill. Also, the report presented a sanitary landfill as the only option for waste disposal. The estimated cost for the landfill is $80 million.

The Las Iguanas proposal was accepted by the municipality and procedures are underway to open the Las Iguanas landfill in the summer of 1994. The collection for the new landfill will be completely privatized, as in the existing landfill at San Eduardo. However, one company will be responsible for the collection of waste and one company will be in charge of running the landfill site.

The companies competing for the collection and operation are in the process of being selected. First, a committee in the municipality reviews the proposals submitted by the companies and determines whether each proposal is socially, technically, politically and legally acceptable. Then, if the proposal passes the above requirements, the committee looks at the financial proposal submitted by the company. If both proposals pass, the

municipality has the option of awarding the overall contract to the company or waiting for a better offer. The entire decision-making process usually takes between four and six months.

The collection procedure will be different for the Las Iguanas landfill from the existing method. The company responsible for waste collection will be paid according to the weight of waste emptied into the landfill. The trucks will be weighed upon entering and leaving the landfill and weights will be kept on record for the duration of the pay period. It is the opinion of Eng. Guillermo Castillo that this method of collection will be an incentive for the collection company to deliver the greatest amount of waste possible to the landfill.

3.3.4 Political Reality in Guayaquil

The following quote by Eng. Guillermo Castillo illustrates why Ecuador lacks the technical levels reached in other countries due to political constraints. It also demonstrates the attitude the municipality has towards the public service problems. According to Eng. Castillo they are looking for technical solutions to the problems and are totally ignoring the social problems created by the same decisions.

> "Guayaquil does not have a good waste collection program because of its lack of a technical administration. There are no adequate technical procedures being applied. Public services should be able to operate autonomously, oriented by non-political boards of directors or technical organizations. No financial, technical, or administrative solutions or efficiency will be reached while public services remain politicized."
>
> Eng. Guillermo Castillo
> Chief of Planning
> Dept. of Aseo Urbano

3.4 SOCIAL IMPLICATIONS OF LAS IGUANAS PROJECT

3.4.1 Introduction to Social Issues

This section is constructed to illustrate the severe social effects of the Las Iguanas project. Valuable information to this section was gathered through on site visits to the San Eduardo landfill and the Las Iguanas site, while the majority was completed with the assistance of economist Luis Torres and Fundación Madredolorosa representative Walter Samaniego. Fundacion Madredolorosa is a non-profit organization, based in Colegio Javier in Guayaquil, that helps the needy in Guayaquil. Engineer Guillermo Castillo also contributed significantly to the following information.

3.4.2 Introduction to the Chamberos

There is currently a group of individuals, known as chamberos, working in the San Eduardo landfill. The chamberos make a living by collecting recyclable materials to sell. The chamberos recover paper, plastic, cardboard, cans, wooden boxes and other materials. The most important material recovered by the chamberos is plastic. Plastic has the highest value as a recyclable in Guayaquil. These people stand in the trash waiting for the trucks to dump the waste. As the waste falls from the truck, with their bare hands, they recover the useful materials, which are sold to intermediaries. The intermediaries, having means of transporting these materials, take the recyclables to factories that buy the materials for reuse.

Some of the chamberos live in the landfill itself. They have constructed housing, similar to the so called "invasiones" which surround Guayaquil, on the sides of the mountains surrounding the landfill. This housing contains no sewage or electrical facilities; thus there are extremely unsanitary conditions. The chambero population, by most recent estimate, is close to 3,000 people. According to Luis Torres, this is a stable

population with little immigration. These individuals make up a very diverse group, presenting a great variety in age groups and places of origin. The chamberos come from all corners of the country, including the city of Guayaquil, the Esmeraldas region, the Chimborazo vicinity, and others. The most common reasons for their migration to Guayaquil are the search for a job, better living standards, family problems and an affinity for city life. Many of these people became chamberos out of desperation for work. Also, a large number of the chamberos are criminals who take refuge in the landfill. Because the police are afraid to enter the landfill, these criminals are free to work as chamberos.

