# LIFE CYCLE ASSESMENT AND COMPARISON OF THE ENVIRONMENTAL IMPACTS OF THERMAL TREATMENT AND LANDFILLING IN PUERTO RICO

by

**Giselle Balaguer Datiz**

**Advisor: Prof. Nikhil Krishan**

**Submitted in partial fulfillment of the requirements for the degree of**

**Master of Science in Earth Resources Engineering**
**Department of Earth and Environmental Engineering**
**Fu Foundation School of Engineering and Applied Science**
**Columbia University**

**May 2008**

EARTH ENGINEERING
Center
Columbia University

## Executive Summary

The management of municipal solid waste (MSW) can be challenging in island settings. The island of Puerto Rico, for example, has faced increasing MSW management challenges in recent years due to the closing of several older landfills because of lack of compliance with federal landfill requirements. As in most island settings, Puerto Rico suffers from limited space for construction of new landfills. Furthermore, Puerto Rico residents generate more waste per capita than the people living on the continental US. Thermal treatment, or waste to energy (WTE) technologies are therefore a promising option for MSW management.

In this paper we quantify and compare the environmental burdens of thermal treatment with modern landfilling for the non-recyclable fraction of MSW in Puerto Rico. The scope of our analysis includes a broad range of activities associated with the management of MSW. We include transportation of MSW, impacts during construction of the facilities, impacts of managing and processing the waste and the energy and material offsets implications from the process. We manage uncertainty in data and models by constructing different scenarios for both alternatives based on realistic ranges of emission factors.

Our results show that when compared with modern landfilling thermal treatment (of the unrecyclable part) of MSW is the preferred alternative. Thermal treatment facilities are shown to be 20-85% superior to the best landfill scenarios in terms of human health damage, ecosystem damage and resource use.

## Table of Contents

## List of Tables

## List of Figures

# 1 Introduction

It is critical to consider environmental impacts when making strategic decisions related to MSW waste management. Increasingly stringent regulations and higher environmental awareness of communities are driving the selection of MSW management systems that have lower environmental footprints (Tchobanoglous, 1993). There is no universal favored design of a waste management system. In order to minimize environmental and economic impacts, the optimal system for a given area should be determined taking local aspects into account, regional particularities in waste composition, sitting concerns for disposal options, markets for recovered resources, local energy mix and economic situations. (McDougal, 2001).

Life Cycle Assessment (LCA) is a systematic methodology to assess the overall environmental impacts of a product or process from cradle to grave (ISO, 2006). The methodology relies on a compilation and evaluation of the inputs, outputs and environmental impacts throughout the life cycle of a product (from raw material acquirement through manufacturing, to its use and disposal). and is a valuable tool when assessing the environmental consideration that need to be part of decision making towards sustainability (UNEP, 2003).

The LCA methodology has successfully been used in the past to understand and assess the overall environmental burdens related to waste management systems, assess the contributions of specific waste fractions and compare the environmental performance of different waste management scenarios. Liamsanguan (2008) assessed the energy consumption and greenhouse gas emissions of landfilling and incineration from a direct activity consideration and life cycle perspective for a providence in Turkey. The conclusions from this study position incineration as superior to landfilling. Environmental impacts from the management of different waste fractions have also been assessed using life cycle methodology. LCA of paper packaging materials (Finnveden, 1998), plastic-based packaging (Ross, 2003) and management of food waste (Lundie, 2005) have been performed in order to analyze the specific impacts related to their treatment. Life cycle methodology has also been used to assess different waste management scenarios from holistic approaches to landfilling (Wanichpongpan, 2006) and anaerobic digestion (Chaya, 2007) in Thailand to the current waste management strategies used in Italy (Arena, 2003) and potential options in Brazil (Mendes, 2004). Even though impact analysis have been assessed for various waste management options and waste streams there exists a continuous need to understand emerging waste treatment technologies land its application in specific localities.

There are few studies that analyze the life cycle implications in small island settings like Puerto Rico. In Puerto Rico, high per capita waste generation and poor management practices have led to a solid waste crisis in the island. Therefore, it would be very beneficial to extend the LCA application to Puerto Rico where a new approach to waste management is planned for the near future. According to a waste infrastructure plan developed for the Solid Waste Management Authority (SWMA), by 2016 the island's current 9,900 tons per day of MSW should be diverted by 35% from landfills by implementing two thermal treatment plants and other diversion strategies (SWMA, 2007). Currently, around 90% of the MSW generated in the island is disposed in 32 operating landfills and the remaining 10% is recycled (Solid Waste Management Authority, 2007). However, according to the Environmental Protection Agency (EPA, 2007) many of the operating landfills in the island do not comply with federal environmental regulations.

