December 9, 2008
Dr. Sergio Musmanni
Executive Director, CNP+L
Apartado 10.003-1000
San José, Costa Rica

Dear Dr. Musmanni,

Attached is our report entitled Biodegradable Municipal Solid Waste in Santo Domingo de Heredia. It was written in Costa Rica during the period of October 21st to December 9th, 2008. Copies of this report are simultaneously being submitted to Professors Bar-On and Robertson for evaluation. Upon faculty review, the original copy of this report will be catalogued in the Gordon Library at Worcester Polytechnic Institute. Thank you for the time and effort you have devoted to us and our project.

Sincerely,
Scott Almquist
Kelton Barnsley

Biodegradable Municipal Solid Waste in Santo Domingo de Heredia

Report Submitted to:

Isa Bar-On Tom Robertson

Costa Rica, Project Center

By

Scott Almquist

Kelton Barnsley

In Cooperation With

Dr. Sergio Musmanni, Executive Director
Carlos Perera, Technical Director

Centro Nacional de Producción más Limpia

BIODEGRADABLE MUNICIPAL SOLID WASTE IN SANTO DOMINGO DE HEREDIA

December 9, 2008

ABSTRACT

This project, prepared for the Centro Nacional de Producción más Limpia, explores the feasibility of using composting and/or biogas technology in the municipality of Santo Domingo de Heredia, Costa Rica, in order to reduce their volume of solid waste and thereby increase the lifespan of their new landfill. Using data obtained through interviews and literature review we prepared a cost benefit analysis of available technologies and developed a course of action to improve the management of biodegradable waste in the municipality.

EXECUTIVE SUMMARY

This report details the shortage of landfill space in Santo Domingo de Heredia and explores the feasibility of implementing various technologies for the conversion of organic waste into compost and biogas.

The landfill in Santo Domingo will be full by March of 2009, and the local government is still negotiating the purchase of nearby land which would be used to build a new landfill. In the interval between the closing of the current landfill and the opening of the new one, Santo Domingo will have to pay to have its waste disposed of in a privately owned landfill. Therefore, the government of Santo Domingo is interested in finding ways to decrease the amount of solid waste that they must dispose of, not just to ease costs in the interval between landfills but also to extend the lifespan of the new landfill once it is built. Since roughly 69% of Santo Domingo's solid waste is organic and biodegradable, composting this material would reduce the volume of waste which must be disposed of in the landfill. A composting or biogas program could also provide potentially salable or otherwise useful products such as solid compost, which can be used to aid the growth of plants, and biogas, which can be burned to produce heat or electricity.

The main goal of this project was to recommend an effective technology for the biodegradation of Santo Domingo's organic waste. To this end, we researched several different commercially available composting and biogas-producing technologies, mainly by contacting the vendors and requesting information. Of these, the Biogas Transformation Unit, or BTU, offered by Blue Technology of Belgium, was selected for closer investigation. In addition to this, we examined the use of open anaerobic compost piles (which do not allow for the capture of biogas) as a low-tech alternative. The latter option is based on an experimental pilot program for composting in the municipality of Jimènez in Cartago.

We then analyzed the costs and benefits of implementing either of these two alternatives in Santo Domingo. Factors considered were the initial investment required, cost of labor, cost of educating the public about the program, extension of the lifespan of the new landfill (thereby avoiding the cost of disposing of waste in a private landfill), selling price of electricity produced from the biogas, benefit to the environment, and improvement of Santo Domingo’s public image in the eyes of the environmentally conscious.

Our analysis showed that while both alternatives would extend the life of the landfill considerably, only a program based on the Jimènez model would be profitable in most scenarios because it would require a smaller capital investment and similar labor costs. Therefore we recommend that Santo Domingo begin a pilot program similar to the one in Jimenez for the time being. We also recommend that they begin collecting more specific data on the composition and density of the organic waste which they produce. Once the officials in Santo Domingo have more reliable data to work with, they should reevaluate the option of investing in Blue Technology’s BTUs or a similar technology. Santo Domingo should also devote attention to educating the public about the need to participate in the pilot program in order to help extend the life of the landfill. Finally, the municipality must formulate and maintain long-term environmental goals so that they can deal with potential problems more effectively in the future.

AUTHORSHIP PAGE

- CHAPTER 1: INTRODUCTION - Scott Almquist
- CHAPTER 2: BACKGROUND - Kelton Barnsley
  - THE WASTE MANAGEMENT PROBLEM IN SANTO DOMINGO - Scott Almquist
  - SUSTAINABILITY IN WASTE MANAGEMENT SYSTEMS - Kelton Barnsley
    - Generalized Problems with Landfill Systems - Scott Almquist
    - The Benefits of Composting and Biogas - Kelton Barnsley
  - ECONOMICS OF A COMPOSTING AND BIOGAS SYSTEM - Scott Almquist
  - SEPARATION OF ORGANIC FROM INORGANIC WASTE - Kelton Barnsley
- CHAPTER 3: METHODOLOGY - Scott Almquist
  - OBJECTIVE 1: PROPORTION OF BIODEGRADABLE WASTE COMPARED TO TOTAL MUNICIPAL SOLID WASTE - Kelton Barnsley
  - OBJECTIVE 2: IDENTIFY AVAILABLE TECHNOLOGIES - Scott Almquist
  - OBJECTIVE 3: COST OF SEPARATE COLLECTION OF ORGAINC WASTE - Kelton Barnsley
  - OBJECTIVE 4: COST BENEFIT ANALYSIS OF THE SYSTEM - Scott Almquist
  - OBJECTIVE 5: SOCIAL AND ECONOMIC REASONS FOR THE PROBLEM - Kelton Barnsley
- CHAPTER 4: RESULTS AND DISCUSSION - Scott Almquist
  - ORGANIC WASTE PRODUCTION IN SANTO DOMINGO - Kelton Barnsley
  - COMPOSTING AND BIOGAS TECHNOLOGIES - Scott Almquist
    - Blue Technology - Kelton Barnsley
    - Municipality of Jiménez - Scott Almquist
    - Other Technologies - Kelton Barnsley
  - COST OF COLLECTION AND SEPARATION OF WASTE - Scott Almquist

ACKNOWLEDGEMENTS

We would like to thank the following people for contributions to our project:

Dr. Sergio Musmanni, Executive Director, CNP+L

Carlos Perera, Technical Director, CNP+L

Diego Rubí, Environmental Officer, Santo Domingo

Claudia Mannix, Student, Colegio Santa Maria de Guadalupe

Isa Bar-On, Professor and Advisor, Worcester Polytechnic Institute

Thomas Robertson, Professor and Advisor, Worcester Polytechnic Institute

TABLE OF CONTENTS

TABLES

FIGURES

CHAPTER 1: INTRODUCTION

Around the world, populations are booming, and resources are being consumed at rates that the environment is unable to sustain. The unsustainable consumption of resources has also caused an unsustainable production of waste. For example, The United States produces a staggering 251 million tons of garbage a year (*Basic information: Municipal solid waste (MSW)***,** 2008). Because of the large amount of land area in the US, there has been little concern over where to put the waste. Recent news reports from the United Kingdom, however, say that the landfills there could all be full by the year 2016 ('Dustbin' UK tops landfill table, 2007). In developing or third world countries, the problem of insufficient space to dispose of garbage in can be compounded with unsafe waste disposal processes. A study done by Al-Yaqout and Hamoda (2002) found that landfills in Kuwait were uncontrolled causing strong odors, fires, and unsafe health conditions for both citizens and workers. Eventually, every country will have to improve their solid waste management plan.

The problem with developing a completely sustainable system for solid waste management is that one hundred percent of waste would have to be recycled, reused, or degrade at a rate equal to or faster than it is being thrown away. This is not an immediately feasible goal for any country, but there are some steps that can be taken to reduce the size of the waste stream. One method that could potentially improve the rates of waste reuse would be the implementation of composting and biogas facilities. These facilities would divert organic material from landfills, allow the material to biodegrade, use the gases produced as a source of energy, and sell the resulting compost for fertilizer.

The municipality of Santo Domingo de Heredia, a town of approximately forty thousand people in Costa Rica, is one area where the need for an improved waste management plan is pressing (Plan for Solid Waste in Santo Domingo, 2008). This municipality's only landfill will be forced to close in March of 2009 due to a lack of space

(Plan for Solid Waste in Santo Domingo, 2008). Once the landfill closes the municipality will be forced to pay a private company to dispose of this waste until they are able to procure land to open a new landfill. In response to this situation, Santo Domingo developed the Plan for Municipal Solid Waste Management in 2008. The report recommends recycling, waste reduction, and composting of organic waste. It may be possible to reduce the cost of disposing of waste in a private landfill or to extend the life of a new landfill by implementing a composting or biogas system.

Simply because composting and biogas may be able to reduce the amount of garbage flowing to landfills does not necessarily mean that a program should be implemented. Economically a composting and biogas facility may not make sense. Although biogas can be used to make electricity, and compost can be sold as fertilizer, the markets for these products must be analyzed in order to determine if a facility could make a profit. Alternatively, if the environmental impact of the waste management system is significantly reduced, the program may be desirable even if it is not justified on an economic basis. If a profit can be made or there is enough of an environmental benefit, diverting organic waste from Santo Domingo's waste stream and producing compost and biogas from it could be a small step towards a completely sustainable society.

The goal of our project, sponsored by the Centro Nacional de Producción más Limpia (CNP+L), was to assess the environmental and economic feasibility of producing compost and electricity from biodegradable waste in Santo Domingo in order to reduce the waste stream and extend the life of the future landfill. The specific objectives were to:

- Estimate what percentage of Santo Domingo's municipal solid waste is biodegradable.
- Identify appropriate technologies for the situation in Santo Domingo.
- Estimate the cost of the separate collection of biodegradable waste.
- Create a model for estimating the value of implementing each technology.
- Determine the social and economic causes of the current problem.

CHAPTER 2: BACKGROUND

This project will consider four main issues of composting and biogas. The first issue is the lack of space for waste storage in Santo Domingo and how composting and biogas may be able to conserve that space. The second issue is sustainability and how it relates to both composting and the current systems of landfills. The third issue is economics, specifically the economic and environmental economic factors that are associated with composting and landfills. Finally, the issue of how biodegradable waste can be separated from the general waste stream must be considered.

THE WASTE MANAGEMENT PROBLEM IN SANTO DOMINGO

The municipality of Santo Domingo de Heredia is a small town just north of San José in Costa Rica. It has a population of approximately forty thousand citizens. Additionally, there are about forty restaurants and sodas contributing to a high volume of organic waste (Plan for Solid Waste in Santo Domingo, 2008).

The municipality of Santo Domingo de Heredia is facing a serious waste management problem; their landfill is nearly full and will be forced to close in March of 2009. The local government is still in the process of negotiating the purchase of more land in order to build a new landfill, so it will be at least a few years before the new landfill is able to be used. In the meantime, the town will have to pay a private company to haul away one hundred percent of the waste generated in Santo Domingo. Because of this, Santo Domingo's immediate goal is to reduce the amount of waste they generate by as much as possible. A study done at the Colegio Santa Maria de Guadalupe by Claudia Mannix in 2008 investigated the effects of educating the public about how they can reduce waste in their own homes by starting small compost piles in their backyards. However, even if Santo Domingo manages to reduce the amount of waste they produce, they will still face a long-term waste management problem. Developing a sustainable system to turn organic waste into useful products could extend the lifespan of the next landfill considerably, especially since there is already a program in place for the collection of conventional recyclables such as plastic, metal, and glass, which has a fifty percent participation rate according to Mannix.

Santo Domingo's lack of action may be surprising to an outside observer, but according to the Municipal Plan for Solid Waste Management in Santo Domingo (2008), the amount of money budgeted for the waste management system is inadequate, and funds often have to be drawn from an extraordinary account. Because Santo Domingo has always had the option of shipping their waste to a private landfill, work relating to the reduction of waste production has been put off in favor of dealing with matters that require immediate funding.

While there are plans to address the waste management problem, they are not close to fruition, and the municipality has enlisted the help of the Centro Nacional de Producción más Limpia (CNP+L) to analyze potentially sustainable alternatives such as composting and biogas production. Composting can be part of a sound waste management system which can prevent substantial amounts of organic material from ending up in landfills.

SUSTAINABILITY IN WASTE MANAGEMENT SYSTEMS

By the most literal definition, a sustainable system would be one that could be used indefinitely. However, both the laws of thermodynamics and the practical limitations of human effort make this definition an impossible goal. For our purposes, a "sustainable system" will refer to one which offers an increase in usable lifespan or a decrease in negative environmental impact when compared to whatever process or system was in place beforehand.

Environmental and Health-related Problems with Landfill Systems

The most common alternative to composting is landfilling. As Freidenrich (2000) points out, composting is differentiated from landfilling in that composting is an attempt to aid the biodegrading process and reuse organic matter, while landfills are meant to bury garbage – a process which can hinder biodegrading. Hoornweg, Thomas, and Otten (2000) report that in some areas landfills can actually be more economical than composting. Biogas can also be harvested through anaerobic digestion from landfills; especially in poorer countries, this may be a better choice than setting up the infrastructure to compost because of the costs involved. Therefore, a municipality should have a cromulent reason to implement a composting and biogas system before reducing their reliance on landfills.