The average chambero family has an income well over the minimum salary, but, by comparison, a chambero family works an average of twelve hours a day, including weekends, and in much more unsanitary conditions than the average worker. One third of the population makes an average of $55 per day (S\. 105.000 per day). Most of this money comes from the intermediaries, who, in 87 percent of the cases, buy the materials from the chamberos. In other cases, the chamberos sell the materials directly to the factories. Fundación Madredolorosa is currently working with the chamberos in a program to provide some of the chambero families with transportation to sell their materials. The transportation helps the chamberos avoid giving the materials to the intermediaries who, in most cases, take advantage of the chamberos because of their lack of dependability and available resources.

The source of the chamberos economic problems is the combination of their low income and poor money management practices. In some cases, the money they make at the landfill site is spent on drugs. The problem is exacerbated by the drug dealers who constantly visit the dump site. In some cases the dealers are the same people who buy the materials; often they are the same military personnel who operate the landfill site.

3.4.3 Social Structure of the Chamberos

Having little conventional social structure, the chamberos live in a society that does not contain any formal commitments to the rest of the individuals around them. The predominant marital status of the chamberos is the "free union", meaning that they live together and share some of the household responsibilities, but in most cases faithfulness is not a part of their lives. Juveniles constitute 54.3 percent of the individuals; of those, approximately 1500 children under fifteen work as chamberos. Education levels among the chamberos is very low. About 45 percent have completed their primary education, while only 6 percent have completed secondary. Health is poor in their homes because of lack of sanitary conditions in which they live and because of the lack of medical aid.

The chamberos organized by the Fundación Madredolorosa formed a cooperative to collect the waste. In this cooperative they work together to collect the waste in an organized fashion, such as assigned rows in the sorting section, so that no duplicate sorting is done and no effort is wasted. Materials are sold to the intermediaries together as a group, and the profits are divided equally between the members of the cooperative. The cooperative can be very selective on the members that join them, excluding those chamberos who have no incentive to improve their situation. Instead, they look for people who want to become a part of their community and who show they do by participating in their activities and community work. This group has obtained housing from the Fundación Madredolorosa and formed a small community comprised of 30 families. There is enough housing for an additional 50 families that may want to join their community.

3.4.4 Social Impact of Las Iguanas Project

Changing landfill sites from San Eduardo to Las Iguanas will have an impact not only on the technology being used for the disposal of the waste, but on the chamberos. The chamberos are totally ignorant of their future work status when the Las Iguanas

landfill is opened. It is their belief that, in the new landfill, they will be able to continue their work. This belief is supported by everybody around them with the purpose of keeping them working happily. The military, for example, tell the chamberos that they will be allowed into the Las Iguanas landfill and will be provided with uniforms and masks. Fundación Madredolorosa is the only source that tells them the truth about their access to Las Iguanas. The foundation finds the situation frustrating because the chamberos are convinced that they will be allowed into Las Iguanas.

Closing San Eduardo will leave the community with the problem of what to do with the people presently living at the San Eduardo site. In the new landfill site these recyclers will not be allowed to continue their collection work. Therefore these 1,000 families will find themselves without work after San Eduardo closes down. Also, the municipality is planning on evicting the chamberos from San Eduardo once the landfill is closed. The chamberos know nothing of the municipality's plan and there will likely be a tremendous conflict when the chamberos are forced out of San Eduardo.

When the decision to close San Eduardo because of its lack of available landfill space was reached, Las Iguanas was chosen to be the designated spot for the new landfill. Although the site fulfills all geotechnical requirements for the construction of a sanitary landfill, its location is still a controversial aspect of the Las Iguanas project. It is the opinion of economist Luis Torres that the geographical location of the new landfill ignores the social part of the problem. The Las Iguanas designated site is located approximately 14 km from the city center, but it lies across the street from the invasiones that inhabit the area illegally, surrounding the city. Within two years, the constant growth of the invasiones will engulf the landfill site, creating health and environmental problems around the vicinity of the landfill.