The government of Puerto Rico is considering emerging thermal treatment technologies because of their ability to reduce the volume of waste while recovering energy. The waste management hierarchy positions thermal disposal with waste recovery, especially incineration, as a viable and proven waste management strategy (Malkow, 2004). However, the dominating method, mass-burn grate incineration has caused concerns to the surrounding communities because of disadvantages related to air emissions and process residues. Recently, pyrolisis and gasification technologies have emerged to address these issues and improve the energy output of the process.

In Puerto Rico, local communities have opposed conventional thermal treatment (mass burn) as a waste management option (Rodriguez-Burns, 2008). Furthermore the local communities also oppose emerging technologies that utilize processes such as gasification because of the lack of consistent information regarding their application in settings such as Puerto Rico ("Puerto Rican Health Officials", 2002). However, the installation of two thermal treatment plants that comply with federal air emissions regulations may lead to less environmental implications for the island when compared to the continuing use of landfills. Particularly waste to energy plants that use the Thermoselect gasification technology, which can convert waste into up to 100% recyclable products while producing less air emissions than the conventional incineration plant, can prove to be a viable alternative to the island ("Wiping out waste", 2000). This study seeks to fill informational gaps by performing a LCA comparing a modern landfill versus a thermal treatment facility using Thermoselect Process technology (Thermoselect website), both located in the island of Puerto Rico.

## 2 Current MSW Management in Puerto Rico

Puerto Rico has an area of about 14,000 km$^2$ (roughly the size of Connecticut), 3.9 million inhabitants and a municipal solid waste generation of approximately 9,900 tons per day. Around 90% of the MSW generated in the island is disposed in 32 operating landfills and the remaining 10% is recycled (SWMA, 2007). Many of the 32 operating landfills do not fully comply with federal landfill regulations, therefore the United States Environmental Protection Agency (US EPA) issued in the past three years consent orders to close four landfills (Vega Baja, Aguadilla, Santa Isabel and Florida) and is currently pursuing a fifth consent order to close one of the island's biggest landfills that receives more than 14% of the island's waste (Toa Baja).

In response to the need to comply with the EPA regulations, the Puerto Rico Solid Waste Management Authority (SWMA) undertook a systematic analysis of the MSW situation in Puerto Rico as well as potential future strategies for the island to pursue. Part of their efforts included the development of the Dynamic Itinerary of Infrastructure Projects in 2007 to provide a planning framework and define infrastructure strategies to manage

Puerto Rico's MSW for the next 25 years in compliance with federal regulations. The Itinerary includes a goal to diverge 35% from landfills by 2016 with the operation of seven landfills (six current landfill expansions and construction of one new landfill facility).

In order to successfully implement the strategy of diverting waste from disposal in landfills, the Itinerary includes the development of two thermal treatment processing facilities with a total capacity of 2,900 tons per day. The SWMA considered emerging thermal treatment technologies such as gasification as a potential alternative (SWMA, 2007). Currently there are no thermal treatment plants in Puerto Rico however Caribe Waste Technologies, Inc., operated by Interstate Waste Technologies, is in final negations to develop a Thermoselect facility in the municipality of Caguas.

# 3 Methodology

The LCA methodology is used and the SimaPro software, developed by Dutch Pre Consultants, is used as the LCA analysis tool with the Eco-Indicator 99 damage assessment model.

## 3.1 Scope

We consider four different landfilling and thermal treatment scenarios for Puerto Rico. The environmental impact of each scenario was normalized and compared per ton of MSW processed. In this study we focus on the waste generated in the municipality of Caguas, where a thermal treatment plant is proposed to be developed in the near future, and in the expansion of the currently in operation landfill in the municipality of Humacao. A GIS study of the waste allocation patterns in Puerto Rico indicated that the waste collected in the municipality of Caguas is processed at the Humacao Landfill around 21 miles to the southeast (Soto, 2004) (Figure 1). The Humacao landfill receives an estimated 14,000 tons of waste per week and it is proposed to be expanded up to an approximate capacity of 20,000,000 tons (SWMA, 2007).