In the United States, the legal operation of landfills is monitored by the Environmental Protection Agency (EPA). The EPA (*Landfills*, 2008) requires that landfills must be far enough away from major populations to prevent health problems and from bodies of water where there is a chance of contamination. The EPA also monitors the presence of liners which will prevent leachate (water containing contaminants from the landfill) from entering and contaminating ground water supplies. The EPA monitors the presence of a leachate removal system to further prevent contamination. Furthermore, the ground water in the surrounding area must be constantly monitored for contamination. Finally, the EPA requires that landfills must have financial backing that ensures that even after it has closed, there will be funds left to continue the testing of the ground water.

Despite all of these precautions, some anecdotal evidence suggests that even in industrialized countries, health risks are associated with landfills. A study performed in Wales in 2005 has shown that living within two kilometers of a landfill is associated with having a statistically significant increase in the risk of congenital abnormalities (Palmer et al., 2005).

In developing countries, the health problems associated with landfills can be much worse. As mentioned earlier, the landfills in Kuwait are unmanaged and create significant health hazards for citizens (Al-Yaqout and Hamoda, 2002). But Kuwait is by no means alone in its poor landfill management procedures. Narayana (2008) reports that ninety percent of waste in India is disposed of in open dumps with waste just being cast into low lying areas of land. In addition to contaminating ground water, becoming infested with vermin and insects, and posing fire hazards due to methane formed from decomposing waste, Ray, Roychoudhury, Mukherjee, Roy, and Lahiri (2005) report that landfill workers in India suffered from high rates of respiratory problems, fungal infection, diarrhea, memory loss, and depression. Sharma, Meesa, Pant, Alappat, and Kumar (2008) report that there are thousands of landfills – both closed and open – in developing and third world countries that have no control systems in place.

Costa Rica maintains a small level of control over its landfills. However, many of the landfills have not historically followed basic health and safety practices. Levesque, Pelletier, and Samuels (2003) found that landfills located in both Rio Azul and Alajuela had inadequate methods for preventing leachates from contaminating ground water, but Rio Azul was implementing a new system that was completed in 2005. Furthermore, they recommended that the municipalities of Santa Ana, San Isidro de Heredia, and Escazu all could benefit from a composting system to reduce the waste sent to landfills.

According to Diego Rubí, the Environmental Officer for Santo Domingo de Heredia, the landfill there does not have many protective measures to prevent ground water contamination because it has been operating for forty years, since before there was very much knowledge about ground water contamination (personal communication, November 4, 2008). In the past few years, drainage systems have been built to trap leachate, but there is no impermeable layer and the landfill is less than a kilometer away from Río Virilla.

While many problems are associated with landfills, they still provide the main source for disposal of municipal solid waste. Whether composting can be a viable option for a country or community is closely related to the condition of the area’s landfills.

The Benefits of Composting and Biogas

Roughly sixty-nine percent of Santo Domingo’s waste stream is organic (Sanez, 2006). This amounts to approximately ten thousand metric tons of trash that could be diverted from the landfill each year, extending the life of a landfill by many years (Sanez, 2006). Although the extension of a landfill’s life is the main advantage that we will be analyzing, there are many other advantages to composting which make doing so a more attractive option than just landfilling organic waste.

The compost produced can provide many positive effects for agriculture, gardening, or landscaping such as erosion prevention, helpful bacterial growth, and nutrients. Some of these benefits are detailed in Appendix D. Additionally, leachate control is much easier for a composting system, as all waste is stored above ground. Biogas, consisting mostly of methane, can be harvested if anaerobic digestion is used, and then burned to provide an energy or heat source.

ECONOMICS OF A COMPOSTING AND BIOGAS SYSTEM

While composting and biogas may offer advantages over landfills regarding environmental impact, one must consider how the costs of a composting and biogas system compare to those of traditional landfills.

According to a study on the feasibility of composting in developing nations, composting by itself will almost never produce a large profit, if it produces a profit at all. Instead, the authors of the study suggest that composting should be viewed as a part of a larger waste management system (Hoornweg, Thomas, Otten, 2000).

In a study by Renkow and Ruben (1998) several composting facility managers around the United States were interviewed about their financial practices. The study showed that, for most facilities, composting was not economically beneficial, even if one considered the potential of extending the life of a landfill. It should be noted that very few of the composting facilities were able to sell the compost that was generated; most facilities simply gave it away. It should also be noted that Renkow and Ruben did not include any facilities in their study that produced biogas and compost, or any facilities that produced biogas from landfill waste. In Santo Domingo, extending the life of a landfill is of greater importance, as there is far less space available than in the United States.

The production of biogas through anaerobic digestion is a process related to composting which must also be considered when trying to determine the feasibility of a composting facility. A major study on the matter was written by K. Braber (1995), and it extensively analyzes many of the factors involved. Braber states that one ton of organic waste can typically produce one hundred to two hundred cubic meters of biogas; this will create one hundred to one hundred fifty kilowatt hours of electricity. At the time he stated that composting was usually cheaper than using landfills, but there were far too many factors that need to be considered about local economies and markets for byproducts of the systems for any generalizations about socio-economic feasibility to be made. There have been more recent case studies that showed different results.

A study done by Zamorano, Pérez, Pavés, and Ridao (2007) in Spain found that a biogas facility on top of a current landfill would be both economically profitable and environmentally sound for at least seven years. This case cannot be applied to all situations, however. Differences in taxes, location, supply of waste, and current infrastructure can all affect the economic viability. A study done by Mæng, Lund, and Hvelplund (1999) in Denmark compared previous studies of economic feasibility of biogas, and concluded that, while biogas production facilities were not feasible to build based upon present-value calculations taking into consideration the market price of energy as well as tax breaks for clean energy, biogas facilities can be desirable in economically developing areas because of their ability to improve local unemployment rates.

SEPARATION OF ORGANIC FROM INORGANIC WASTE

Municipalities need to separate the waste which they want to convert to biogas and compost from the other types of waste. The two main methods that exist are separating at the source and separating at a central processing facility. Separating at the source requires that citizens or businesses separate their own waste and that organic waste be collected separately from other waste. With a central facility method all of the waste would be collected together and taken to some intermediary location where the waste to be put into landfills would be separated from waste which can be composted, used to create biogas, or recycled.

Very little research has been done which compares these two models, and almost no information from a study in one location can be applied to another. For example, one of the studies by Gomes, Matos, and Carvalho (2008) found that in Portugal, there could be a decrease in costs for collecting biodegradable waste separately from other wastes if forty per cent of the population participated in the program. However, some of the variables that Gomes and his team took into account – such as the cost of fuel, the cost of vehicles, the cost of drivers, taxes, and the population – will vary widely between different areas. None of the data collected by Gomes and his team is directly applicable to Costa Rica, but we can formulate some ideas as to where separating at the source would be better than separating at a central location based on Gomes’s models.

Separating at a central facility provides the benefits of creating more jobs, and may be cheaper if most of the waste is industrial and homogenous in nature. Separating at the source may be more useful when the waste is more heterogeneous, but the population needs to be willing to participate.

CHAPTER 3: METHODOLOGY

The goal of our project was to assess the costs and feasibility of developing a system for the production of compost and electricity from biodegradable waste in Santo Domingo in order to reduce the waste going to landfills. Based on the project description from Centro Nacional de Producción más Limpia (CNP+L) and discussions with representatives from Santo Domingo we developed five research objectives that helped us meet our goal:

1. Estimate what proportion of the municipal solid waste stream is biodegradable and could be diverted from landfills.
2. Identify available technologies that are appropriate for the situation in Santo Domingo.
3. Estimate the cost of collecting biodegradable waste separately from the rest of the waste stream as well as the cost of operating the technologies mentioned in objective two.
4. Perform an economic and environmental cost benefit analysis of various available technologies for the situation in Santo Domingo.
5. Determine the social and economic reasons for the lack of initiative in dealing with Santo Domingo’s waste management problem

The first objective was to estimate, on average, what proportion of the municipal solid waste stream in Santo Domingo is composed of biodegradable materials which could potentially be diverted from the waste stream.

Questions we wanted to answer included:

- How much solid waste is processed per unit time in Santo Domingo?
- What percentage of this solid waste is composed of organic materials which can biodegrade?
- What portion of the biodegradable waste could potentially be diverted from landfills by using it to produce compost and biogas?

The first two questions, regarding how much solid waste is processed and what fraction of it is biodegradable, was answered using data that our team gathered from the municipality. A study done at the Colegio Santa Maria de Guadalupe by Claudia Mannix in 2008 provided much of the information we needed. The portion of the total municipal solid waste stream which could potentially be diverted from landfills by using it to produce compost and biogas is the same as biodegradable fraction in theory; however, in our models we needed to take into account participation rates.

Mannix also studied employing an education program aimed at informing the public about composting in their homes. It was determined that many citizens already do compost much of their yard waste, but they lack adequate space and resources to compost any other organic materials. The municipality determined from this that a centralized composting facility would be worth investigating.

The second objective was to identify available technologies that are appropriate for the situation in Santo Domingo

The questions which needed to be answered were:

- How does a compost-biogas system work?
- What are the available technologies and what are the requirements (land, organic waste, and labor) for those technologies to work?
- How much biogas and compost could be produced per unit of waste?

The first question is very general and is answered in the background and appendix sections of this report. To recap, a compost-biogas system breaks down biodegradable material into more stable compounds using anaerobic bacteria. The products of this process are solid compost, which can be used as fertilizer, and gases such as methane which can be burned to produce heat or electricity.

While the basic methods for composting and biogas are simple, there are a host of available technologies which take advantage of various types of bacteria, sorting methods, amount of waste, and available space. CNP+L specifically was interested in implementing Blue Technology from Belgium, however, we researched various other technologies in order to obtain a wider view of the options which were potentially available to us, including DRANCO technology, EnvironTec, and simple piles of compost.

The amount of compost and biogas that can be created from waste can be roughly estimated based on the waste flow and the specific technology that is being used. Being able to predict how much biogas and compost can be produced per unit of waste material was vital to estimating the market potential of an operation.

The third objective was to estimate the cost of collecting organic materials separately from the rest of the municipal solid waste and the cost of running a facility that produces biogas and compost from the diverted waste.

There are several questions which need to be answered to determine this:

- What is the best method for separating the waste?
- What would be the expected costs for each method?

The first question was one of the hardest questions to determine for our project. There are two main philosophies for separating waste: separating at the source and separating at a centralized facility. Unfortunately, as mentioned in the literature review, there is a distinct lack of research that is applicable to studying which is better. Which method is better is closely related to the technology that is used, the participation and education rates, and the size and operating costs of a facility.

Santo Domingo recently implemented a new recycling program, which has many of the same separation issues that an organic waste facility would have. We used data that was available about the recycling program to estimate the cost of separating at the source. For separating at a central facility, we used data obtained from a separation facility for recyclables in the municipality of Jiménez.

The fourth objective was to perform a cost benefit analysis of various available technologies for the situation in Santo Domingo.

We wanted to know if a composting facility could produce a profit, and if so, how much. The criteria for determining marketing potential can be divided into several questions:

- How much biogas can be produced?
- How much electricity could be generated from this biogas?
- How much could this electricity be sold for?
- How much are people willing to pay for compost?
- How much would a facility to process the waste cost?
- What are the other economic factors that are important for a complete view of the economic feasibility?

The amount of biogas that can be produced can be estimated from the amount of organic waste. The amount of electricity that can be produced can be determined from the amount of biogas that is harvested. Solving these questions was fairly straight forward as the required information was provided by previous objectives.

One major factor which was also part of our economic analysis was the improvement of the environment. A plant may increase the lifespan of the next landfill by several years, reducing the need to expand it or build a new one later. Furthermore, compost will reduce the impact on the environment when used in place of fertilizers.

Finally, we needed to determine how much the facility where the composting would take place might cost. Santo Domingo has very little land available for building. The Environmental Officer for the municipality, Diego Rubí said that the only location that would be easily obtained would be on top of the current landfill after it closes in March (personal communication, November 4, 2008). This narrowed the feasible technologies and gave us a finite amount of land to work with.

The fifth objective was to determine the social and economic reasons for the lack of initiative in dealing with Santo Domingo's waste management problem.

The main questions we wanted to answer for this objective were:

- Why has there been so little action directed towards fixing this problem?
- Why is this project being done now as opposed to many years ago?
- How might problems like this be avoided in the future?

This objective is more qualitative than the other sections, so our answers are more speculative than those for other objectives. Instead, for this section, we were more focused on discovering what people believed were the causes for the lack of action.

To accomplish this objective, we informally interviewed people who work for the municipality and asked their opinions on the matter. From these, we developed several hypotheses on what went wrong and why.

CHAPTER 4: RESULTS AND DISCUSSION

With information we gathered from representatives in Santo Domingo and technology vendors, we were able to determine how the waste management problem in the municipality should be approached. This chapter will first discuss the organic waste production in Santo Domingo. Then we will introduce the two technologies which we chose to focus on for our study. Next we will give details regarding the variables associated with separation of the organic waste. We will then provide our cost benefit analysis. Finally, we will introduce some of the social aspects involved in the project and why there has been a lack of action until recently.