Originally, the municipality considered the idea of involving the chamberos in a source separation program. This program would have the chamberos transported around

the city collecting waste separated at the home. The suggested program was designed to be a reasonable solution to the chamberos' problem, but many factors proved that such plan would not work. To involve the chamberos in a source separation program would require their organization by the municipality, their cooperation and the cooperation of the citizens of Guayaquil. The social perspective of the citizens of Guayaquil towards these individuals showed that it would be unlikely that both could work together because the chamberos are unlikely to leave the dump site to work in the city with others, and because others might not adapt well to working with them. Many citizens are afraid of the chamberos because they are perceived as poor, dirty and prone to criminal behavior. Most of the chamberos fear leaving the dump site and its protection from society.

3.4.5 Bogota Case Study

In Bogota, Colombia, there was a similar situation, where the government decided to close the existing landfill and open a new one. The landfill was similar to the San Eduardo landfill in Guayaquil in that a large number of families lived in it, recycling materials for a living. For sanitary and operational reasons, when the landfill site was changed the government decided not to let the recyclers enter the new landfill site. Information on the whereabouts of the recyclers is unknown, except all of them had to go to the streets to find a living. The materials that these recyclers collected went on to be landfilled in the new landfill site, leaving the recyclers without a source of income and the industries without the materials to substitute for the costly virgin materials. This is a good example of what could happen in Guayaquil to industry and the chamberos if no measures are taken by the municipality.

In Guayaquil, no recovery program is being scheduled for the new landfill, so the materials being recovered by the chamberos in the San Eduardo landfill will not be recovered in the new site. In order to recover these materials a separation process could

be designed involving either a manual separation facility or including machinery that will do the work.

3.4.6 Medellin Case Study

In Medellin, Colombia, an outstanding achievement was reached by the Recuperar Cooperative. The Cooperative supports the manual recyclers and helps them become small businesses by giving them financial support as well as technical and administrative advice.

After eleven years of living in the open landfill, when the landfill site was scheduled to be closed, the basuriegos (Colombian chamberos) got together to fight for the same cause. For the first time, government, the basuriegos and private enterprise got together, forgetting past confrontations, to find that they had similar goals and they were all willing to put their efforts together to reach them. A precooperative was formed in order to help the basuriegos become entrepreneurs, and although it was difficult to achieve, most basuriegos reached a level of self support and a stable business. The precooperative taught the basuriegos such basic skills as: basic accounting, first aid, industrial safety, human relations, fire safety, and, most of, all they talked to them to gain their confidence. With the support of other established companies, the precooperative became a cooperative and the basuriegos became stable businessmen.

Today, the cooperative manages recycling enterprises from paper and cardboard to plastics. These are private enterprises that collect recyclables, sort them, clean them and transport them to the industries buying them. Recuperar also has a sorting plant next to the landfill site from which they sort and recover the recyclable materials going into the landfill site.

The similarities between the Bogota case and the current situation in Guayaquil

are striking. As in Bogota, the government of Guayaquil has no current plan to help integrate the chamberos into society. The Bogota basuriegos' experience gives hope and a possible solution to the crisis the chamberos will soon face in Guayaqil.

4.0 CONCLUSIONS

- After analyzing the application of alternatives to a sanitary landfill in Guayaquil, we have come to the conclusion that the most feasible alternative is a separation program to recover the recyclable materials from the waste stream.

- Although the waste management processes described in this paper are aimed at the efficient reduction of waste, the implementation of these processes in the city of Guayaquil would not be successful due to a number of reasons. The implementation of a composting plant would be unsuccessful because of the competitive market occupied by fertilizer companies. An incineration facility would be too expensive and would contribute to the already existing problem of pollution. And Guayaquil does not have the technology or adequate personnel to run a landfill gas extraction facility.