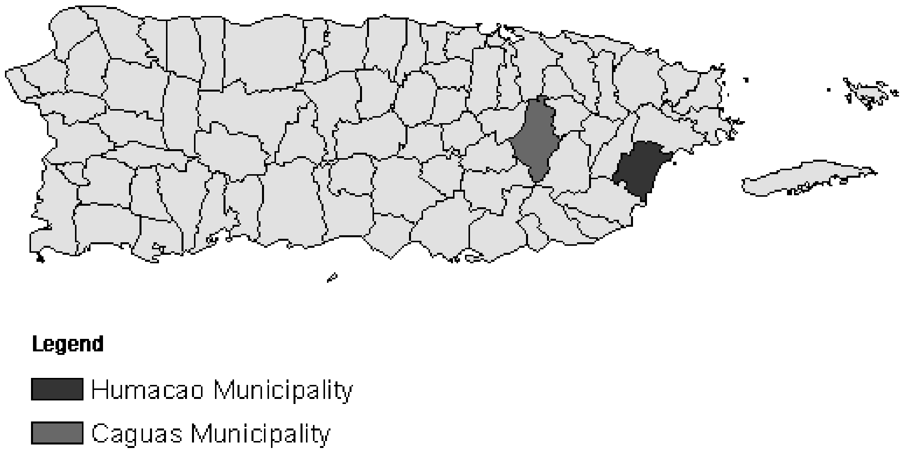

**Figure 1. Locations of proposed thermal treatment plant and modern landfill expansion in Puerto Rico**

The system boundary includes transportation from curbside to processing facility, process specific burdens from gasification and landfilling, such as energy and resource recovery, leachate collection and treatment, and gas collection systems (Figure 2). Since the distance from the Caguas municipality to the landfill and thermal treatment plant location is small, it is assumed that the waste is transferred directly from curbside to the processing facility; therefore the impact of transfer stations is not included. Impacts related to capital infrastructure were estimated using available life cycle inventory databases. The emissions associated with the extraction, transportation, and refining of fossil fuels inputs required for transportation of waste are included in this study.

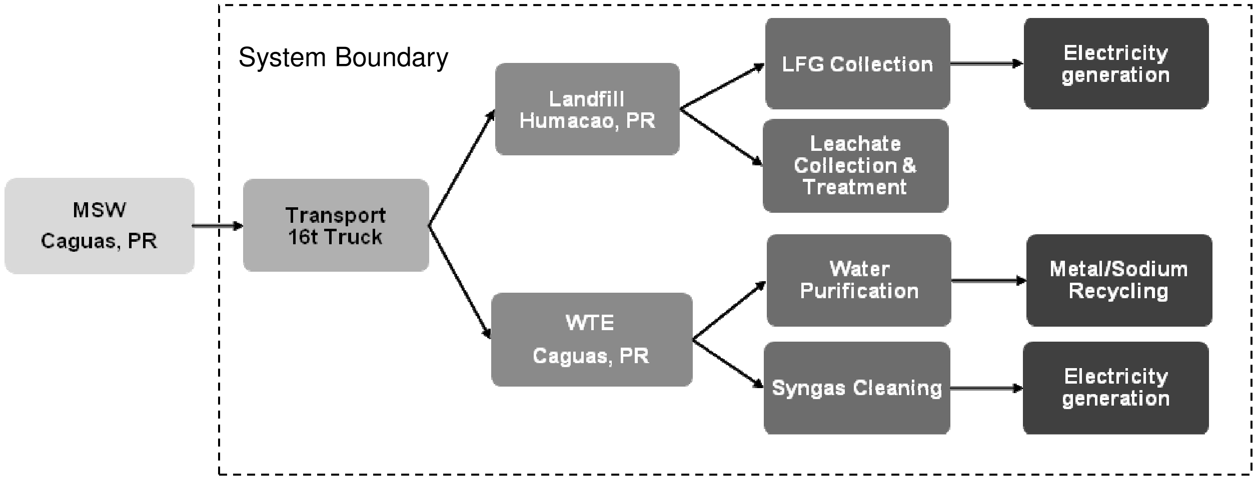

**Figure 2. Schematic of Life Cycle Operations**

The environmental parameters to be analyzed in this study include the net energy consumption, the air emissions of (Criteria air pollutants, hazardous air emissions and other relevant contaminants) and the water emissions of total-N and total-P. These emissions were grouped into three main damage assessment categories: human health, ecosystem damage and resource use.

## 3.2 Scenarios

We investigate potential alternatives by establishing four scenarios that incorporate thermal treatment and landfilling. Two thermal treatment scenarios with different emission factors and resource recovery conditions and two landfilling scenarios, one with and one without energy recovery and with different gas and leachate collection efficiencies, were assessed for their environmental impacts. The processes in each scenario were selected based on current technologies.

