Report Submitted to:

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ALTERNATIVES FOR THE RE-USE OF FLY ASH

May, 1 2002

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

Abstract

The following study is an investigation into the nature and use of fly ash from municipal solid waste (MSW) incinerators for Energy Answers Corporation. The current regulatory climate surrounding fly ash, as well as the use of fly ash in various products was examined. Finally, this study lists possible uses of fly ash in Puerto Rico, and recommends to Energy Answers which are the most promising and what further issues should be examined.

Authorship

This project was completed by O'Malley Barton, Carlos Perez, and Vinayak Rao. Each member was responsible for equal an amount of research and The Background and Literature Review was written be all three project participants. The remainder of the document was a collaborative effort between O'Malley Barton and Carlos Perez. Vinayak Rao was responsible for attaining much of the cost information for products in Puerto Rico through phone interviews and emails. The document was edited by all three partners.

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Executive Summary

While the amount of waste generation per capita in Puerto Rico is comparable to the United States and other industrial nations, landfilling of over ninety percent of waste and lack of recycling have created a space shortage for the disposal of municipal solid waste. These landfills have, in turn, caused their own share of problems by leaching toxic materials and releasing noxious gases into the atmosphere. In the 1970s the United States passed the Resource Conservation and Recovery Act (RCRA), which attempted to clean up landfills and prevent toxic residue. In Puerto Rico, many landfills could not meet the standards set forth in RCRA and their closing has further reduced available space for disposal. To help solve their waste management problems, waste officials have suggested both recycling programs and waste-to-energy plants (WTE).

Puerto Rico first suggested recycling initiatives, which have set target municipal recycling rates at thirty-five percent, as an alternative to landfills. These initiatives, set almost ten years ago in 1993, are still a long way from fulfillment. The second alternative proposed was to build two WTE plants, which burns trash to produce energy in the form of heat or electricity. WTE in Puerto Rico however, has experienced problems with implementation due to environmental concerns.

Energy Answers Corporation would like to be one of the companies to build a WTE plant in Puerto Rico, using a refuse-derived fuel incineration process. Energy Answers' main goal is to achieve zero disposal by recycling every by-product of the WTE process. One of the largest problems Energy Answers faces is using the fly ash created in the incineration process. This material accounts for about ten percent of the waste by weight. Using the fly ash is difficult, partially due to the fact that untreated fly ash is considered a hazardous material. Before Energy Answers goal of zero-disposal can be met, it will have to support its claim that fly ash poses little or no threat to the environment and can have various commercial applications.

The goal of this project was to review past and present regulations for the management of fly ash and evaluate the risk of using fly ash in Puerto Rico. In addition, we identified potential uses for fly ash and recommended those which would be most successful in Puerto Rico.

We reviewed how fly ash is managed to provide a status report on the regulation of fly ash in different countries around the world. Information for this review was found on environmental agency websites and through government reports. We did a comparative analysis of this information to determine possible safety issues. We were able to identify some trends in fly ash regulation and use around the world. The results are summarized below:

- Fly ash is considered hazardous in the United States if it does not pass the Toxic Characteristic Leaching Procedure (TCLP) and must be landfilled in hazardous waste landfills.
- Ash that passes the TCLP test can be landfilled in non-hazardous landfills.
- Fly ash from all WTE facilities in the United States routinely passes the TCLP test.
- Treatment of ash is usually required before landfilling in most countries in Europe and Asia. Treatment involves solidification, chemical stabilization, the use of acid solvents, or a form of vitrification.
- Ash is not considered a health risk to workers when handled properly according to the Occupational Safety and Health Administration.
- Use of fly ash in the United States as combined bottom and fly ash includes landfill liner, landfill daily cover, asphalt road bed, and concrete bricks/blocks
- Combined bottom and fly ash in Europe is used in civil engineering projects, bricks/blocks, road bed, asphalt, and cement.
- Combined ash in Asia is used as fill material, roadbed, bricks/blocks, and asphalt aggregate

After reviewing the regulation and use of ash around the world, we studied possible uses for fly ash in Puerto Rico. The feasibility of using fly ash in products was determined first, by identifying materials that fly ash could replace. Second, we interviewed producers of the potential products in Puerto Rico to find if they believed using fly ash as a replacement material would introduce any problems. With help from the producers of the product, we preformed a preliminary chemical and physical comparison of fly ash and the materials being replaced. Finally, a cost analysis was done to determine if the substitution of fly ash was economically feasible.

The uses of ash we researched included aggregate for concrete and road base, and landfill liners and caps. We also presented vitrification as a possible means of further treating the fly ash for use in more products. Listed below are the advantages, potential problems, and cost estimates of using fly ash in particular applications.