ORGANIC WASTE PRODUCTION IN SANTO DOMINGO

Organic waste makes up the majority of the waste that is produced in Santo Domingo. Mannix states that sixty-nine of all the solid waste in Santo Domingo is organic (2008). She reports that each person in this municipality produces, on average, between 670 and 829 grams of organic waste each day. Additionally, the average restaurant in Santo Domingo produces between seven and eight kilograms of organic waste daily. Santo Domingo has 37,833 citizens and about forty restaurants and sodas. This information is summarized in Table 1.

Table 1

Organic Waste Production in Santo Domingo

	Population	Individual waste/day (LB)	Individual waste/day (UB)	Individual waste/year (LB)	Individual waste/year (UB)	Collective waste/year (LB)	Collective waste/year (UB)
People	37833	0.67	0.829	244.55	302.585	9252060.2	11447698.3
Restaurants	40	7	8	2555	2920	102200	116800

	Total waste/year (LB)	Total waste/year (UB)
Kilograms	9354260.2	11564498.3
Tons (U.S.)	10311.307	12747.6773

Note. All values are in kilograms unless otherwise noted. LB columns are the lower bounds for waste production estimates; UB columns are the upper bounds.

To estimate the amount of waste which would actually be diverted from the landfill, we used numbers for the participation in Santo Domingo's recycling program. Diego Rubí reports that for the past two years Santo Domingo has had separate collection for glass, plastic, and metal (personal communication, November 4, 2008). He estimates that the participation rates for the program are around fifty percent and growing.

COMPOSTING AND BIOGAS TECHNOLOGIES

For our cost benefit analysis, we decided to focus on two specific methods for composting and biogas. In this section, we will discuss Blue Technology and a method that is employed by the municipality of Jiménez in Costa Rica.

Blue Technology

Blue Technology is a Belgian technology company which specializes in both environmental and communications technology. Blue Technology offers a product called the Biogas Transformation Unit (BTU). This is a large, closed container or reaction vessel in which organic waste is allowed to decompose anaerobically. The end products are compost, which can be used as fertilizer, and methane, which can be burned to produce heat or electricity. Each tank is forty feet long and has a digester with a volume of thirty thousand liters. Each tank is equipped with a mixer, a feed trap, two extractors and two gas tanks with security valves and pressure indicators (Bury, 2007). A typical BTU is pictured in Figure 1.

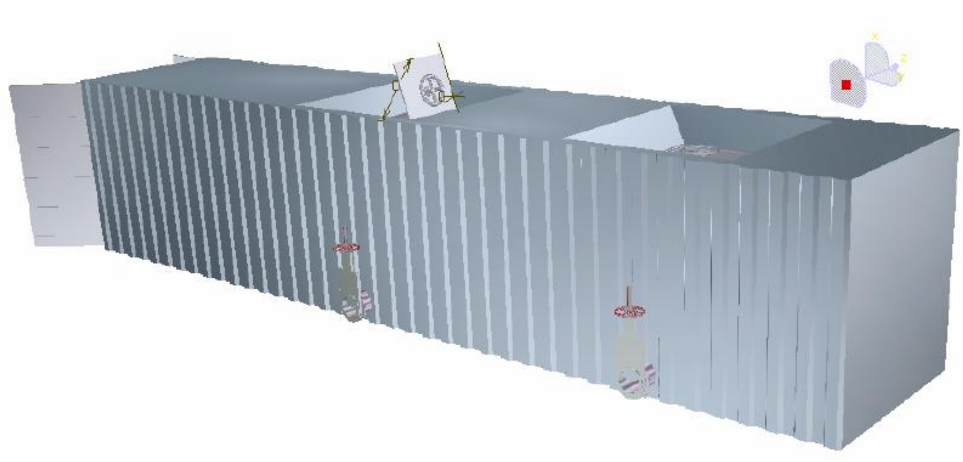


Figure 1: An illustration of a BTU. From *Biogas Transformation Unit (BTU)*, by Jean-Marc Bury, 2005.

The Blue Technology BTU takes between ten and sixty days to digest a batch of organic waste, but it typically takes twenty to twenty-five days for a batch of eighteen thousand liters to be processed. The BTU can produce eighteen cubic meters of biogas from a batch of fresh vegetable matter, or between fifty and sixty cubic meters of biogas from a batch of drier materials (Bury, 2007).

A BTU is very easy to maintain, and requires only one supervisor with only basic tools and education to oversee the device for one or two hours a day (Bury, 2007). Because of these limited requirements for operation, Blue Technology is a good choice for projects that do not have much continuous funding, but can obtain initial capital through a loan.

The Jiménez Model

A very low-tech option would be for Santo Domingo to emulate what the municipality of Jiménez in Cartago is currently doing with their organic waste. Two years ago, this community began an experimental composting program for their organic waste. The waste is allowed to decompose in outdoor piles covered with straw. Each pile contains approximately one and a half tons of organic waste initially. The piles are not turned or aerated, so the process is anaerobic; therefore, methane is produced. The methane is not harvested; instead, it is allowed to escape through a PVC pipe sticking out of each compost pile. It takes between two and three months for a pile to fully decompose, after which the material is allowed to dry out for a day. At this point, the compost exists in the form of large pieces; these are fed into a chipper which breaks the compost into smaller pieces. The resulting compost can be packaged and given away to people who need it. The municipality chooses to give away the compost rather than to try to sell it because the finished product would have to meet certain standards of quality before it could legally be sold. According to Natalia Jojart, an Environmental Officer of Santo Domingo, these standards only apply in Cartago, and there are no laws governing the sale of compost in Santo Domingo (personal communication, November 20, 2008).

The program has been met with much success in the district. Laws have been passed which mandate composting in the population, and, as a result, there is an eighty to ninety percent participation rate according to the mayor of Jiménez, Jorge Solano (personal communication, November 13, 2008).

This method is appealing because of the relatively low initial investment and requirements for maintenance. Furthermore, Jiménez is the closest town to Santo Domingo in terms of demographics and culture that employs a composting program. Although Jiménez differs in size from Santo Domingo – Jiménez has a population of approximately 14,000 according to Solano – the program seems easily scalable.

Other Technologies

We chose to analyze the two above methods in greater detail because they seemed to be the most applicable to the situation in Santo Domingo. Other technologies we researched do not apply because Santo Domingo does not produce enough waste. For example, DRANCO technology requires at least twenty thousand metric tons of organic waste per year to work, while Santo Domingo only produces approximately ten thousand metric tons. Some technology companies, such as MeWa, also provide consulting services, and are reluctant to release detailed information about their products without payment. Also, many companies, such as EnvironTec, design composting systems based on the requirements where the system will be used – preventing us from forming cost estimates without hiring the companies.

There are many other technologies that may be used in Santo Domingo. This report will only analyze two because of time restraints and lack of information available.

COST OF COLLECTION AND SEPARATION OF WASTE

To estimate the potential costs for the separate collection of organic waste we need to consider the costs for the current waste collection and the cost of disposal in a private landfill. Diego Rubí, the environmental officer for Santo Domingo, provided us with this information, which is listed in Table 2.

Table 2

Cost for Transportation and Disposal of Waste (in colones)

	Cost per ton	Cost per year for all waste		Cost per year for organic waste	
		Lower bound	Upper bound	Lower bound	Upper bound
Transport	11000	149125887	184361567	102896862	127209481
Disposal	11250	152515112	188551603	105235427	130100606
Total	22250	301640999	372913170	208132289	257310087

Note. Disposal costs are only for disposal in a private landfill. With the current landfill, the municipality does not have to pay any disposal costs.

If a composting system is implemented, separating the waste at a central facility will require many more workers than separating at the source. Rubí reports that an average salary for a manual worker is 2,080,000 colones per year. In contrast, the educational system will need to be much more extensive for separating at the source. The municipality spent 141,000 colones on printed material and 108,000 colones on information distribution to educate the public about the town's recycling program. However, separating at the source will divert less waste. For our estimates on separate collection, we will assume that about fifty percent of the total organic waste can be diverted because that is the participation rate of the current recycling program.

In Jiménez, they separate all of the collected recyclables in a central facility. They employ six workers to separate approximately 624 tonnes of waste per year. If we assume that workers in Santo Domingo could separate the same amount of material per year, then each worker could separate 104 tonnes of waste annually. The upper bound for the amount of waste produced in Santo Domingo per year is approximately 16,760 tonnes, which would require 160 workers to sort through at a cost of over 335 million colones per year. This is more than the cost to ship all of the organic waste to a private landfill. In fact, if we assume that all 130,100,606 colones that could be saved by diverting organic waste is spent on separation, Santo Domingo could hire approximately 63 workers who would only be able to sort through forty percent of the waste (not even including costs for social security and healthcare). Since all of the workers would not be able to divert the amount of waste needed to save that money, the percentage of waste that could actually be sorted would be far less than forty percent. Therefore we will only include separation at the source in our analysis because it has the most potential to be economically feasible.

COST BENEFIT ANALYSIS OF THE SYSTEM

We decided to separate our cost benefit analysis between tangible costs and benefits and intangible costs and benefits. This will make it easier for the municipality to decide how much benefits such as being a leader in sustainable waste management would be worth.

Tangible Cost Benefit Analysis

There were many variables and assumptions that we used in our cost benefit analysis, which are summarized in Table 3.

Table 3

Variables Included in the Cost Benefit Analysis

Variable	Lower Bound	Expected	Upper Bound	Notes
Discount Rate	12%	13.5%	15%	This rate comes from Jose Salas an adviser to the Chamber of Industry (personal communication, December 1, 2008)
Kilograms of Organic Waste	9354260.2	10459379	11564498.3	The lower and upper bounds come from Table 1. The expected value is simply the average of the values.
Density of Waste (Kilograms/Liter)	.115	.23	.345	The expected value comes from a study done on waste in rural Guatemala (Zarate, Slotnick, Ramos 2008). Because we were unable to locate other values, we assumed a 50% variance from the expected.
Participation Rate	.25	.5	.75	The expected is the current participation rate. We assume 50% variance because we have no other data points.
Cost per Kilowatt Hour of Electricity (US Dollars)	.055	.11	.165	The expected value is the average price in the US for August 2008 according to the EIA (*Average Price of Electricity*, 2008). Because values are difficult to obtain for Costa Rica, we assume a 50% variance.
Investment in Generators (US Dollars)	5000	10000	15000	A quick internet search will show values of generators between $2000 and $5000. These prices are for two generators with installation costs.
Kilowatt Hours per Tonne of Organic Waste	100	125	150	Braber reports the average electricity produced is between 100 and 150 kilowatt hours per ton (1995).
Percent of Total Waste that is Organic	54.5	69	83.5	69% was given to us by Mannix (personal communication, November 4th, 2008). We assume 21% variance because that is the percentage of difference between the lower and upper bounds of the organic waste produced per year.

From these values we were able to calculate important information relating to the financial success of the systems. The values we calculated, and how we performed the calculations are summarized in Table 4.

Table 4

Summary of Calculations in the Cost Benefit Analysis

Value	Calculation Involved
Biogas Transformation Units Required	$\frac{Organic\ Waste\ \times Participation\ Rate}{Density} \times \frac{1}{18{,}000 \times 12}$ We divided by 12 because it takes approximately a month to digest and divided by 18,000 because that is the capacity (in liters) of a unit.
New Lifespan	$\frac{1}{1 - Particpation\ Rate} \times 15$ We multiply by 15 because that is the current expected lifespan.
Value of Extended Lifespan per Year	$(New\ Lifespan - 15)\ \times Tonnes\ of\ Waste\ \times 11{,}250$ The value of each year is the amount of waste that does not have to be sent to a private landfill times the cost of disposing it in a private landfill (11,250 colones). This value is in colones and only applies after the landfill would have closed without the program.
Workers Required For Blue Tech	$\frac{BTUs\ Required}{4} \times 1.08^{Project\ year}$ Each Biogas Transformation Unit requires 2 hours of monitoring per day, meaning one full time worker can watch 4. We rounded this number to the nearest part time worker and included an eight percent raise per year for each worker.
Workers Required For Jiménez	$\frac{Tonnes\ of\ Organic\ Waste\ \times Particpation}{208} \times 2\ \times 1.08^{Project\ year}$ The facility at Jiménez processes approximately 208 tonnes of organic waste according to the mayor, Jorge Solano (personal communication, November 25, 2008). They employ two workers at their composting facility. We assume that as the size increases, the number of workers required will increase as well. We also included an eight percent raise per year for each worker
Investment Required for Blue Technology	$\frac{BTUs\ Required\ \times 30{,}000 + Generator\ Investment}{Years\ the\ Landfill\ Life\ is\ Extended} \times 1.20$ Each Biogas Transformation Unit costs $30,000. We multiply by 1.20 to add a twenty percent maintenance cost. We assume a fifteen year loan. This value is in US dollars.