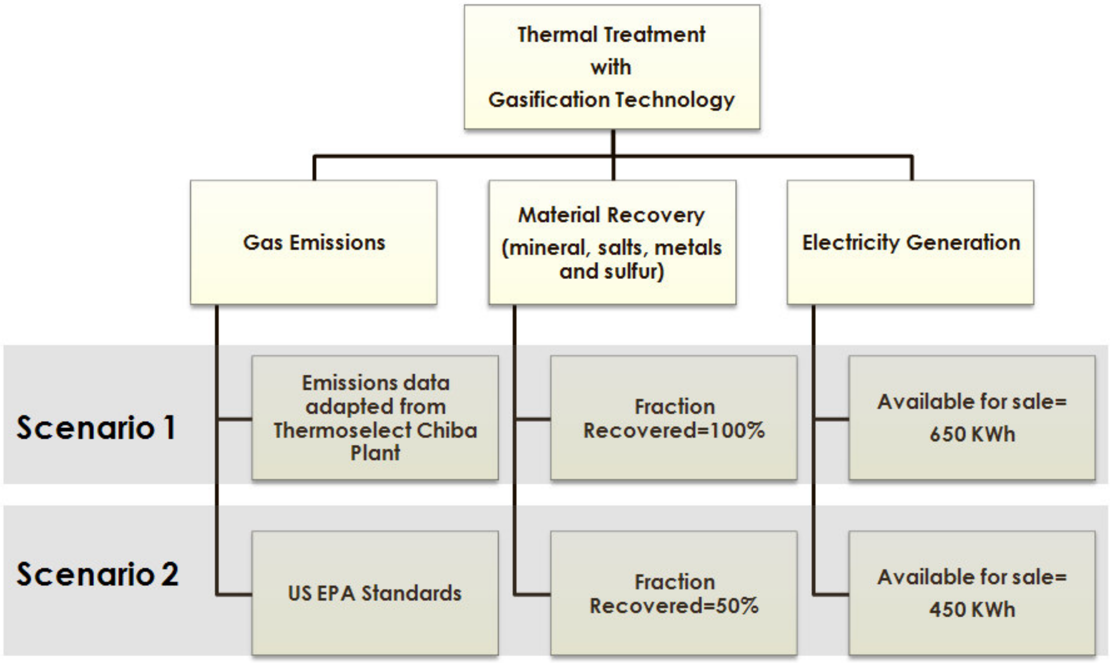

**Figure 3. Description of Thermal Treatment Scenarios per ton of MSW**

In scenario 1 and 2 (Figure 3), waste is thermally treated by the Thermoselect-Process. The Thermoselect-Process uses a high temperature technology to degasify waste and recover synthesis gas, minerals, metals, sulfur and salts. The process consists of a press degassing channel, high temperature reactor and homogenizer, and gas purification and water treatment systems (Miyoshi, 2002). Water streams from the process of water vapor condensation in the synthesis gas, pass through a water purification unit (Calaminus et al., 1998). The effluent from this water treatment process is used for cooling medium and therefore there are no water emissions from the Thermoselect facility.

The material and process data for the modeling of scenarios 1 and 2 was adapted from the Chiba JFE Thermoselect Facility in Japan. Specific modeling data for Puerto Rico include facility capacity, distances for waste transport from curbside to gate, location of the facility and local electricity mix. As pointed out before, the development of a Thermoselect facility in Puerto Rico is in the process of final negotiations. Facility capacity and distances were estimated based on information from the proposed facility in Caguas. In both scenarios the distance required to transport the waste generated in the municipality of Caguas to the thermal treatment facility proposed is 16 t-km. The facility would be expected to process 490,000 tons per year (SWMA, 2007). According to the Puerto Rico Electric and Power Authority data for 2006, the local source of electricity in the island came from burning imported fossil fuels (Figure 4).

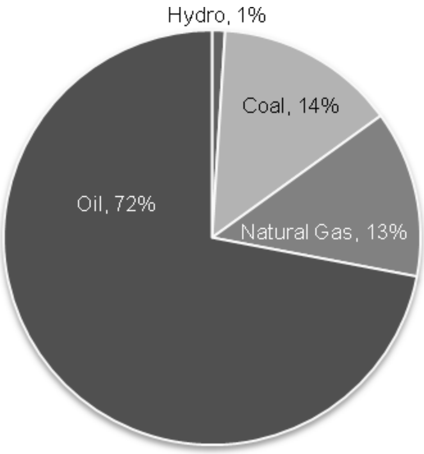

**Figure 4. Electricity mix for Puerto Rico (PREPA, 2006).**

In scenario 1, best case thermal treatment, the waste is thermally-treated with 650 KWh/ton electricity available for sale (energy recovery efficiency of 18%). In this scenario a 100% of the outputs of the Thermoselect Process (mineral, salts, sulfur and metals) are recycled in the metallurgy, concrete aggregate or chemical industries. Emissions data from the Thermoselect Chiba Plant in Japan were adapted to model air emission impacts. Emissions from this facility are lower than the US EPA air emission standards for large MSW combustors (Table 1).

Scenario 2 represents the worst case thermal treatment. The net electricity available for sale is 450 KWh/ton (energy recovery efficiency of 15%). We assume that a 50% of the outputs of the Thermoselect Process (mineral, salts, sulfur and metals) are recycled in the metallurgy, concrete aggregate or chemical industries. The remaining 50% of the outputs are assumed to be landfilled. As a worst case setting, air emissions from this scenario will comply with US EPA emission standards for large MSW combustors (Table 1).

**Table 1. Air emissions from the Thermoselect Process and US EPA emission standards for large MSW combustors.**

| Pollutant | Thermoselect Emissions[a,b] (Gas Engine) [mg/Nm$^3$] | US EPA Standards[c] [mg/Nm$^3$] |
|---|---|---|
| Particulate Matter (PM) | 0.2 | 11 |
| Sulfur Dioxide (SO2) | 0.16 | 63 |
| Nitrogen Oxides (NOx) | 14 | 264 |
| Hydrogen Chloride (HCl) | <5 | 29 |
| Carbon Monoxide (CO) | 3 | 45 |
| Mercury (Hg) | 0.002 | 0.06 |
| Total Organic Carbon (TOC) | 1.71 | 10[d] |
| Dioxins (TEQ), ng/m3 | 0.00039 | 0.14 |

[a] Emissions adapted from Thermoselect Plants in Chiba, Japan.