- The success of a recycling program depends on the awareness of the citizens of Guayaquil, shown by the practice of source separation and the support of a selective collection system.

- The Medellin experience shows that chamberos are not excluded from the business world and that with the support of the municipality, they can expand quantitatively and qualitatively, becoming an important part in the recycling community.

- If the chamberos are allowed access to the new landfill, then they will be assured of a means of living in the future, and the companies that buy materials from them

will be assured of a continued supply of reusable materials.

- Because of the similarity between the situations in Bogota and Guayaquil, the results of the Bogota case present a probable outcome to the present situation in Guayaquil. That is, if no action is taken to assist the chamberos, they will end up unemployed and unsheltered.

- The proposed collection program for the Las Iguanas landfill does not account for the inspection of city zones, therefore, some areas might be overlooked and become overrun with municipal waste.

- The social crisis involved with the landfill implementation program will not be resolved until the municipality begins searching for humane solutions to problems instead of merely technical solutions.

5.0 RECOMMENDATIONS

- The implementation of a secondary separation facility at the landfill site would prevent the loss of the recyclable materials that will not be collected by the chamberos at the new landfill site. Therefore, it would be beneficial for the city of Guayaquil to implement a secondary separation program at the Las Iguanas landfill to retrieve the recyclable materials.

- The municipality should support the recycling process and set an example by promoting the process from the small collection enterprises to the big industries to create an overall growth of the recycling business.

- The municipality could encourage separation at home through media exposure and educational programs. An incentive to a source separation could be set by the municipality, proposing, for example, alternate collection days for organic and inorganic materials. The success of such a program will depend on the awareness of the public, which has no intervention with the collection process.

- Combining the present collection process with the proposed process would allow for a more comprehensive strategy for maintaining the cleanliness of the city streets. Decreasing the number of members on the present supervising team, instead of eliminating it, would give the collecting company more of an incentive to collect all the waste.

- Negotiations between the Municipalidad and the chamberos should provide solutions to problems faced by both groups. The negotiations could take place through Fundación Madredolorosa. Negotiations should begin immediately to assure a peaceful transition between the San Eduardo and Las Iguanas landfills.

APPENDIX A.

ESPOL - WPI - USAID LINKAGE.

This project was funded by the United States Agency for International Development. USAID supports projects which bring technology to developing nations. This project will serve as a resource for future USAID ventures in developing countries.

The host for this project was Escuela Superior Politecnica del Litoral, in Guayaquil, Ecuador. The faculty of ESPOL presented this project out of concern for the current situation in Guayaquil. The Earth Science Department expressed deep concern over the social effects of opening the Las Iguanas landfill and closing the existing landfill at San Eduardo. These concerns, compounded by the search for appropriate technological alternatives to a sanitary landfill, provided a basis for this project.

It should be noted that the proposal for the Las Iguanas landfill was submitted by ESPOL. The Las Iguanas proposal was meant to be a working manual for the new landfill. This project in no way aims to dispute or contradict the Las Iguanas proposal. This project was designed to analyze the social implications of the Las Iguanas proposal and to propose alternatives to a sanitary landfill that might benefit the people of Guayaquil.

APPENDIX B

TYPES OF SIZE REDUCTION MACHINERY

Cutters

Cutters, such as chippers, shears, and granulators use sharp edges to shear materials, after which the materials are passed through apertures.

Chippers are high speed rotary devices (with speeds up to 1800 rpm) designed to reduce logs or heavy members of wood to chips by allowing the wood to enter a cavity in a rotating cylinder, sufficiently for the sharp cutting blades to shave off a chip as the rotating blade passes a stationary blade. These machines are as unsuited to cutting paper or rubber as they are ideal for wood. The cutters can be damaged by metals and other hard objects in the feed.