Investment Required For Jiménez	$\frac{Tonnes\ of\ Organic\ Waste\ \times Particpation}{208} \times 9{,}000{,}000\ \times 1.20$ Jorge Solano reports that there was a 9,000,000 colones initial investment in the project at Santo Domingo. We multiply by 1.20 to add a twenty percent maintenance cost. We assume a fifteen year loan. We assume that the initial investment will scale linearly with the size of the project. This value is in colones.
Educational Costs	$141{,}000 +\ 108{,}000$ Diego Rubí reports that Santo Domingo spends 141,000 colones to print materials for the educational program for their recycling program and 108,000 colones to distribute the materials per year. We assume a similar program would work for composting.
Value of Electricity Produced	$Tonnes\ of\ Organic\ Waste\ \times Particpation\ \times Electricity\ per\ Tonne \times Cost\ of\ Electricity$

At the time of the analysis, each United States dollar was worth 525 colones. We used this value for our exchange rate in all of our analyses.

Because of the wide range of some of the values, it would be futile for us to make long-term recommendations based solely on the data that has been gathered so far. Instead, we will focus on defining how the variables influence the overall cost benefit analysis and our conclusions will be based on how a program can be built despite the limitations in data and accuracy.

The first situation we analyzed was the net present value of the projects over their lifetimes using the expected values for all categories. The results of the cost benefit analysis in this case are shown in Figure 2.

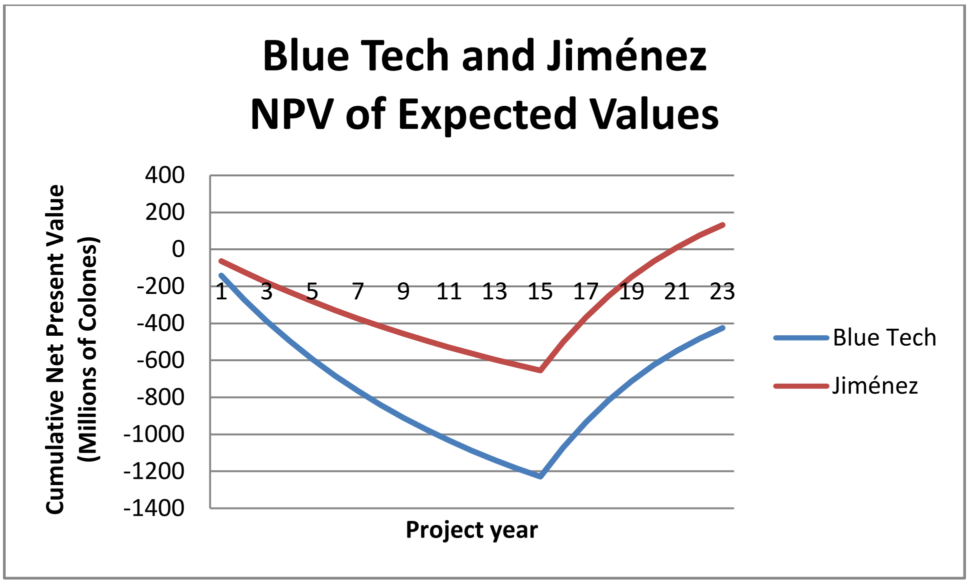
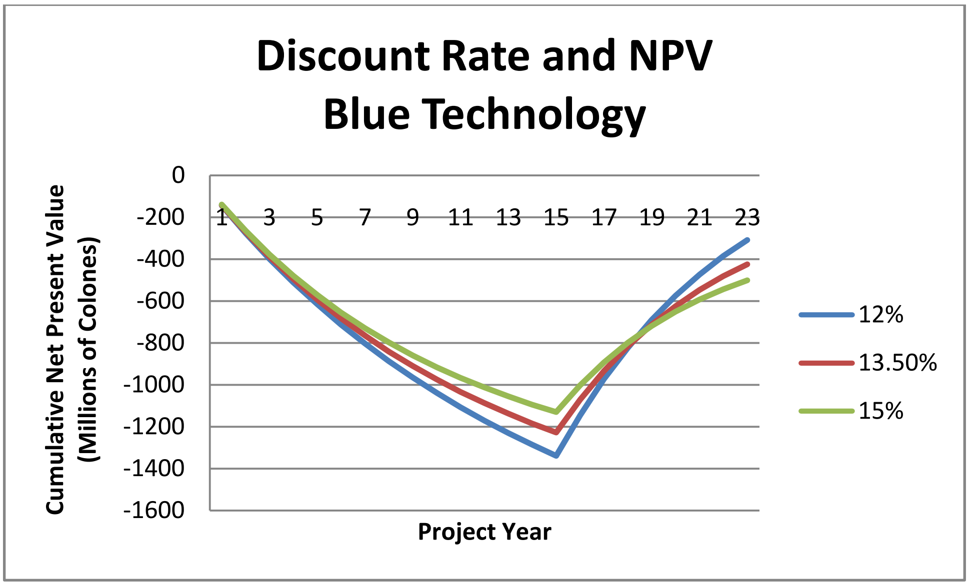


Figure 2: The net present value of both projects using the expected values.

On the vertical axis we display the cumulative net present value. A positive net present value at the end of the project (twenty three years in this case) indicates that Santo Domingo should invest in the project, a negative value indicates that they should not. On the horizontal axis we display the year of the project. For the first fifteen years, the projects will generate very little income and, therefore, be of very little value. They will lose money over all until after the first fifteen years, at which point the value of the project will start to increase dramatically because of the money that will be saved by increasing the lifespan of the landfill. Because of the large initial investment required for Blue Technology the project will never reach a positive value within the timeframe using the expected values for our variables. We can also see that the harvesting of biogas does not add enough value to Blue Technology to make it profitable.

The next variable in our analysis was the discount rate. We wanted to see if a fluctuating discount rate would significantly affect the value of either project. The results of this analysis are shown in Figure 3.



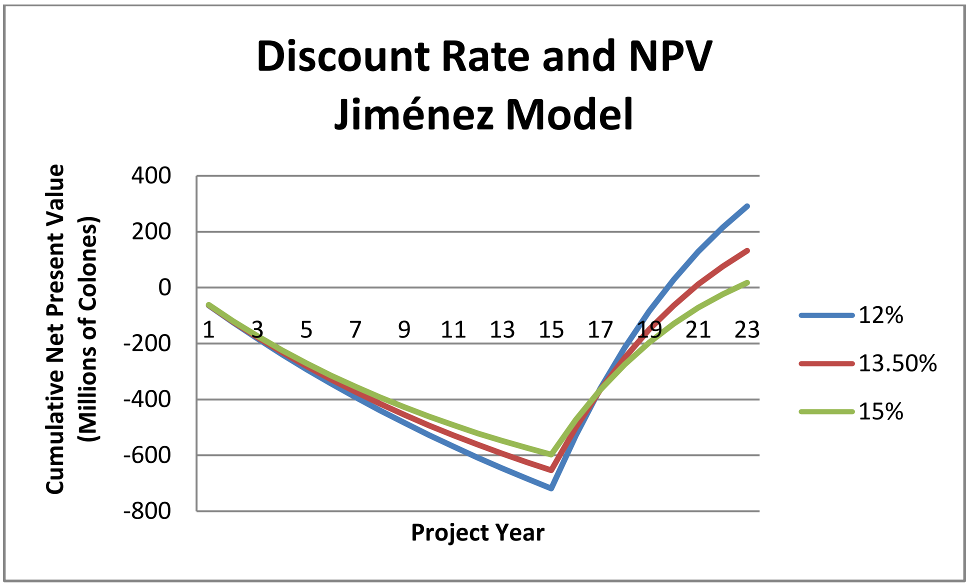


Figure 3: The discount rate and its relationship to the net present value of both projects.

We can see from the graphs that the discount rate, although it affects the value of the project, does not remove the value of the Jiménez model nor does it make Blue Technology profitable. In order to get a negative present value the discount rate would have to be sixteen percent for the Jiménez model. This indicates to us that neither project will produce large sums of money for the municipality.

Next, we investigated the relationship between the amount of organic waste produced and the net present value. The results are shown in Figure 4.

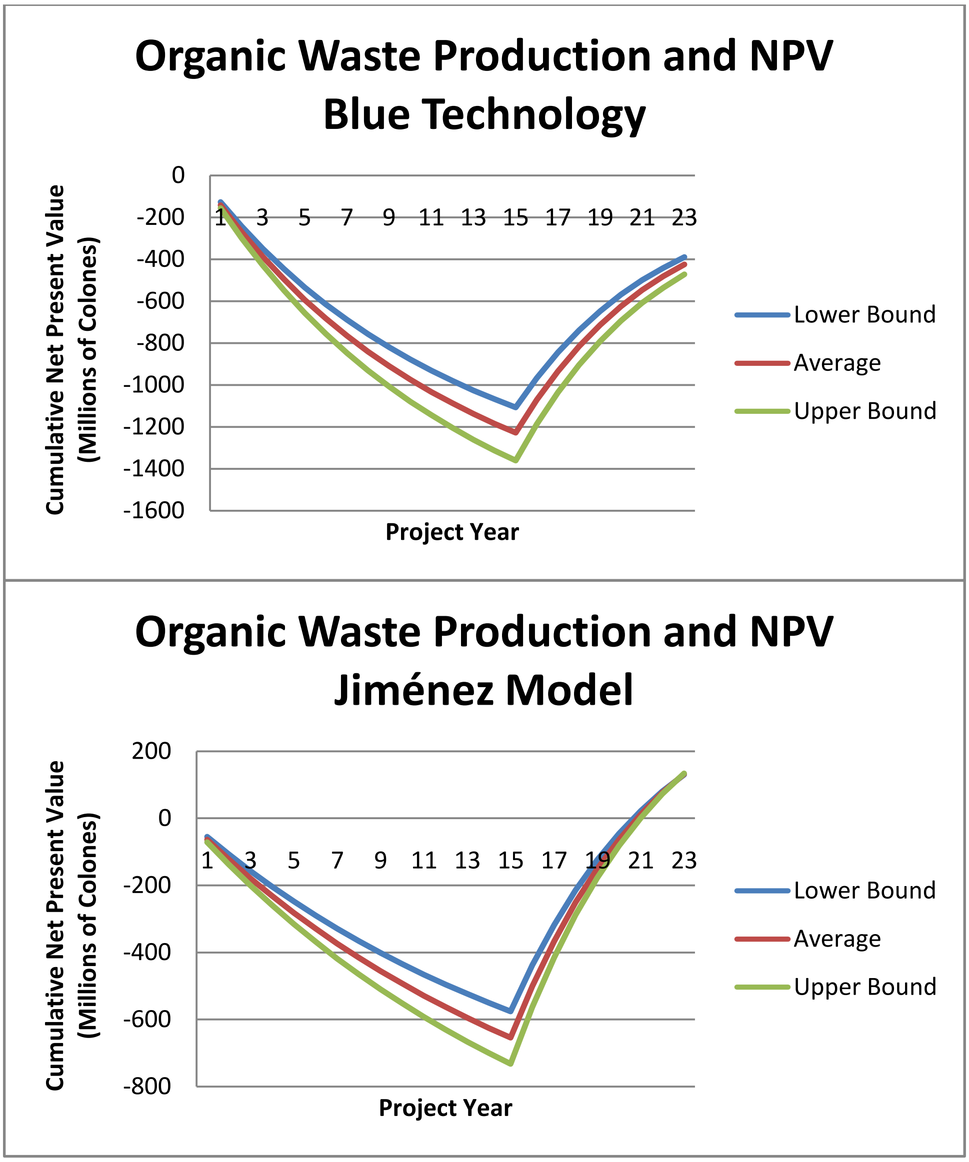


Figure 4: Organic waste production and net present value calculations.

We can see from these graphs that within the bounds given to us from Santo Domingo the amount of organic waste produced is not a significant factor in the value of a project.

Many of the calculations for Blue Technology depend on the density of organic waste. Santo Domingo was unable to provide us with information that could tell us what the average density is. Although we obtained a value in the literature review, many things including demographics, urbanization, and culture could affect this value. The results of manipulating the density are shown in Figure 5.

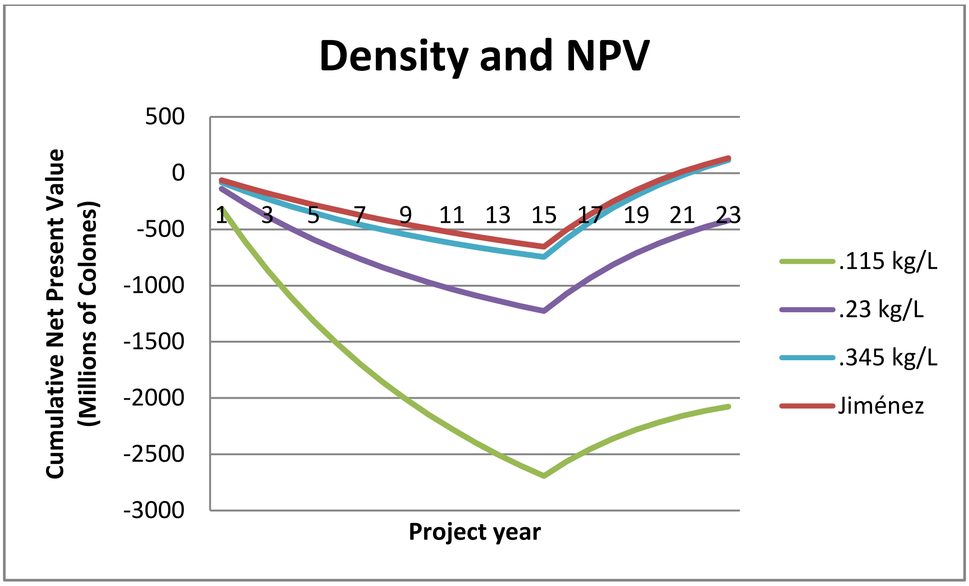


Figure 5: Density of organic waste and its relationship to the net present value of a project. A project similar to Jiménez would not be affected in our models by density, but is included for comparison and calculated using the expected values.