[b,c] Emission factors corresponding to scenario 1 and 2, respectively.

[d] EU emission standard

In order to thermally treat 1 ton of waste the Thermoselect Process utilizes inputs like Hydrogen chloride, oxygen, natural gas, Sodium hydroxide and additives (Table 2).

These inputs were modeled as part of the process specific inputs of the thermal treatment scenarios.

**Table 2. Summary of process specific inputs for Thermal Treatment of Waste in Scenarios 1 and 2**

| **Thermal Treatment**<br>Inputs | units | Values[a] |
|---|---|---|
| HCl | kg | 3.6 |
| Additives | kg | 0.58 |
| Oxygen | kg | 470 |
| Natural Gas | kWh | 380 |
| NaOH | kg | 4.4 |

[a] Same values for both scenarios.

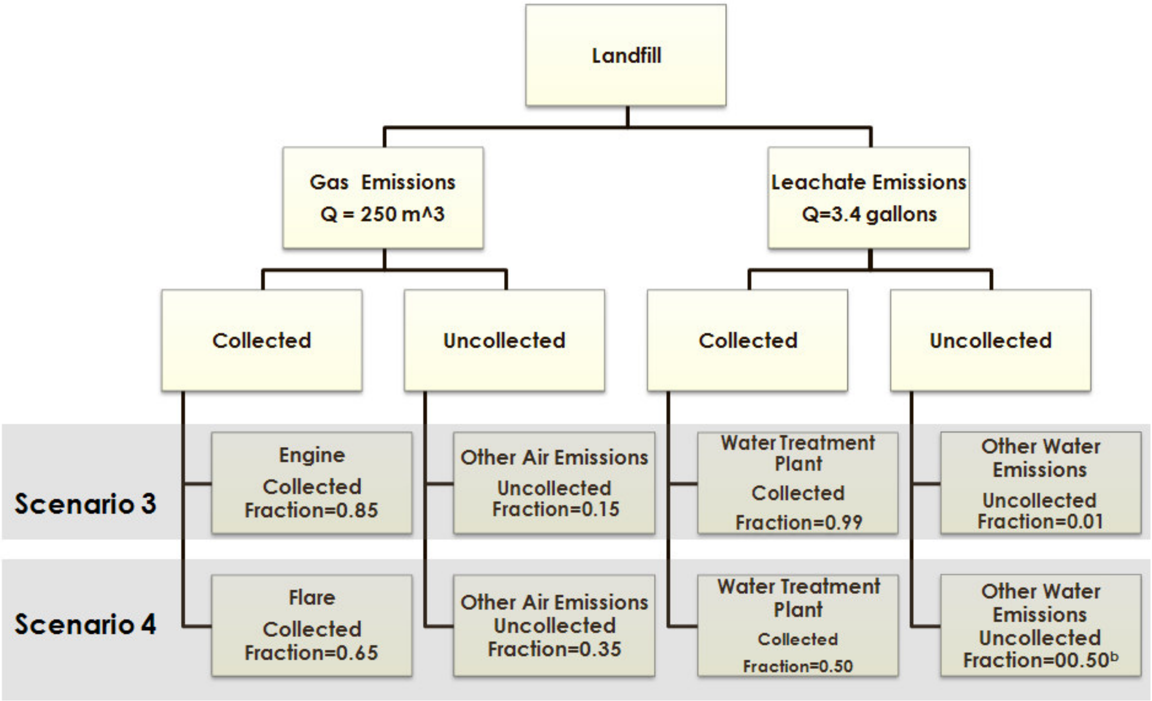

**Figure 5. Description of Landfill Scenarios per ton of MSW**

In scenario 3 and 4 (Figure 5), waste is disposed of in a modern engineered landfill that follows federal regulations in 40 CFR Part 258 (Subtitle D of RCRA.). The landfill design specifications under Subtitle D include composite liners, leachate collection and removal systems and top coverage. Furthermore, additional design provisions under the Clean Air Act (56 FR 24468) require owners of landfill facilities to install gas collection and control systems when landfill design capacity exceeds 111,000 tons (EPA, 1993).

Air emissions from landfills are generated principally due to the anaerobic digestion of waste. Landfill gas (LFG) consists primarily of methane and carbon dioxide in fractions of approximately 0.5 each. The quantity of methane generated is determined by applying the methodology recommended by the IPCC guidelines (IPCC, 2001). Other air pollution emissions generated from the landfill are based on US EPA AP-42 emission factors for MSW landfills (Table 3).