Granulators are medium-speed rotary devices having sharp knives in the rotor that engage in a scissor-like manner with angled stationery knives to cut plastics and other dense, uniform materials. The feed material is kept in suspension above a grate so that the cutters keep cutting the material until it will pass through the holes in the discharge grate. These machines are designed to minimize fines, as are the chippers, and rely on the sharpness of the knives. They are not suited for sticky or abrasive materials. Air movement is required to assist the material passing through the grate.

Rotary shear cutters are slow-moving devices (20-30 rpm), having one or two rotors. The single rotor type has blades mounted on the rotor that pass by stationery blades, shearing the feed and forcing a portion of it through the gap between the blades. The double-rotor type has crescent-shaped cutters, assembled on the shafts with spacers between them. The rotor move in opposite directions at different speeds, so that the cutters engage the feed material, shear it, and carry a portion of it through a

space between the rotors. This results in a shearing and tearing action that is effective in cutting tires, metals and other dense materials into slabs of a size determined by the dimensions of the gap. These cutters are particularly suitable for shredding wood, nonferrous extrusions and castings, and aluminum and light steel cans. Municipal refuse without excessive amounts of paper and cardboard can be shredded by these machines. Paper is particularly difficult for this type of machine to handle due to its toughness, which requires great power and sharp knives, and low density, which reduces capacity. When used for cutting rubber, cutters can cause the rubber to heat up to the point at which it gets sticky, ultimately reducing capacity. This heat can be controlled by water cooling or by feeding sufficient amounts of other materials, such as paper and wood.

Rotary shears are usually driven by hydraulic drives, which will disengage when loaded beyond their maximum safety tolerance. Thus, they are not subject to damage when heavy metal objects are encountered or when the piece of material engaged becomes compressed in such a way that it cannot be passed. The Saturn rotary shear is provided with a hydraulic control, which automatically reverses the rotors to discharge the jammed material, then returns to normal rotation (Hasselriis, 1984).

The capacity of a rotary shear is limited by the length and diameter of the rotors, which represents the size of the feed hopper; the circumferential speed of the rotors and the clearance between them; the density of the feed material; and the ability of the cutters to grab the feed.

The machines are well suited to relatively low capacity applications. The largest Saturn cutter, equipped with two 300-hp hydraulic drives, is suitable for shredding municipal and industrial refuse, passenger and truck tires and wood pallets (Hasselriis, 1984).

Flail Mills

Flail mills are relatively high-speed horizontal-shaft rotary machines having one to four rotors, to which are attached swinging hammers, either single or double articulated. Single rotor flail mills are used as bag breakers. The rotors are spaced so that the hammers nearly touch when running free, to engage and impact material entering from the top or side, cutting or smashing it as it is passed through. The rotor clearance, minus the hammers, determines the dimension of the largest object that can pass through without change of shape, such as a log of wood. The rotors may be operated at different speeds to increase shearing effects.

The hammers fold back or withdraw when they engage dense objects, passing them through relatively unaffected. This reduces the power requirements for the mill but requires that these object be separated from the product downstream of the mill. A rotary screen is useful for this purpose.

Flail mills tear or smash the feed without forcing it through a screen. Large or difficult objects are passed through directly, whereas lighter materials may be entrained by the flails and passed through more than one time. Breaker bars, located under the flail discharge, are used to smash objects that otherwise could pass through unaffected.

Hammermills

Hammermills have rotating shafts onto which are attached stationery or pinned hammers, which attack the feed material in different ways and drive the materials through the discharge, with or without grates. Grates may range in size from a full discharge opening, with only breaker bars to smash the material, to small holes that ensure that all the material passing through will be less than the hole size. The thickness of the hammers used ranges from 1/8 inch to 6 inches and that of the gate openings from 1/8 inch to 12 inches (Hasselriis, 1984). The feed handled ranges from

automobiles to office waste paper. There are two basic types:

-Horizontal-shaft hammermills have hammers that smash the materials against the breaker bars and the grates; oversize objects are retained until the material is able to pass through the grate, unless it is rejected unto a metal trap.