Density is perhaps the most sensitive of the variables to change. A fifty percent swing in either direction can take the project from not having a value to being approximately equal to the Jiménez model.

The success of a project will also depend upon the number of people who would participate in it. Figure 6 shows the net present value of the projects with varying degrees of participation.

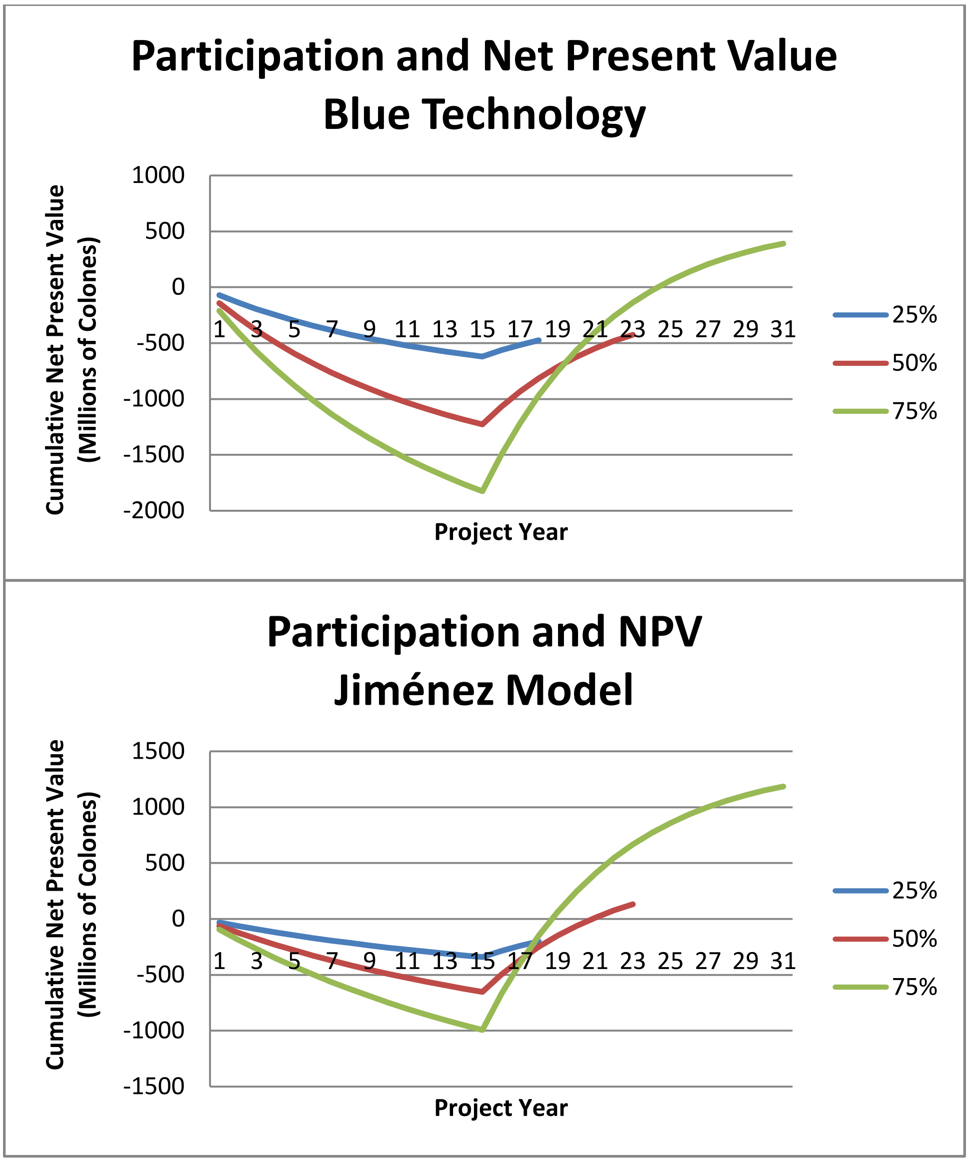
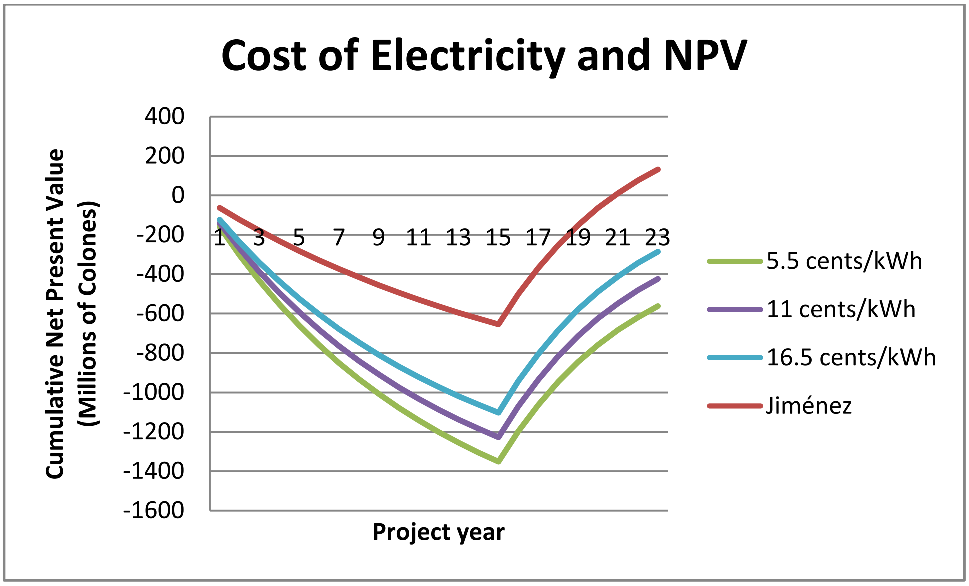
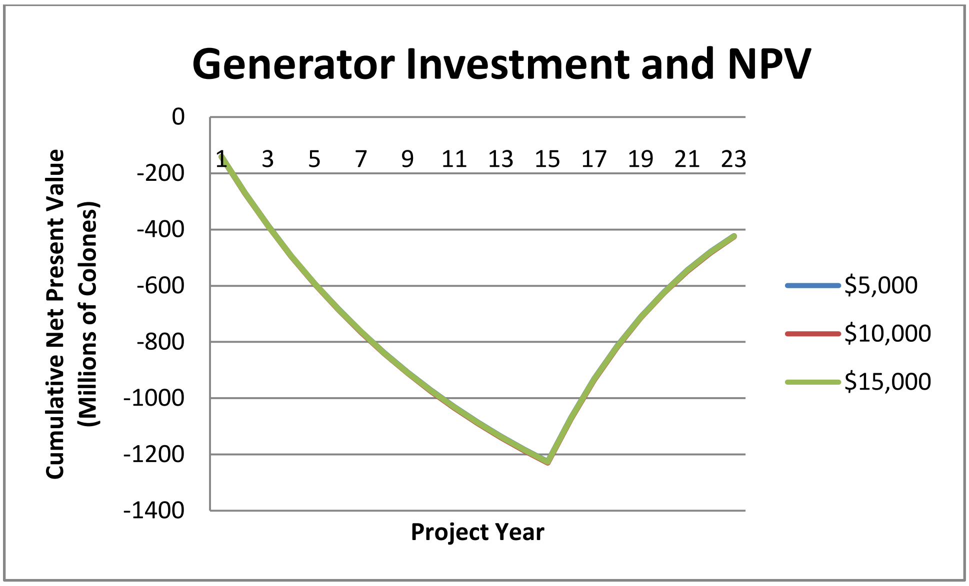


Figure 6: Participation and net present value.

A larger amount of participation will require a larger initial investment and more labor costs. However it is clear that the benefits from the savings after the landfill close are extensive. If a seventy-five percent participation rate can be achieved, then the new landfill's life can be more than doubled. This also shows that Blue Technology can be successful if there is enough waste to be composted. However, using our models, which do not include land costs, the Jiménez model is still superior.

One of the main benefits of using Blue Technology over composting in anaerobic piles like Jiménez is that you can collect the biogas and create electricity from it. Figure 7 shows the several scenarios for various selling costs of electricity, costs spent on generators, and electricity produced.





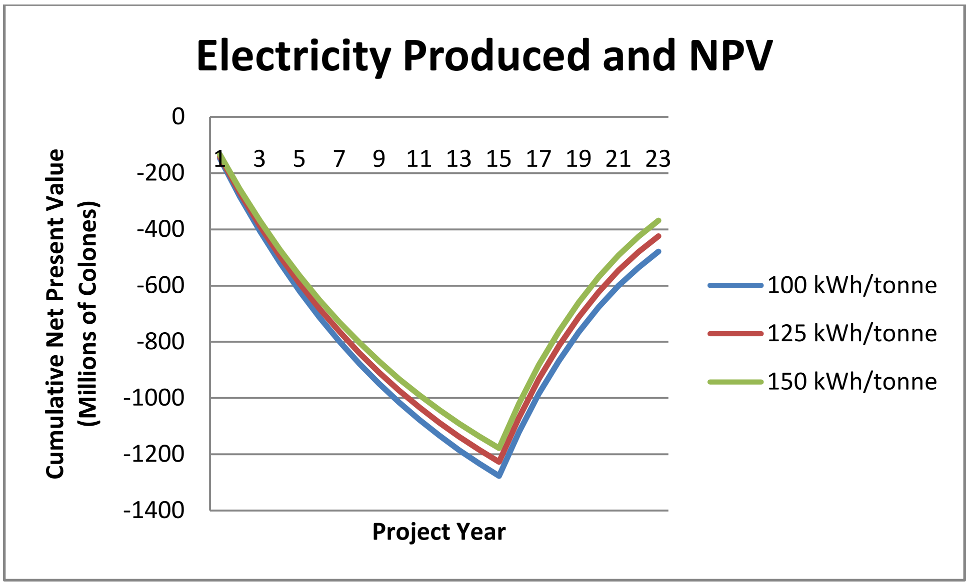
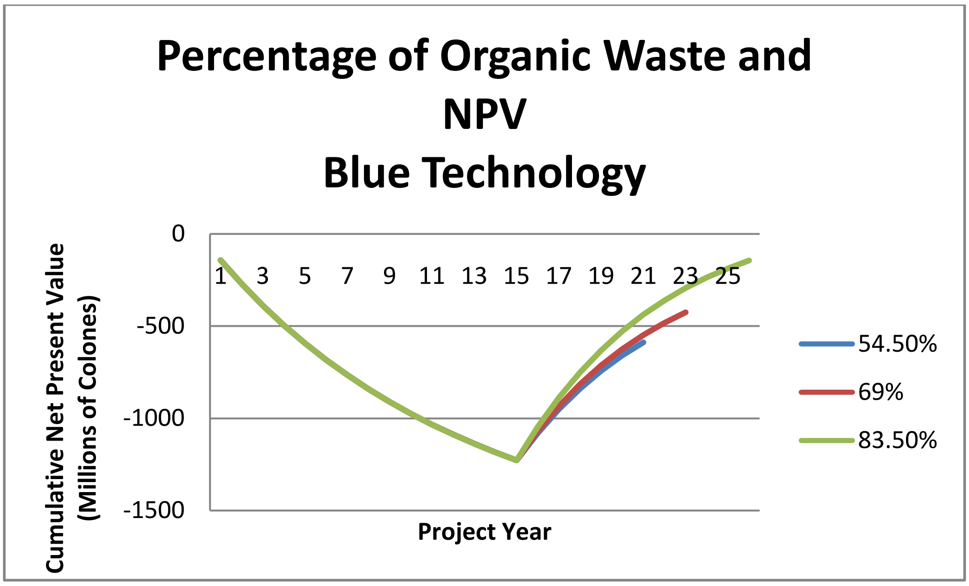


Figure 7: Graphs relating electricity costs and benefits to net present value. Changes in variables do not affect calculations on the Jiménez model.

We can see that even with high prices for electricity or a high amount of electricity produced per tonne of waste, a project modeled after Jiménez is still more profitable. We can also see that the investment in generators is almost negligible when looking at the entire life of the project.

The extended lifespan of the project is tied to the percentage of the total waste that is organic. We analyzed scenarios which assumed variance in the value given to us by Santo Domingo. These scenarios are shown in the graphs in Figure 8.