**Table 3. Calculated emission factors for uncontrolled emissions of air pollutants from landfill.**

| Pollutant | Calculated emission factor [kg/ton][a,b] |
|---|---|
| Carbon dioxide | 620 |
| Nitrogen Oxides | 0.0702 |
| Particulates | 0.029 |
| Carbon monoxide | 1.3 |
| Methane | 51 |
| Ethane | 8.7 |
| 2-Propanol | 0.99 |
| Xylene | 0.42 |
| Ethanol | 0.41 |
| Hydrogen Sulfide | 0.40 |

[a] Source: US EPA AP-42

[b] Emission factors per landfill scenario were calculated based on respective gas collection efficiencies.

Landfills also generate leachate from rainwater that trickles though the waste inside the landfill, collecting contaminants in the process. Depending on the efficiency of the leachate collection system, a fraction of the leachate may leak out without any treatment and a higher fraction will be treated. The collected fraction of the leachate is assumed to be treated in a treatment facility inside the landfill. We use the Ecoinvent database as a source of the modeling parameters for energy, land and resource requirements for the leachate treatment system. The amount of leachate generated in the landfill area per ton of MSW was roughly estimated using Humacao landfill site specific data for precipitation and catchment area (Table 4). The amount of trace elements present in the leachate was calculated from concentrations summarized by Christensen (Table 5) (Christensen, 2001).

**Table 4. Potential leachate quantity**

| Parameter | Units | Value[a] |
|---|---|---|
| Precipitation | m/yr | 82 |
| Area of expansion | $m^2$ | 510,000 |
| Refuse buried | Tons | 10,010,000 |
| Efficiency[b] | Fraction | 0.99 or 0.50 |
| Year of Operation | yrs | 24 |
| Potential leachate percolation | l/ton | 13 |

[a] Humacao site-specific data

[b] Leachate collection efficiency for scenario 3 and 4, respectively.

**Table 5. Potential leachate quality**

| Substance | Concentration [µg/l][a] | Generation[b] [mg/ton] |
|---|---|---|
| Benzene | 820 | 10 |
| Toluene | 6200 | 78 |
| Xylene | 1800 | 22 |
| Ethylbenzene | 640 | 8.2 |
| Trimethylbenzene | 130 | 1.6 |
| Naphtalene | 130 | 1.7 |
| Chlorobenzene | 55 | 0.70 |
| Trichloroethylene | 380 | 4.8 |
| Tetrachloroethylene | 130 | 1.6 |
| Methylene chloride | 33 | 0.41 |
| Chloroform | 36 | 0.45 |
| Phenol | 600 | 7.6 |
| Cresols | 1100 | 13 |
| Mecoprop | 5.5 | 0.07 |
| Acetone | 2200 | 28 |
| Diethylphthalate | 340 | 4.3 |
| Di-n-butylphthalate | 10 | 0.13 |
| Tetrahydrofuran | 220 | 2.8 |
| Tri-n-butylphophate | 180 | 2.3 |

[a] Adapted from Christensen, T.H., 2001, "Biogeochemistry of landfill leachate plumes", Applied Geochemistry 16, 659-718

[b] Rough approximation using : Leachate = precipitation*Area*years in operation*(1-efficiency)/refuse MSW

In scenario 3 we consider a best case landfill with very effective leachate collection system efficiency (99% impermeable). This landfill also has a very efficient landfill gas collection system (85%) and energy recovery from landfill gas combustion in a gas engine (30% energy recovery efficiency). The electricity available for sale is calculated

assuming a LFG heating value of 21 MJ/m$^3$ with a gas generation of approximately 250 m$^3$/ton. This provides an electricity offset of 87.5 kWh per ton of waste in the landfill.
In scenario 4 we consider a worst case landfill with poorer quality liner and collection system (50% efficient). This landfill also has poorer LFG collection system efficiency (60%) and no energy recovery from landfill gas combustion. LFG is flared.

# 4 Results and Discussion

The inputs and outputs of each scenario were related to three impact categories: human health damage, ecosystem damage and resource use per ton of MSW processed (Figure 6-8). The avoidance of environmental burdens as a result of energy and material recovery is shown as negative values in the figures below.

Analysis of the health damage per ton of MSW processed shows how implementation of thermal treatment in a large scale is preferred due to the avoidance of respiratory and carcinogenic compounds such as particulate matter (PM), nitrogen oxides (NOx) and sulfur oxides (SOx) (Figure 6). The thermal treatment scenarios are 20-30 % lower than corresponding landfilling scenarios. The offsetting of emissions of these compounds for the thermal treatment scenarios is due to the displacement of fossil fuel electricity. Scenario 4 (the worst case landfill) has the highest human health impacts. This is due to the fact that human health damages are sensitive to greenhouse gas emissions due to their climate change potential. In this scenario the main contributors to the impacts are methane and carbon dioxide.