-Vertical hammermills control particle size by the clearance between the hammers and the irregular wall, rather than by the size of the grates.

Some rugged, high-horsepower hammermills are designed to shred large and difficult objects, such as appliances, pallets, logs, tires and engine castings. Lighter machines must be protected from such feed materials.

If such objects can arrive into the feed and can fall into the mill, either the mill must be designed to discharge these objects through the grate or another discharge must be provided. Several methods are available to accomplish this.

Horizontal-shaft mills can be equipped with metal traps that catch the metals that do not get caught to grate size. These traps become ineffective if they fill up during the operating period of the machine.

The heil vertical-shaft mills are designed with conical sides to throw dense objects out of the mill. In this way they are not forced to remain in the machine until they are reduced to a size that can pass through the discharge openings (Hasselriis, 1984). Along with the undesirable heavy objects, a considerable amount of other material is discharged to a conveyor.

Vertical-shaft mills rely on the clearance between the hammers and the conical cylinder within which they rotate to determine the size of the particles discharged, rather than the size of the discharge openings. Vertical bars are attached to the cone to provide more effective cutting of tough materials, such as textiles. They are sensitive to air movement through the grates and work best with an induced air flow.

Many of the mechanical and design features of hammermills influence their

performance, such as feed configuration, grate size and shape, means of adjusting hammer-grate clearance, ability to relieve under jamming situations, and ability to operate in both directions to avoid reversing hammers. The metallurgy of the liners and hammers, methods of building up worn hammers by half-facing, and optimum methods of replacing hammers have been the subject of extensive research, making the new technology accessible to the user.

Densifying Machinery

Pelletizing machines are used to compress shredded refuse fuels into dense pellets, which can be stored, retrieved and fed to be burned on stoker-fired boilers. The pelletizer feed must have sufficient moisture content and be reduced to a small enough particle size before feeding.

Powdered refuse fuel can be fed to a briquetting machine and densified into briquettes suitable for burning in a coal stove or stoker.

The true densities of briquettes must be greater than 65 lb/ft^3 to assure integrity. Bulk density of these densified refuse fuels is about 25-35 lb/ft^3. About 15 kW/ton of power is required for densification (Hasselriis, 1984).

APPENDIX C

CHEMICAL COMPOSITION OF LANDFILL GAS PRODUCTION

Aerobically:

cellulose

$(C_6H_{12}O_6)\ n > n\ (C_6H_{12}O_6)$

microorganisms

$n\ (C_6H_{12}O_6) + 6n\ (O_2) > 6n\ (O_2) + 6n\ (H_2) + n$ (Calories)

glucose

Anaerobically:

$(C_6H_{12}O_6)_n > {}_n(C_6H_{12}O_6)$

cellulose glucose

${}_n(C_6H_{12}O_6) > 2n\ (CH_3CH_2OH) + 2n\ (CO_2)$

glucose ethanol + n calories

methano bacteria

$2_n\ (CH_3CH_2OH) + {}_n(CO_2) > 2_n\ (CH_3COOH) + {}_n(CH_4)$

ethanol acetic acid

methano bacteria

$$2_n\,(CH_3COOH) > 2_n\,(CH_4) + 2_n\,(CO_2)$$

acetic acid methane

APPENDIX D

The following handout was provided to the audience of the formal presentation on Dec.3, 1993 at ESPOL, Guayaquil, Ecuador.

Administración de Desechos Urbanos en la Ciudad de Guayaquil, Ecuador

Convenio, WPI & ESPOL
con la colaboración de Daniel Tapia

Preparado por:

Allan Concepción
Francisco Pereyó
Obadiah Plante

Diciembre 1993

Agradecimientos

Quisiéramos agradecer especialmente a los individuos quienes colaboraron durante el desarrollo de este progecto y por su aportación de data la cual ayudó a concluir el mismo. Particularmente deseamos agradecer a los señores Walter Samaniego, Luis Torres y el Ing. Guillermo Castillo por su cooperación.