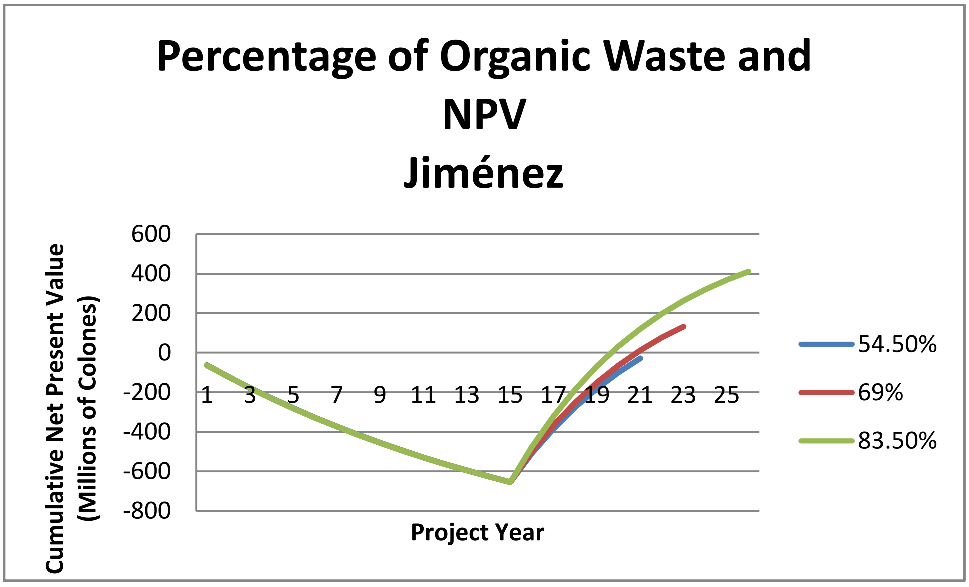
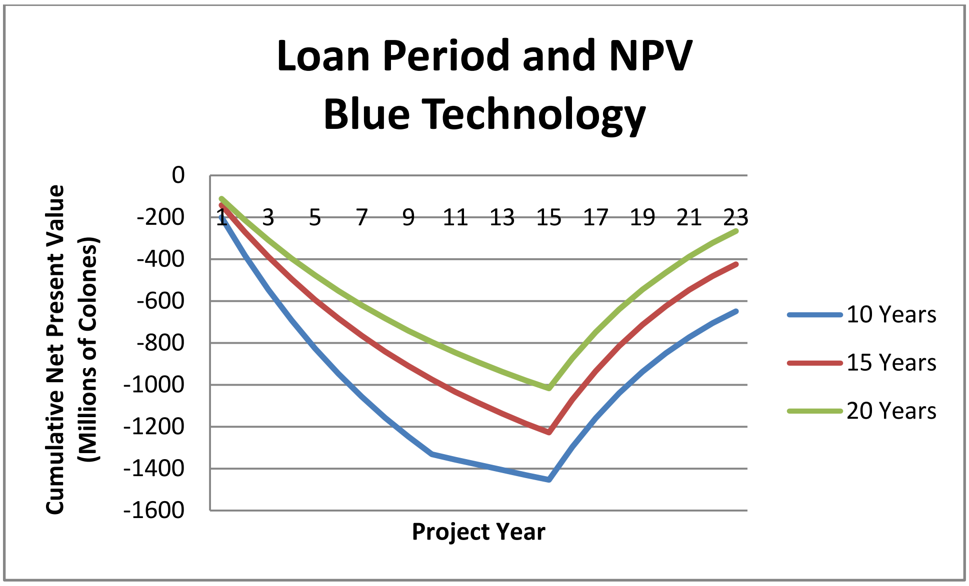


Figure 8: Percentage of the total waste stream that is organic and its relationship to net present value.

We see that if Santo Domingo did not estimate its percentage of organic waste correctly, it would result in a higher or lower value for the project. If the value of organic waste was grossly overestimated, then a program modeled after Jiménez would lose its value.

For previous scenarios, we assumed that Santo Domingo would pay for the project with a fifteen year loan. We wanted to investigate how a longer or shorter loan period may affect the value of a project. The results of these scenarios are shown in Figure 9.



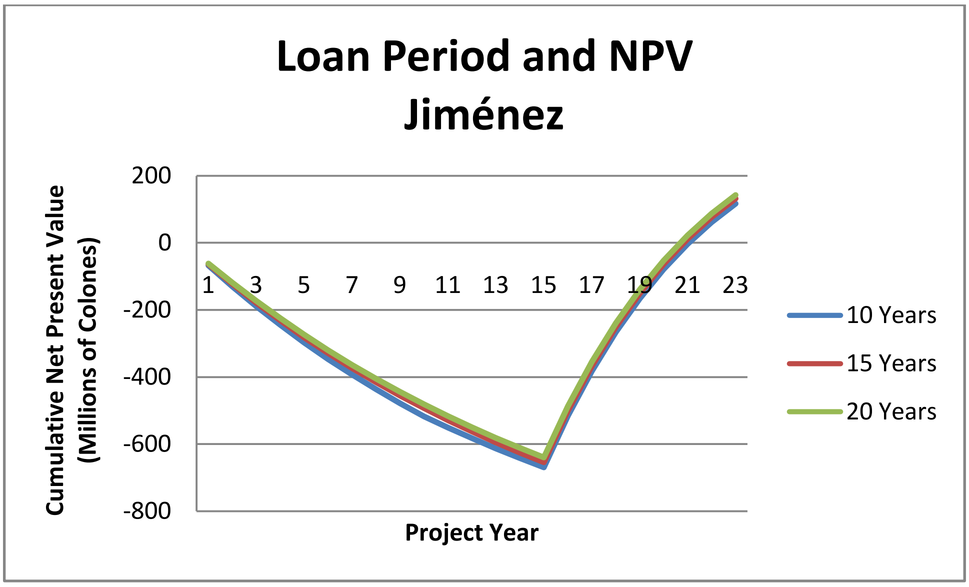


Figure 9: Loan period and its effect on net present value.

A longer loan period would defer costs until later in the project, and because we are considering the net present value a longer loan period would be desirable. Because of the large investment required for Blue Technology, the loan period will affect the value of the project significantly, and almost make it profitable if the loan period were twenty years. A project modeled after Jiménez would not see a significant affect due to the low initial investments.

Intangible Costs and Benefits

In addition to the tangible costs and benefits, which can be quantified and expressed as monetary values, there are also some intangible costs and benefits involved with implementing or not implementing a particular technology for the management of organic waste. While these costs and benefits cannot be expressed quantitatively, they are still important and must be considered before any well-informed decision can be made.

A major reason for beginning a compost-biogas program in Santo Domingo is that such a program would establish a precedent and provide an example after which other eco-conscious municipalities could model themselves. This is an especially important reason in light of Costa Rica's commitment to protecting the environment. By saving space in their landfills, municipalities will reduce the number of landfills which will need to be constructed in the future. This is consistent with Costa Rica's interest in preserving the natural beauty of the country.

If Santo Domingo is able to extend the life of their landfill by implementing a compost/biogas system, then other municipalities who are struggling with finding enough space for their solid waste will likely follow suit. Eventually, this could have a sort of "domino effect" which could lead to the majority of Costa Rica composting their organic waste rather than letting it take up precious space in a landfill. This would mean that less land in Costa Rica would need to be dedicated to storing trash, lessening Costa Rica's impact on the environment.

Variables Not Included in the Analysis

Some variables, while seemingly relevant to the problem of installing a compost-biogas system in Santo Domingo, were not included in our analysis because their values turned out to be moot, insignificant, or impossible to determine in the present situation.

The cost of land is difficult to include in our analysis because, since there is no other available land on which to build a compost-biogas facility, the biodigestors or compost piles will have to be placed within the limits of the current landfill, which is already owned by the municipality. There is a certain amount of opportunity cost that is lost by building a composting facility on top of the landfill. A study done on reclaiming land from old landfills in Florida found that the space was best used for recreational purposes (Martin and Tedder, 2002). The researchers do not recommend building structures – especially residential structures – on top of old landfills due to the dangers of methane buildup and problems with building a solid foundation. In Santo Domingo, the old landfill is not a good site for recreational facilities because of its proximity to the new landfill that is going to be built. This leaves very few options for other potential projects, and because of the situation we assume that the opportunity cost is negligible.

Since the organic material would be composted at the site of the current landfill, we do not anticipate any significant increase in cost for the transportation of organic waste. The same trucks that already bring Santo Domingo's organic waste to the landfill would be bringing it to the same place; they would just be picking them up from separate containers or on separate days. Although there may be an increase in the costs of transportation, it is beyond the scope of our project to determine it and we assume it is negligible for our calculations.

The potential selling price of compost is being excluded from our analysis because although it would be possible to estimate the potential profits of selling compost based on prices obtained at hardware and gardening stores, such an estimate would be meaningless because there is no guarantee at all that the compost produced in Santo Domingo will be of similar quality to that which is sold commercially. There is a possibility for Santo Domingo to enrich the compost they produce to make it conform to commercial standards. However, because there is a lack of information on the composition of the organic waste, the amount of enrichment required and the cost of enrichment is impossible to determine. In any case, the prospect of extending the lifespan of the landfill alone is enough to justify the implementation of composting program similar to that in Jimènez.

Green house gas emissions may be lowered because of composting. A study done by Ngnikam, Tanawal, Rousseaux, Riedacker, Gourdon, and Rémy (2002) showed that, by composting, a country with a moist tropical climate may be able to reduce emission levels by 1.8 tons of carbon dioxide equivalent per ton of municipal solid waste. However, Ngnikam and his team admit that the amount of reduction in green house gasses depends largely upon the mixture of the compost. Brown, Kruger, and Subler (2008) report that by decreasing the amount of liquid that is being composted along with increasing the ratio of carbon to nitrogen, a significant reduction in emissions can be achieved; they admit that these values are hard to predict, and must be determined based on samples taken at the site where composting is taking place. Because there is no data available on the composition of the organic waste in Santo Domingo, the amount of reduction on greenhouse gasses is impossible to determine, but with this is one potential benefit that may be obtainable with a composting or biogas program. While both the Blue Technology BTUs and the Jiménez model produce methane, a potent greenhouse gas, the BTUs allow for this gas to be captured and used, while the Jiménez model allows the gas to escape into the atmosphere. Although it is difficult to be certain, given the number of variables involved, it is likely that using Blue Technology would result in a greater decrease in greenhouse gas emissions than the Jiménez model.

According to Natalia Jojart, an Environmental Officer in Santo Domingo, there are no laws and regulations governing composting or biogas production in Santo Domingo (personal communication, November 20, 2008). There are several laws that may be passed soon that will govern the management of landfills. The Integral Waste Management Law has been proposed to govern the management of landfills, but does not deal with compost. It was beyond the scope of this project to determine the potential effects of legislation on the cost of running a landfill, but, if passed, the law would only increase the value of a potential composting facility by creating higher standards for landfills in Costa Rica.

Estimated Space Requirements for Each Project

The amount of space required to build a facility is incredibly important as Santo Domingo is working with the limited amount of space in the old landfill. Diego Rubí estimates the space available for the project to be two thousand square meters (personal communication, November 4, 2008).

Each Biogas Transformation Unit is forty feet long and eight and a half feet wide. This amounts to 31.59 square meters. Using all of the expected values for variables (fifty percent participation and .23 kilograms per liter density), Santo Domingo would need 106 Biogas Transformation Units to process all of its waste. This is equal to 3253 square meters plus space to move the waste and space for equipment.

In comparison, Jiménez has six concrete slabs which occupy the majority of space at its facility. We estimate each slab to be no larger than 15 meters long and 2.5 meters wide. This is a generous estimate and they may be slightly smaller. This amounts to 37.5 square meters for the slabs. Using the expected values for all of our variables, Jiménez would have to process 12.5 times more waste. This would require 2812.5 square meters of space plus space to move the waste and space for equipment.

These are surprising results because we expected the Jiménez model to require much more land than Blue Technology. There are two likely reasons behind the discrepancy. The first is that Biogas Transformation Units require more space for similar amounts of waste due to biogas collection equipment, mixers, and other equipment mentioned earlier in this report. The second possible explanation is that we could simply have errors in our estimates. A onehundredth of a kilogram per liter change in the density changes the required number of Biogas Transformation Units by five.

Both Blue Technology and the Jiménez model require more space than is available on top of the current landfill. However, we do not believe that the lack of space should necessarily be cause for concern. It could be possible to use some of the land allocated to the new landfill since Santo Domingo will not immediately be using the entire landfill at once. As the new landfill fills up, equipment can be relocated on top of the full areas. This would present a logistics challenge and civil engineering challenge but is not outside of the realm of possibility.

SOCIAL AND ECONOMIC FACTORS OF WASTE MANAGEMENT

One of the difficulties which we faced in comparing these different technologies was that in order to do so, we had to obtain various pieces of information, much of which was difficult to find, unreliable, or simply did not exist. The reasons for this lack of information are mostly social and economic, and they directly tie into why the government of Santo Domingo has waited until now to begin researching solutions to their waste management dilemma, since it is impossible to determine the best solution to a problem without first understanding the extent of the problem.