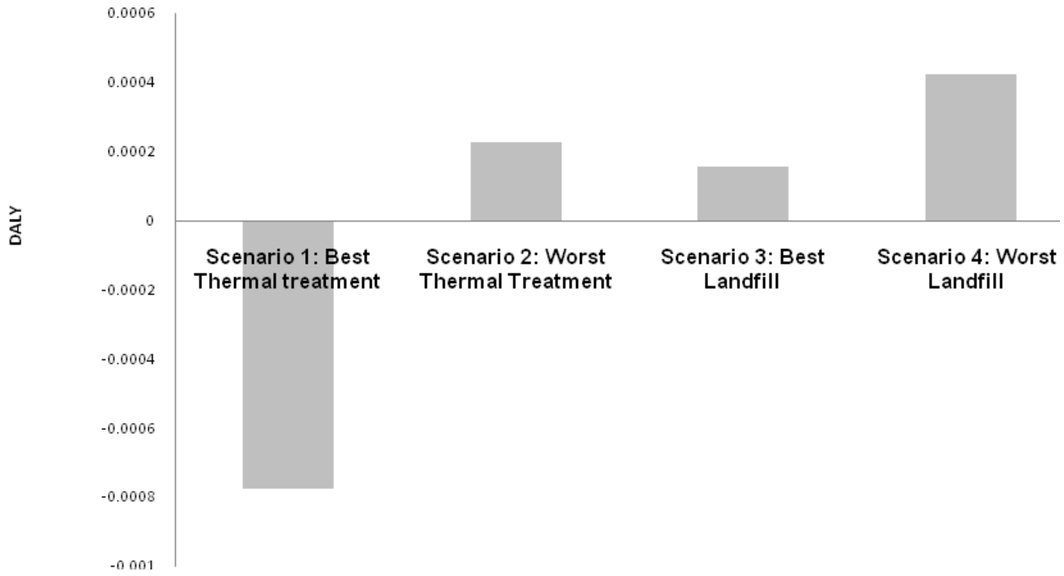

**Figure 6. Summary of human health damage per ton of MSW.**

Regarding ecosystem impacts, it can be seen that thermal treatment represents the preferred option due to lower damages to ecosystem quality (Figure 7). The thermal treatment scenarios 50-80% lower than the corresponding landfill scenarios. The ecosystem quality damage category consists of impacts from ecotoxicity, acidification and eutrophication, land use and land transformation. The thermal treatment scenarios show a negative impact primarily due to the avoidance of extensive land use and land transformations.

**Figure 7. Summary of ecosystem damage per ton of MSW.**

Resource use represents the additional energy it would take to mine and extract materials, given the resources consumed in the systems analyzed. Overall resource credits are given to scenarios 1 and 2 due to the ability of thermal treatment to significantly offset grid electricity and Thermoselect's capability to recycle most if not all of its outputs (Figure 8). Overall, the thermal treatment scenarios are 20-85% better than the corresponding landfill scenarios. It is important to note that we have not included temporal aspects of land use and transformations in this study. Landfill areas are restricted to that use for long periods of time, while land occupied by thermal treatment facilities could be more readily transformed into other uses.

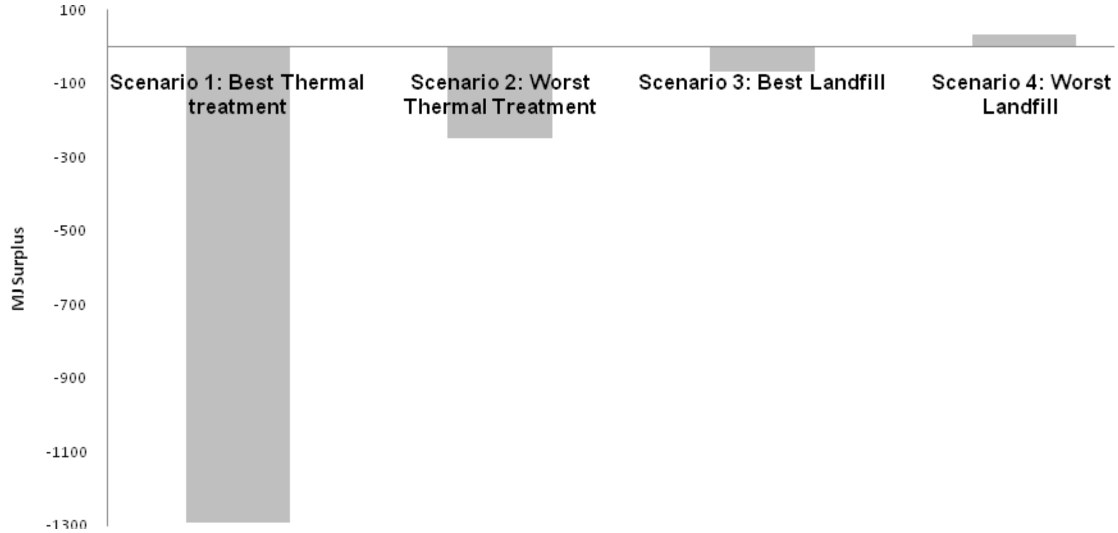

**Figure 8. Summary of resource use per ton of MSW.**

# 5 Summary

The results of the environmental life cycle assessment of thermal treatment and landfilling of the MSW of Puerto Rico are presented in this paper. Every possible effort should be made to reduce wastes and source-separate materials that can be recycled or composted. However, even in the most environmentally conscious nations a large fraction of the MSW is not recyclable. Currently there are only two alternatives for non recycled MSW landfilling or energy recovery by means of thermal treatment process and these are the alternatives that the government of Puerto Rico is considering.