Concrete:

- Calcium content of municipal solid waste (MSW) fly ash can complement the binding qualities of Portland cement, resulting in stronger concrete, when used as an aggregate.
- The refuse-derived fuel process creates fly ash that always has similar quality, texture, and composition, which is important because a non-homogenous mixture can weaken the concrete.
- Many projects using combined and bottom ash in concrete have occurred throughout the United States over the past twenty years, but none using only fly ash.
- The high chlorine and sulfur concentrations in MSW fly ash could be reason for concern if used in reinforced concrete because when combined with water, acids corrosive to metal can be formed.
- The density of the fly ash is lower than that of many aggregates, which may weaken concrete by the increased volume. This might be overcome by using fly ash in small quantities, we estimate a fifteen percent replacement of aggregates.
- Energy Answers could save a total of over $800,000 per year by using 38,000 tons of fly ash in concrete.
- The amount of money that could be saved using fly ash in concrete for one producer is approximately $100,000.

Road Base:

- The chemical composition of fly ash is less important for loose aggregate because there are no bindings or reinforcements that may break down.
- Combined ash is already used as road base in California and Pennsylvania.
- A potential problem caused by fly ash may be volume change after contact with groundwater and rainwater.
- The low density of the fly ash may make it unsuitable. In road base, fly ash could be used in small quantities to overcome this problem, we suggest a fifteen percent mix replacement here also.
- Energy Answers could save a total of $250,000 per year by using 10,000 tons of fly ash as road base.
- The money that could be saved by road base manufacturers using ash as a road base in highway projects is approximately $40,000 a year.

Landfill Liners and Caps:

- When mixed with water, fly ash can become hard and virtually non-permeable. This is the most important trait a landfill cover needs. The required permeability is $1*10^{-5}$ cm/sec or less. A study done by the National Renewable Energy Laboratory (NREL) in Hawaii indicates that fly ash has a permeability that should meet this requirement.
- Combined MSW ash has been used as a landfill cap in as many as four states in the United States.

- A study in Hawaii concluded that using fly ash as a landfill cover was safe and saved money and space when compared to landfilling the ash.
- Most landfills in Puerto Rico are not currently lined and capped which limits the market for a landfill liner in Puerto Rico. Plastic is required to be used in Puerto Rico for liners and caps, so fly ash can only be used as daily cover.
- Energy Answers could possibly save about forty percent per ton compared to the amount it would cost to landfill fly ash by using ash as a landfill cover.
- At this time we cannot determine the savings to landfill owners by using fly ash.

Vitrification:

- Vitrification was created to stabilize nuclear wastes and has recently been implemented for non-hazardous wastes to reduce the volume.
- Vitrification forms a glass by-product with high bending strength and hardness. This product resembles marble or granite when cooled quickly and can be used in applications such as countertops and tile, etc.
- Vitrified ash formed into smaller particles could be used as concrete aggregate or as road bed aggregates.
- Japan uses vitrified ash as aggregates in a variety of construction materials, such as tiles and bricks.
- France is changing from chemical stabilization techniques to vitrification to solidify ash.
- Vitrification requires a large amount of electricity and high temperatures. The expense is too high even if the final vitrified product is sold as a commercial product. France and Japan require subsidization to use vitrification.

Recommendations

Our final recommendations for the management of fly ash include research that should be done to use fly ash:

- Do a more detailed analysis of the physical and chemical properties of fly ash for the uses suggested to determine the effects of density, hydraulic permeability, volume change, and the chlorine and sulfur content.
- Continue research on using fly ash as a landfill daily cap by contacting the EQB for specific regulations and determining the best way to lay the ash as a cover. Some helpful information on this topic may be found in the NREL study *Utilization of Ash from Municipal Solid Waste Combustion* by Jones, C.M; Hahn, J.L; Magee, B.H; Yuen, N.Q.S; Sandefur, K; Tom, J.N & Yap, C. (1999 September).
- Research using fly ash in concrete by working with Grupo Carmelo by sending fly ash to their lab for testing as an aggregate, obtaining more price information and cost data, and contacting other concrete producers to determine if they would use fly ash and what prices they have as compared to Grupo Carmelo.

- Research using fly ash as a road base by determining the public perception of using fly ash as a road base and contacting producers of road base for more exact information.
- Review how combined and fly ash have been used in asphalt in other countries. We were not able to study this use due to time limitations, but Energy Answers could review this more carefully by pinpointing the companies that make asphalt and obtaining cost and use data from them.
- Vitrifying fly ash as a further treatment is not recommended due to its extreme expense.