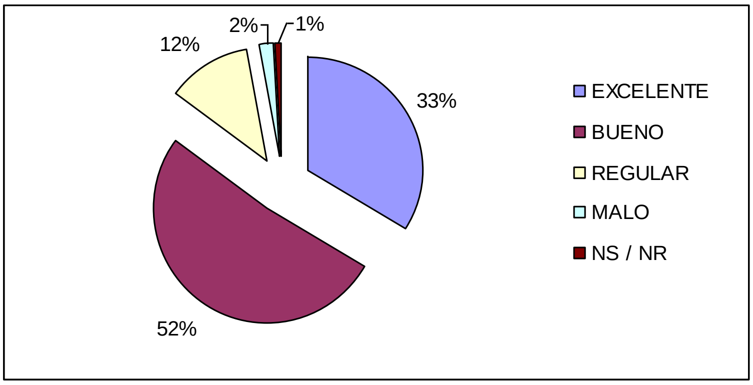
Economically, the reason why very little has been done until now is because there is no money in the budget for researching this problem. In fact, no money has been allotted to tackling this problem for the 2009 budget, so the earliest that the town government will be able to actually spend money on any environmental project will be the year 2010, unless they get a loan. This is the reason given by Diego Rubí, the environmental officer for Santo Domingo. However, it still remains to be explained why no money has been allotted to addressing this problem.

The reason why no money has yet been allotted to researching the makeup of organic waste in Santo Domingo or investigating sustainable alternatives to landfilling such as composting and anaerobic digestion is that it was not seen as a necessity to do so until now. According to Mayor Raul Isidro Bolañas of Santo Domingo, “it is a cultural thing”. There is a mindset among the citizens of Santo Domingo (although this mindset can certainly be found elsewhere) that a problem which is not imminent is not worth worrying about, even if the problem would be much easier (and often less expensive) to manage by dealing with it as early as possible.

The best way to avoid this sort of problem in the future would be for the municipality of Santo Domingo to begin keeping track of how much and what kinds of organic material are thrown out in the town. This can be done by surveying the public as well as by analyzing random samples of waste that are sent to the landfill. Building a solid foundation of information is the most important factor in making informed decisions.

There is also a historical reason behind the landfill problem. Dr. Sergio Musmanni, director of the Centro Nacional de Producción más Limpia, says that many landfills in the past were run very poorly. He cites the former dump in Cartago where people who lived nearby were forced to stay inside of their homes most of the time because of insect infestation. Santo Domingo’s landfill was run relatively well, but because of the poor conditions of dumps – which citizens called landfills – in other parts of Costa Rica, there are negative connotations associated with landfills (personal communication, November 26, 2008). This lead to citizens not understanding the problems associated with waste management, but a strong desire to avoid having landfills built nearby.

The public of Santo Domingo is not aware of the municipality’s waste management problems. This is confirmed by a survey done in 2008 which showed that eighty-five percent of citizens rated the trash collection system “excellent” or “good”, but sixty-eight percent did not know or did not respond to a question about the quality of the treatment of their garbage, implying that many people do not know what happens to their waste after it is picked up. The graphs of these surveys are shown in Figure 10.



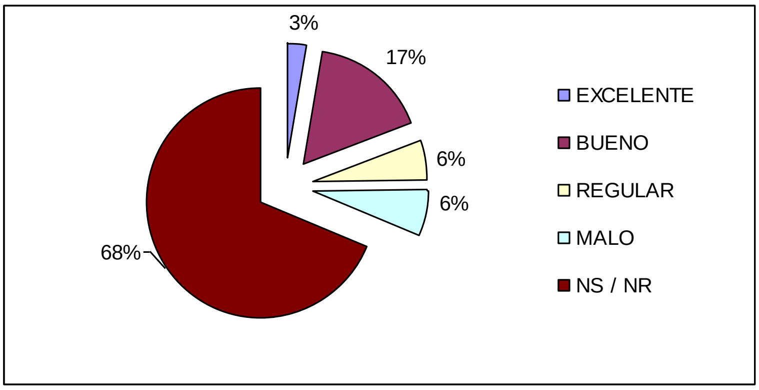


Figure 10: Public perception of waste management program. The top figure shows the responses to people's feelings about the waste collection system. The bottom figure shows how people feel about the waste treatment system. From "*Plan for Solid Waste in Santo Domingo*", 2008.

Whatever program Santo Domingo chooses to implement, it needs to be accompanied by an educational program. If an educational program is instituted now, it may help avoid problems in the future.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

After interviewing various officials of Santo Domingo, gathering data relating to the biodegradable fraction of the municipal waste stream, researching available biogas and composting technologies, and performing an extensive cost-benefit analysis we drew four conclusions:

- Data regarding the municipal solid waste flow in Santo Domingo, especially relating to density and composition, are either scarce or nonexistent.
- Separation of biodegradable from non-biodegradable waste at the source is a better option than separation at a central facility because of the high volume of waste produced in Santo Domingo.
- The main value of a biogas program comes from extending the lifespan of the new landfill rather potential profits from electricity production.
- Our models indicate that a composting program based on the Jiménez model would be a valuable investment for Santo Domingo.

Based on the above conclusions we have developed four recommendations for Santo Domingo with regards to their waste management system.

RECOMMENDATION 1: MONITOR SOLID WASTE PRODUCTION

The calculations in the previous chapter were based on values which were, at times, very rough estimates. Santo Domingo needs to develop methods for monitoring their solid waste production and cataloguing more accurate and reliable data. Especially when dealing with density, differences from our estimates can greatly affect the overall value of a project. Therefore, Santo Domingo should perform physical testing on random samples of organic waste taken from various restaurants and residential areas in the municipality. They should perform these tests continuously on a large number of samples in order to obtain reliable data and a more complete understanding of the composition and density of the municipal waste stream. Empirically determined data can also be supplemented by public surveys regarding the types of food and other materials people throw out.

RECOMMENDATION 2: IMPLEMENT A PILOT PROGRAM BASED ON THE JIMÉNEZ MODEL

We recommend that Santo Domingo begin a pilot program that uses the same principles and methods as the program in Jiménez. It appears that in the majority of the situations, the Jiménez model could add value to the waste management program and increase the lifespan of the landfill considerably (approximately 8 years if fifty percent of the organic waste is diverted). However, Blue Technology could still be valuable if our estimates for density or electricity production are incorrect. A pilot program would provide an opportunity to gather more data concerning the municipal solid waste stream, and would also help to determine specifics about day to day operations of a facility (for example how non-biodegradable organic waste such as cooking oil could best be dealt with). After more data has been gathered, Santo Domingo should reevaluate their situation to see if Blue Technology or other types of programs would be beneficial.

RECOMMENDATION 3: DEVELOP A COMPREHENSIVE ENVIRONMENTAL EDUCATION PROGRAM

The municipality of Santo Domingo needs to be active in educating the public not only on how to compost, but also on why they need to compost. A public awareness of the amount of funds that can be saved or diverted to other public projects could encourage higher participation rates. Furthermore, a composting project could produce thousands of tonnes of organic compost, which the municipality may not be able to sell. The public should be aware of this resource so that there is not a buildup of unused compost at the site. The more engaged the public is with any program Santo Domingo pursues, the greater the success of that program will be.

RECOMMENDATION 4: MAINTAIN LONG-TERM WASTE MANAGEMENT GOALS

The municipality could have avoided some of the problems it is facing today if they had started projects to fix the solid waste management many years ago. As mentioned in the results, some officials in Santo Domingo believe that part of the problem is cultural. Part of the problem was procrastination or a lack of foresight which prevented projects like this from being pursued. Santo Domingo has shown initiative by starting this project and others like the recycling project, but these efforts must be sustained even after the new landfill has been built. This problem is not short-term, and when the new landfill closes, they should already have plans in place to deal with the management of their solid waste.

REFERENCES

Al-Yaqout, A. F., & Hamoda, M. F. (2002). Report: Management problems of solid waste landfills in Kuwait. *Waste Management Research, 20*, 328 - 331.

Average retail price of electricity to ultimate customers by end-use sector, by state . (2008). http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html

Basic information: Municipal solid waste (MSW). (2008). Retrieved 9/14, 2008, from http://www.epa.gov/epaoswer/non-hw/muncpl/facts.htm

Börjesson, P., & Berglund, M. (2007). Environmental systems analysis of biogas systems—Part II: The environmental impact of replacing various reference systems. *Biomass and Bioenergy, 31*(5), 326-344.

Braber, K. (1995). Anaerobic digestion of municipal solid waste: A modern waste disposal option on the verge of breakthrough. *Biomass and Bioenergy, 9*(1-5), 365-376.

Bury, J. (2007). *Biogas transformation unit (BTU)*

Campbell, A. (2008). *Composting science for industry*.http://www.recycledorganics.com/training/compostingscience/composting_science_lecture.htm

'Dustbin' UK tops landfill table.(2007, 7 January). *BBC,*

Electricity. (2008). Retrieved October 01, 2008, 2008, from http://www.bbc.co.uk/schools/gcsebitesize/science/21c/radioactive/generatingelectricityrev_print.shtml

Gomes, A. P., Matos, M. A., & Carvalho, I. C. (2008). Separate collection of the biodegradable fraction of MSW: An economic assessment. *Waste Management, 28*(10), 1711-1719.

Henry, C., & Bergeron, K. (2005). *Compost use in forest land restoration* No. EPA832-R-05-004

Hoornweg, D., Thomas, L., & Otten, L. (2000). Composting and its applicability in developing countries.

Landfills. (2008). Retrieved 9/15, 2008, from http://www.epa.gov/osw/nonhaz/municipal/landfill.htm

Levesque, A., Pelletier, B., & Samuels, E. (2003). *Solid waste management in Costa Rica and the United States: A comparative analysis of five municipalities*. Worcester, MA: WPI.

Mæng, H., Lund, H., & Hvelplund, F. (1999). Biogas plants in Denmark: Technological and economic developments. *Applied Energy, 64*(1-4), 195-206.

Mannix, C. (2008). *Propuesta plan de manejo de residuos orgánicos habitacionales generados en el distrito central del cantón de Santo Domingo de Heredia*

Martin, W. L., & Tedder, R. B. (2002). Use of old landfills in Florida. Paper presented at the *16th GRI Conference, Geosynthetic Institute*, Philadelphia, PA.

Narayana, T. Municipal solid waste management in India: From waste disposal to recovery of resources. *Waste Management, In Press, Corrected Proof*

O'Leary, P. R., & Walsh, P. W. (1995). *Decision maker's guide to solid waste management* No. EPA 530-R-95-023). Solid and Hazardous Waste Education Center, University of Wisconson-Madison/Extension: EPA.

Palmer, S. R., Dunstan, F. D. J., Fielder, H., Fone, D. L., Higgs, G., & Senior, M. L. (2005). Risk of congenital anomalies after the opening of landfill sites. *Environmental Health Perspectives, 113*(10), 1362-1365. Retrieved from http://www.jstor.org/stable/3436102

Plan municipal de gestión de residuos sólidos: Municipalidad de Santo Domingo de Heredia(2008).

Ray, M. R., Roychoudhury, S., Mukherjee, G., Roy, S., & Lahiri, T. (2005). Respiratory and general health impairments of workers employed in a municipal solid waste disposal at an open landfill site in Delhi. *International Journal of Hygiene and Environmental Health, 208*(4), 255-262.

Read, A. D., Phillips, P., & Robinson, G. (1998). Landfill as a future waste management option in England: The view of landfill operators. *The Geographical Journal, 164*(1), 55-66. Retrieved from http://www.jstor.org/stable/3060545

Renkow, M., & Rubin, A. R. (1998). Does municipal solid waste composting make economic sense? *Journal of Environmental Management, 53*(4), 339-347.

Sanez, L. (2006). *Estudio de diagnostico ambiental: Relleno sanitario Santo Domingo de Heredia*.

Sharma, A., Meesa, S., Pant, S., Alappat, B. J., & Kumar, D. (2008). Formulation of a landfill pollution potential index to compare pollution potential of uncontrolled landfills. *Waste Management Research, 26*, 474 - 483.

Smith, R. C. (1995). *Composting practices.* Retrieved 9/15, 2008, from http://www.ag.ndsu.edu/pubs/plantsci/hortcrop/h885w.htm

Zamorano, M., Ignacio Pérez Pérez, J., Aguilar Pavés, I., & Ramos Ridao, Á. (2007). Study of the energy potential of the biogas produced by an urban waste landfill in southern Spain. *Renewable and Sustainable Energy Reviews*, *11*(5), 909-922.

Zarate, M. A., Slotnick, J., & Ramos, M. (2008). Capacity building in rural Guatemala by implementing a solid waste management program. *Waste Management*, *28*(12), 2542-2551. doi:DOI: 10.1016/j.wasman.2007.10.016

APPENDIX A: CENTRO NACIONAL DE PRODUCCIÓN MÁS LIMPIA

The Centro Nacional de Producción más Limpia is a private non-profit organization which is actually a collaboration of la Cámara de Industrias de Costa Rica, the CEGESTI, and the Instituto Tecnológico de Costa Rica. It works internationally with the United Nations Organization for Industrial Development, the United Nations Enviornmental Development Program, and the government of Switzerland.

CNP+L provides a number of services intended to help industries reduce their impact on the environment. They perform on-site evaluations, qualification of problems, in addition to providing information and technology to help the national sectors to meet their environmental goals.