Objetivos

- Analizar las vías alternas para el manejo de desperdicios con el fin de proponer un sistema apropiado para la ciudad de Guayaquil.

- Investigar las implicaciones sociales y los aspectos políticos relacionados con la implementación del relleno sanitario en el sector de Las Iguanas.

Métodos de Administración de Desperdicios Investigados.

- Composte- La fermentación acelerada de desperdicios orgánicos con el fin de disminuir el volúmen de los desperdicios que sean rellenados, y la producción de material acondicionador de suelo. La dificultad de implementar este proceso es el competitivo mercado que presentan los fertilizadores de producción extranjera.

- Incineración- Mediante la selección de desechos combustibles y su adecuada preparación, la implementación de un

proceso de incineración presenta un método de reducir los desechos rellenados mientras se recupera energía del proceso de incineración. Desgraciadamente este proceso incluye maquinaria costosa e implica una gran aportación al existente problema de la contaminación ambiental.

- Extracción de Gas- La extracción de gas del relleno sanitario en el sector de Las Iguanas se presenta como una opción viable debido a la cantidad de desechos putrecibles presentes en la basura de la ciudad de Guayaquil. Debido a que este proceso requiere el manejo dedicado del relleno, ademas del uso se equipo técnico elaborado, la falta de técnicos apropiados presenta una complicación en la aplicación de este método.

- Reciclaje/Reuso- Mediante un método de separación selectivo es posible la recuperación de materiales reciclables con el propósito de ser vendidos a las fábricas para sustituir el uso de materia prima. Este proceso puede ser implementado en la fuente (en los hogares), o en el relleno de Las Iguanas mediante separación manual o mecánica.

Impacto Social

La implementación de un nuevo relleno sanitario tiene ciertos efectos secundarios. Al cerrar el botadero actual, la Municipalidad se enfrenta con el problema de tratar con los individuos que practican el reciclaje en el botadero. Por razones higiénicas y de manejo del relleno sanitario, a estos individuos no le será permitida la continuación de su trabajo en el relleno sanitario de Las Iguanas. La Municipalidad no cuenta al presente con un programa de organización ni trato hacia estos "chamberos".

Por esta razón el futuro de estas personas es desconocido. Por otra parte, los materiales que son actualmente reciclados por los chamberos, no seran recuperados en el relleno de Las Iguanas debido a la falta de un programa de reciclaje y la falta de los chamberos recicladores.

Conclusiones

- Luego de analizar las opciones se ha concluido que la alternativa óptima para Guayaquil es un programa de separación para recuperar los materiales reciclables.

- El éxito de un programa de reciclaje depende de la conciencia y el apoyo de la ciudadanía Guayaquilena, desempeñándose en un programa de separación en la fuente.

- La similitud de los hechos ocurriendo en el botadero de Guayaquil con los hechos ocurridos el la ciudad de Bogotá, Colombia, presentan un posible desenlace de los hechos al cerrar el botadero en el sector de San Eduardo. Los individuos que se emplean en el presente botadero se veran sin trabajo ni medios de sobrevivir al no poder ingresar al botadero en Las Iguanas.

- La crisis social involucrada con la implementación del relleno sanitario de Las Iguanas, debido a la prohibición del ingreso de los chamberos a dicho relleno, no será resuelta mientras la municipalidad busque únicamente soluciones técnicas sin considerar los aspectos sociales del problema.