In summary, fly ash produced from the WTE process can be considered non-hazardous and is likely to have a number of uses. The recommendations presented here are the results of a first order analysis. In the future, this information should be used by Energy Answers as a guide to study possible uses of fly ash. There are numerous leads and connections that have been obtained in the process of finishing this report which should be exploited as Energy Answers continues to pursue its zero disposal policy. This will allow the WTE plant to be both environmentally friendly and useful to the island by replacing sand, stones, and other natural materials with fly ash. Besides not having to landfill the fly ash, the WTE plant will be reducing the amount of trash that is sent to the landfills in Puerto Rico by almost a third per day.

1 Introduction

In Puerto Rico solid waste generation has increased over the past ten years at about 1.5 percent annually (Analyses Genreracion y Reciclaje por Municipos Año 1999, 1999; Informe Annual Reciclaje, 1995). As the amount of trash being produced increases, the amount of land available for disposal decreases. Being an island, Puerto Rico has little space to deal with this increase in solid waste, and the current methods of waste disposal are becoming much more expensive and problematic.

Several methods of waste management have been developed worldwide, but the most widely used method of waste disposal is landfilling. Landfilling accounts for the disposal of ninety-two to ninety-eight percent of trash in Puerto Rico (Caribbean Recycling Foundation, 2001; Informe Annual Reciclaje, 1995; McPhaul, 2002). This method separates the garbage from the general population and is cheaper than most other methods of disposal. However, landfills can become ecological contaminates, allowing toxic water to leach into the surrounding areas and come back into contact with the general population. This leachate can potentially reach the groundwater of surrounding areas, severely affecting the health and environment of neighboring communities.

To deal with the problems landfills cause the United States passed the Resource Conservation and Recovery Act (RCRA) which attempted to clean up landfills so that they did not release as many toxic residues. RCRA gives guidelines for the disposal of garbage, as well as regulations for managing landfills (Caribbean Recycling Foundation, 2001; Figueroa, 2001; Ruiz, 1999). With the passage of RCRA, landfills in Puerto Rico were required to meet these regulations, which involve the lining and daily capping of landfills.

However, many of the landfills located in Puerto Rico could not meet the regulations of RCRA and have been or are in the process of being closed. The closing of so many landfills has reduced the available disposal area and even the San Juan Municipal Landfill has been shut down (Ruiz, 1998). The closing of this landfill, which served all of the San Juan metropolitan area and accepted approximately forty percent of solid waste produced in Puerto Rico, has left the area with a large waste management problem (Ruiz, 1998). As a result of the challenges caused by RCRA, management officials at the Solid Waste Management Authority (SWMA) began to explore composting, recycling, and waste-to-energy (WTE) as solutions to make up for the loss of those landfills.

Recycling and WTE became the first part of the SWMA's plan to manage garbage. The SWMA began pushing for recycling initiatives in 1993; however Puerto Rico is still well behind the set recycling goals. SWMA also considered WTE plants, in addition to recycling, as an alternative to landfills. The proposal for WTE plants in Puerto Rico, however, has become a political issue. The current commonwealth government does not support the construction of a WTE plant, but it has not attempted to stop the project. It has left the decision to build a WTE plant to the individual municipalities. At the moment, the municipality of Caguas is deciding whether or not to build a WTE plant to manage its waste.

Energy Answers Corporation is one of the companies vying to build a WTE plant in Puerto Rico. Energy Answers has already built one WTE power plant in southeastern

Massachusetts where recycling is a major focus of its waste management plan (http://www.wte.org; http://www.ref-fuel.com). This focus is part of the goal of zero-disposal of Energy Answers. It wants to recycle as much waste as possible including the by-products of its incineration process. However, the safety of one of the by-products of the incineration process, fly ash, is the source of considerable debate.

Energy Answers will first have to address the issue of the fly ash safety debate. Untreated fly ash has been considered a hazardous material by many countries, but fly ash that has been treated can be regularly landfilled. In the United States, fly ash must pass the Toxic Characteristic Leaching Procedure (TCLP) to be considered non-hazardous. Although both treatment techniques and toxicity tests are used to render fly ash non-hazardous, some still believe fly ash poses environmental and health problems. Energy Answers will have to demonstrate to the communities that fly ash is an acceptable risk and can be handled in an environmentally responsible manner.

Another challenge Energy Answers faces is putting fly ash to beneficial use in commercial applications. Fly ash has been used in combination with bottom ash throughout the world in many civil engineering projects. However, fly ash is not often used by itself in applications. This means experimentation will have to be done in order to use fly ash in a beneficial use. For Energy Answers to achieve its goal of zero-disposal, a use for fly ash will have to be found.

The goal of our project is to produce a review of the past and present regulations associated with the management of fly ash and evaluate the risk of fly ash on Puerto Rico. In addition, we will identify potential uses for fly ash and recommend those which would be most successful in the Puerto Rican product market.