Thermal treatment facilities are shown to be 20-85% superior to the best landfill scenarios in terms of human health damage, ecosystem damage and resource use. Furthermore, the current impacts of landfills in Puerto Rico are higher than the worst case landfill scenario presented in this study due to the lack of compliance of the island's landfills with federal regulations. On the whole, therefore, our results indicate that thermal treatment with high material recovery efficiency is the preferred alternative for MSW management in Puerto Rico.

In this study thermal treatment and landfilling were investigated only from an environmental point of view. Consequently, it may be supported with other decision-making tools that reflect on the economic and social effects of solid waste management.

## 6 References

ISO, 1997. Environmental standard ISO 14040, Environmental management—life cycle assessment—Principal and framework, Reference Number: ISO 14040: 1997(E).
UNEP, 2003. Environmental management tools: life cycle assessment, available from: /http://www.uneptie.org/pc/pc/tools/lca.htms.

Liamsanguan C., Gheewala S. LCA: A decision support tool for environmental assessment of MSW management systemts. Environmental Management 87 (2008) 132-138

Den Boer J., den Boer E., Jager J. LCA-IWM: A decision support tool for sustainability assessment of waste management systems. Waste Management 27, 2007, 1032-1045

Finnveden, G., Ekvall, T., 1998. Life cycle assessment as a decision support tool—the case of recycling vs. incineration of paper. Resource, Conservation and Recycling 24, 235–256.

Ross, S., Evans, D., 2003. The environmental effect of reusing and recycling a plastic-based packaging system. Journal of Cleaner Production 11, 561–571.

Berlin, J., 2002. Environmental life cycle assessment (LCA) of Swedish semi-hard cheese. International Dairy Journal 12, 939-953.

Lundie, S., Peters, G., 2005. Life cycle assessment of food waste management options. Journal of Cleaner Production 13, 275-286

Denison, R., 1996. Environmental life-cycle comparisons of recycling, landfilling, and incineration: a review of recent studies. Annual Review of Energy and Environment 21, 191–237.

Mendes, R.M., Aramaki, T., Hanaki, K., 2004. Comparison of the environmental impact of incineration and landfilling in Sa˜o Paulo City as determined by LCA. Resource, Conservation and Recycling 41, 47–63.

Arena, U., Mastellone, M.L., Perugini, F., 2003. The environmental performance of alternative solid waste management options: a life cycle assessment study. Chemical Engineering Journal 96, 207–222.

Chaya, W., Gheewala, S.H., 2007. Life cycle assessment of MSW to energy schemes in Thailand. Journal of Cleaner Production 15, 1463-1468.

Tchobanoglous G., Theisen H., Vigil S., Integrated solid waste management: engineering principles and management issues. Singapore: McGraw-Hill; 1993.

Morselli, L., De Roberts, L., Luzi, J., Passarni, F., Vassura, I., 2008. Environemtnal impacts of waste incineration in a regional system (Emilia Romagna, Italy) evaluated from a life cycle perspective. Journal of Hazardous Materials, in press.

Environmental Protection Agency. (2007, November 13). Retrieved February 10, 2008, from http://www.epa.gov/region2/cepd/solidwaste_in_puerto_rico.html

Malkow, T., 2004. Novel and innovative pyrolisis and gasification technologies for energy efficient and environmentally sound MSW disposal. Waste Management 24, 53-79.

Rodriguez-Burns, F.(2008, March 15). Enfrentados por el plan con la basura, *Primera Hora.* Retrieved May 31, 2008, from http://www.primerahora.com/noticia/otras_panorama/noticias/enfrentados_por_el__plan_con_la_basura/36066

Puerto Rican health officials warn against incinerator. (2002, July 23). *EFE News Services*. Retrieved May 31, 2008, from http://www.mindfully.org/Air/2002/CMCPR-Against-Incinerator23jul02.htm

*Thermoselect* (n.d.) Retrieved May 1, 2008, from www.thermoselect.com

Gigante, L. (2000, August 10). Wiping Out Waste: Gov. Pedro Rossello Signs Bill To Allow Construction Of Plant In Caguas To Process 30% Of Puerto Rico's Garbage, Including San Juan. *Puerto Rico Herald.* Retrieved May 1, 2008, from http://www.puertorico-herald.org/issues/vol4n32/CBWaste-en.html