APPENDIX B: BIOLOGICAL PROCESS OF COMPOSTING

The process of composting is essentially that of microorganisms “eating” complex organic materials and breaking them down into simpler organic compounds, carbon dioxide, and water. In chemical terms, this is simply oxidation - the breaking of chemical bonds between carbon and hydrogen and the formation of new bonds between carbon and oxygen - although it is not a complete oxidation, as the product of this process still includes some organic compounds. This process is also exothermic, meaning that some heat is produced as well.

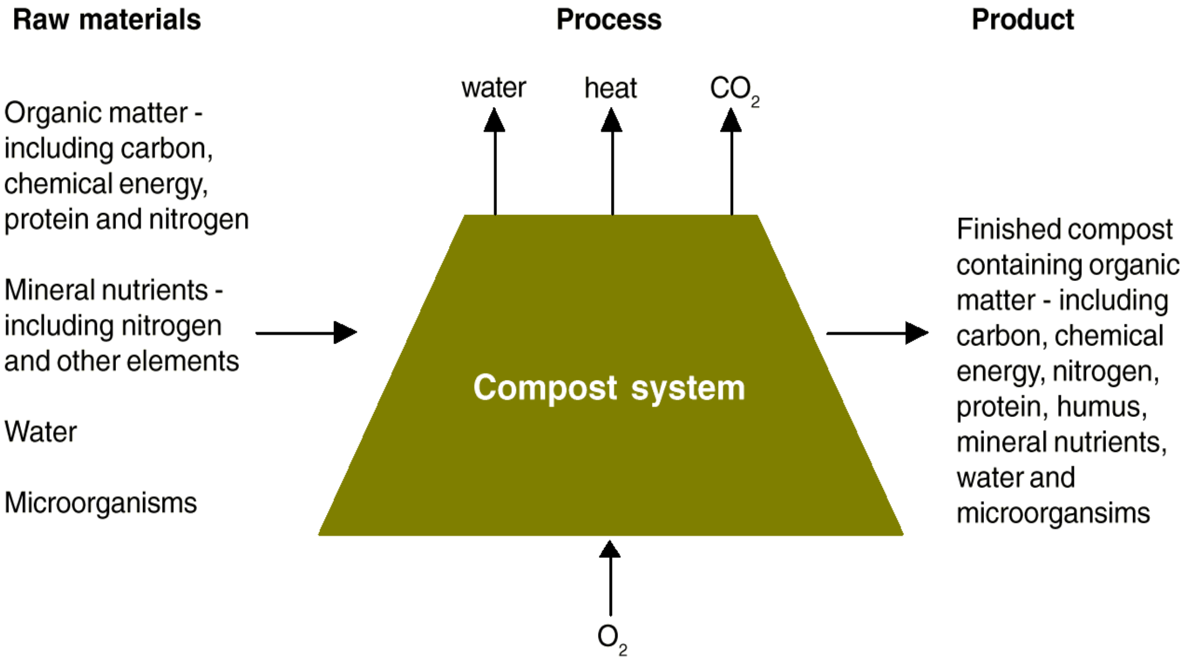


Figure 11: Compost Process. From A. Campbell “*Composting science for industry*”, 2008

Since composting depends on the activity of microorganisms, the right conditions must be maintained for these organisms to thrive and digest the material as quickly and completely as possible. They require certain amounts of moisture, oxygen concentration, airflow, temperature, carbon, and nitrogen. These requirements are outlined in a 1995 Decision Maker’s Guide to Solid Waste Management published by the EPA and directed by Philip O’Leary and Patrick Walsh. Walsh and O’Leary report that these conditions are largely affected by variables such as the volume of the compost pile, the sizes of particles in the pile, the specific materials in the pile, frequency of watering, and ambient temperature.

The microorganisms responsible for composting, like all living things on Earth, require water in order to survive. Therefore, a compost pile must be kept sufficiently moist in order for the organic material to be digested. According to O'Leary and Walsh, the ideal moisture content for a compost pile is fifty to sixty percent of the total mass of the pile. Angus Campbell (2008) reports this same figure, and adds that the activity of microbes in a compost pile all but ceases at water concentrations below thirty percent. However, O'Leary and Walsh add that too much water can be a detriment to composting because it can inhibit the free flow of oxygen and promote the existence of odor-causing anaerobic bacteria.

Standard composting relies on aerobic (oxygen-breathing) bacteria. It is important to maintain the right level of oxygen and allow the piles to "breathe" properly. Walsh and O'Leary state that most compost materials require air with an oxygen concentration of at least ten to fifteen percent. Campbell reports that the oxygen concentration of the atmosphere is twenty-one percent but this does not mean that the air inside of a compost pile will contain this much oxygen. Proper aeration of the inside of a pile, according to Campbell, can be achieved by turning the pile or by mechanically pumping air into it. Again, there is such a thing as too much of a good thing; O'Leary and Walsh stipulate that too much air can dry out the pile or cause the temperature to drop.

The temperature of the pile is also very important. While this variable is somewhat self-sustaining due to the exothermic nature of composting, the pile must be monitored regularly and protected against the elements if it is outside. According to O'Leary and Walsh, a temperature between thirty two degrees and sixty degrees Celsius is ideal for the microorganisms involved in aerobic composting, and a sustained temperature of fifty five degrees throughout the pile for three days is sufficient to kill unwanted pathogens while sparing the beneficial organisms. Campbell confirms these figures and also states that at temperatures between sixty-five and seventy degrees Celsius, the beneficial microorganisms become less active.

In addition to proper moisture, temperature, and oxygen levels, microorganisms also require the right nutrients. More specifically, they require the proper ratio of carbon to nitrogen. O'Leary and Walsh state that while other elements such as phosphorus and sulfur are needed as well, they are usually abundant enough or are needed in such trace amounts that they are not limiting factors in the decomposition process, and therefore the ratios of these elements is not very critical to the rate of decomposition. Campbell reports that the ideal ratio of carbon to nitrogen (by weight) is somewhere between twenty-five and thirty to one, but ratios as high as forty to one are considered to be suitable for composting. Different materials contain different ratios of carbon to nitrogen. According to Campbell, wood chips tend to be very high in carbon, usually containing 200-300 parts for every part nitrogen, while manure and food organics contain very high concentrations of nitrogen (between five and ten parts carbon per part nitrogen for manure and fifteen parts for food organics). Campbell further states that yard waste such as grass clippings tends to have a ratio between fifty and eighty to one. O'Leary and Walsh write that the optimal carbon/nitrogen ratio can be achieved by mixing materials that have low concentrations of nitrogen with materials that have higher concentrations. They report that as decomposition proceeds, carbon is consumed faster than nitrogen, resulting in the carbon-to-nitrogen ratio decreasing to between fifteen and twenty to one, which is typical of finished compost. Campbell notes that ratios less than this can result in foul odors, while very high ratios will cause the decomposition to occur very slowly.

According to Campbell, there are several different ways to compost organic waste, but they can be grouped more or less into two main categories: those in which the material is decomposed outside in a big pile known as a “windrow”, and those in which the process takes place in some kind of sealed reaction vessel. Composting in open, piles, reports Campbell, presents relatively low capital costs but requires long decomposition times and also makes it difficult to capture leachate from the pile and also to control odors. In contrast, Campbell states, in-vessel composting methods present a high capital cost but allow for the more automation during the composting process. Finally Campbell adds that they also take much less time to produce finished compost, usually on the order of a couple of weeks. What kind of system is used depends on how much money is available for the operation, how quickly the material must be processed, and what the limitations are in terms of odors and leachate produced.

APPENDIX C: BIOLOGICAL PROCESS OF ANEROBIC DIGESTION

While, in general, composting is thought of in the sense of aerobic digestion by microbes, it is possible to deprive the waste of oxygen, resulting in anaerobic digestion. The purpose of this is the production of biogas. Braber (1995) performed a comprehensive study on the production on biogas and reports that as matter decomposes, the microorganism will emit various types of gas (mostly methane and carbon dioxide, with trace amounts of hydrogen sulfide). He further states that the energy content of the gas produced is usually around fifty five to seventy percent methane depending on the composition of the waste with the rest being carbon dioxide. The production of methane is significant, because it can be burned to create energy for heat or electricity.

Braber states that anaerobic digestion can occur naturally at the bottom of large bodies of water. The process that Braber details is important to understand as replicating the conditions is key to creating a sustainable biogas system. Braber informs us that conditions for anaerobic digestion for a commercial product can be replicated and sped up in several ways. It can be produced in either a wet or dry environment and it can be produced in batches or continuously. Also, Braber states, you can subject your waste to “co-digestion” where it will be mixed with liquid manure or sewage sludge.

The benefit of anaerobic digestion (besides methane) is that after the gas has been gathered, the left over waste can generally be used in the same ways as compost can. The drawback is that anaerobic digestion is not suitable for all types of organic material. Braber reports that while materials like kitchen waste are perfectly suited for anaerobic digestion over aerobic digestion (because the water content does not promote the best decomposition in aerobic conditions), most yard waste (such as tree trimmings and grass) contain a high amount of lignocellulose, which prevents the waste from decaying well in anaerobic conditions.

Braber stipulates that because of the requirements for anaerobic digestion, it is very difficult to predict exactly how much biogas may be recoverable from a large amount of waste without knowing specifics about the waste's composition. Furthermore, he adds that steps must be taken in order to be able to separate desirable waste for either composting or anaerobic digestion from waste which is not useful for these reactions (such as glass or plastic).

APPENDIX D: BENEFITS OF COMPOSTING

Perhaps the biggest benefits from composting come when the compost, after degrading, is used as soil or mulch. Compost has been widely praised for improving the structure of the soil. Smith reports that the benefits from using this soil include higher water retention rates (which will increase plant growth and reduce erosion), a reduction in weeds, and higher rates of helpful microbial growth (1995). One large scale example of the effects of composting was seen in an EPA experiment in forests. Compost is so effective at harboring growth that the EPA has produced a report detailing their use of compost to restore land that has been damaged in forests in Washington, Oregon, and Colorado. The land that was targeted mostly included areas that had been cleared for human use, such as roads and campsites. Most of these areas were devoid of plant life, and many were degrading due to soil erosion. Results were positive, with erosion being reduced and significant increases in biomass being observed (Henry & Bergeron, 2005).

APPENDIX E: THE LANDFILL IN SANTO DOMINGO

This is the uncovered trash in the only remaining space left in the old landfill.

Wild dogs live at the landfill eating uncovered garbage.

The leachate control system consists of several channels that drain rainwater into wells.

The wells in the landfill are often poorly covered and infested with insects.

The residential areas are visible from the landfill.

The municipality has planted lines of trees to prevent the unsightly view of the landfill.

Tubes like this release methane into the atmosphere to prevent explosions.

Río Virilla is visible from the landfill site.

APPENDIX F: COMPOSTING PROGRAM IN JIMÉNEZ

MUNICIPALIDAD DE JIMÉNEZ

PROYECTO DE TRATAMIENTO DE RESIDUOS DOMICILIARIOS

¿ COMO COLABORAMOS?

Cada Familia deberá separar los residuos en su domicilio en **ORGANICO** e **INORGANICO**

Orgánico

Orgánico

-Cáscaras
-Restos de madera
-Cuero
-Plumas
-Cabellos
-Fósforos
-Yerba
-Papel Carbón

-Cáscaras de huevo
-Grasas
-Carnes
- Huesos
-Café
-Residuos de comidas
-Cenizas
-Toallas de Cocina
-Servilletas

Reciclable

Inorgánico Reciclables

- Bolsas de Nylon
- Tapas de Gaseosas
- Corchos
- Papeles
- Tetrabrite (leche y frutas)

- Vidrios
-Cartones
-Metales
-Plásticos
-Aluminio-Latas
(atún, Sardinas, etc)

NO ORGANICOS NI RECICLABLES

- Pilas
- Solventes
- Hojas de afeitar
- Pinturas
- Y todo lo que puede provocar focos contaminantes.
-Embolturas de Mantequilla, Confites y Meneitos, etc...

- Pañales
- Algodón
- Gasas
- Medicamentos
- Jeringas
- Paños
- Y todo lo que pueda provocar focos infecciosos o contaminantes
-Cerámicas, adornos y ropa en mal estado

DIAS Y HORARIOS DE RECOLECCIÓN

1- Residuos Orgánicos Bolsa Verde, No reciclables Bolsa Negra (Lunes y Viernes, a partir de las 6 a.m.)
2- Residuos Inorgánicos Reciclables (Miércoles a partir de las 6 a.m.)

Primeros y Terceros Miércoles de cada mes.

This is an example of an educational flyer distributed to citizens of Jimènez.

Jimènez gives away the compost produced due to regulations which prevent it from being sold.

Compost is left to digest for two to three months with a pipe to allow for the release of methane.

After digesting, the compost is left to dry for a day or two.

Most of the compost consists of pieces that are too large for plants. Jimènez uses a chipper to reduce the size of the compost particles.

Some of the compost is digested for another six months with the assistance of worms as part of an experiment to determine the best composting methods.

Jimènez produces its own microbes to assist with the digesting process.