ACRONYMS

EPA- Environmental Protection Agency

ESPOL- Escuela Superior Politecnica del Litoral

HDPE- High Density Polyethylene

LFG- Landfill Gas

MSW- Municipal Solid Waste

PET- Polyethylene terephthalate

PVC- Polyvinyl Chloride

RDF- Refuse Derived Fuels

RES- Recycle Energy Systems

TCLP- Toxic Characteristic Leading Procedure

USAID- United States Agency for International Development

WPI- Worcester Polytechnic Institute

GLOSSARY

aerobic- any biological process which requires oxygen.

anaerobic- any biological process occurring in an oxygen-free environment.

basuriegos- scavengers.

cullet- crushed glass.

chamberos- scavengers.

cryogenic- very low temperatures.

fermentescible- able to decompose organically.

flare- the combustion of gas without the implementation of energy recovery processes.

mesophyllic- a term which describes a chemical or biological process occurring within a moderate temperature range - generally 15 to 40 degrees Celsius.

methanogenic- a biological or chemical process which generates methane.

pressure-swing water scrubbing- process in which the pressure is varied greatly in order to remove dissolved contaminants.

putrescible- decomposable organic matter.

stratification- separation into layers by weight, density, or any other physical properties.

temperature-swing- process in which temperature varies greatly in an activated carbon medium in order to remove hydrogen sulfide from the sample.

thermophyllic- a term which describes a chemical or biological process occurring at relatively high temperatures, generally 45 to 65 degrees Celsius.

REFERENCES

Barton, Allan. Resource Recovery and Recycling. New York: Wiley-Interscience, 1979.

Brown, Lester. Saving the Planet. New York: W.W. Norton & Company, 1991.

Butson, J, et al. Landfill Gas. From environment to Energy. Luxembourg: Office for Official Publications of the European Communities, 1992.

Castillo, Guillermo. Personal Interview. 4 Nov. 12 Nov. 1993.

Currie, R.E. "Landfill Gas to Electricity Project." Local Government Engineering Conference. Hobart, 1991.

Denison, Richard, and John Ruston. Recycling and Incineration. Washington DC: Island Press, 1990.

Ecuador. M.I. Municipalidad de Guayaquil. Impacto Socioeconómico del Relleno Sanitario Las Iguanas. ESPOL, prepared by Luis Torres, 1992.

Ecuador. M.I. Municipalidad de Guayaquil. Manual de Operación y Mantenimiento, Relleno Sanitario Las Iguanas. Convenio: La Cementos Nacional, Fundación Francisco de Orellana, and ESPOL, prepared by Hector Collazo, 1992.

Espinoza, Guillermo G, and Thomas M. Jantzen. "Use of Landfill Gas Will Save Money and Reduce Emissions." Fuel Strategies for Conventional and Unconventional Fuels. ASME, 1991.

García, R. Higinio. Residuos Sólidos Urbanos. Escuela de Organización Industrial, Ministro de Industria, Comercio y Turismo. 1992.

Golueke, Clarence. The Biocycle Guide to Composting Municipal Wastes. New York: The J.G. Press Inc, 1989.

Hasselriis, Floyd. Refuse Derived Fuel Processing. Boston: Butterworth Publishers, 1984.

Henstock, Michael E. Design for Recyclability. London: The Institute of Metals,

1988.

Herbst, Kris. "Brazil, Advances in Recycling in the Third World." Waste Age Sept. 1992: 51-56.

Knox, Peter J. Resource Recovery of Municipal Solid Wastes. New York: American Institute of Chemical Engineers, 1988.

Lechter, Robert C. "Source Separation and Citizen Recycling, Chapter 10." Solid Waste Handbook.

Meade, Kathleen. "Mexico City Moves Mountains of Waste." Waste Age. April, 1992: 150-154.

Porteous, Andrew. Refuse Derived Fuels. London: Applied Science Publishers LTD., 1981.

Powellson, David, and Melinda Powellson. The Recyclers Manual for Business, Government and the Environmental Community. New York: Van Nostrand Reinhold, 1992.

Processing Costs for Residential Recyclables at Materials Recovery Facilities. National Solid Wastes Management Association, 1992.

Samaniego, Walter. Personal Interview. 16 Nov. 28 Nov. 1993.

Torres, Luis. Personal Interview. 9 Nov. 28 Nov. 1993.

Williams, Susan. Trash to Cash. Washington DC: Investor Responsability Reaserch Center, 1991.