2 Background and Literature Review

Taking into account the waste disposal problems in Puerto Rico, in this chapter, we first review the various methods of waste management and how they are used in Puerto Rico. Next, Energy Answers WTE plan for Puerto Rico, the RENOVA Project, is considered. Finally, we discuss the safety debate over fly ash, the possible uses, and the composition of fly ash.

2.1 Municipal Solid Waste Management

Waste generation in Puerto Rico is steadily increasing. Puerto Rico currently produces approximately 2.4 million tons of garbage annually, with about a 1.5 percent rate of increase each year. This increase is slowly leading to a space problem because ninety-seven percent of trash is landfilled. While Puerto Rico produces less waste per capita than the mainland United States (3.25 lbs/day vs. 4.4 lbs/day), there is less room to deal with the trash produced and far less material is recycled (~4% vs. 25%). Techniques for dealing with waste in Puerto Rico have had to be found (Levy, 1997; Analisis Genreracion y Reciclaje por Municipos Año 1999, 1999; Informe Annual Reciclaje, 1995).

Waste management practices that are currently implemented are landfilling, recycling, composting, and incineration. In Puerto Rico, landfilling is the main approach for managing waste, but as more trash is landfilled, environmental and health concerns have increased. In this section, we discuss each common method; landfilling, recycling, composting, and incineration. The advantages and disadvantages of each technique are explained, as well as why they are or are not being used in Puerto Rico.

Landfills

Landfilling has always been one of the most common approaches for managing waste. Landfills have evolved over time from a pile of trash on the outside of town to the current "sanitary landfill." Severe pollution problems can occur when leachate, which is a toxic substance produced by water flowing through or coming in contact with municipal waste in landfills, travels into the groundwater. The Resource Conservation and Recovery Act (RCRA), passed in the 1970s, gives guidelines for the managing of landfills throughout the United States. Beginning in the early 1990s, laws went into effect requiring landfills to use liners and caps to avoid creating leachate. These "sanitary landfills" have reduced leachate and eliminated more hazardous chemicals from our landfills (Cornell & Naiman, 1996; Kreith, 1992; Miranda& Hale, 1997). However, because no water is flowing through the trash there is little or no decomposition (Kreith, 1992; Miranda& Hale, 1997). This means that trash could be around for hundreds of years after it has been landfilled, reducing available space. Landfills are generally the least expensive alternative in waste management. However, in a place where there is not a lot of land, it may be more expensive than other waste disposal methods to find and use areas for landfilling (Kreith, 1992; Miranda& Hale, 1997).

Currently most of the waste in Puerto Rico is being landfilled. Puerto Rico produces between 8,000 and 10,000 tons of municipal solid waste daily which needs to be disposed of properly (Ruiz, 1998; Gigante, 2000; Caribbean Recycling Foundation, 2001). Few of Puerto Rico's landfills can comply with the regulations set forth in the

RCRA, and out of the thirty landfills currently operating in Puerto Rico, more than twenty cannot meet standards required by the act (Caribbean Recycling Foundation, 2001; Figueroa, 2001; Ruiz, 1999). Not only can the landfills not comply with the RCRA guidelines, but Puerto Rico lacks the resources to enforce the regulations.

As a result, new landfills have been built in Puerto Rico without liners or caps and others have continued to operate, allowing leachate to escape and contaminate the surrounding area. Methane gas generated from decomposing garbage can sometimes lead to fires within the landfills releasing dioxins and other toxic emissions into the environment in large quantities (Martinez, 1999). As an example, one landfill located in the Arecibo municipality is bordered on one side by dairy industries and on the other by an ecological reserve. This landfill, which is unlined and uncapped, is emitting leachate into the reserve and frequently catches fire, polluting the surrounding dairy farms (Martinez, 1999; Rosario, 2001).

Recycling

Another practice for reducing waste is recycling. Some materials are better used for recycling than for landfilling (Lea, 1996; Kreith, 1992). One such product is aluminum; the value of recycled aluminum is close to its original value. Plastic, on the other hand, can cost more to recycle than it is worth (Lea, 1996; Miranda& Hale, 1997). In the United States, on average, forty-four percent of aluminum, fifty-one percent of paper packages and cardboards, and fifty-seven percent of steel used is recovered (O'Connell, 2002; Platt & Seldman, 2000).

According to SWMA, the recycling rate in Puerto Rico is about eighteen percent. However, this is a disputed number, and other sources estimate this rate at eight percent or less (Caribbean Recycling Foundation, 2001; McPhaul, 2002). Compared to the mainland United States that has an overall recovery rate of twenty-eight percent, this number seems small indeed (O'Connell, 2002; Platt & Seldman, 2000). The SWMA has tried to increase the recycling rate by implementing a few initiatives. One initiative was to increase municipal recycling through local programs. The target was to achieve a thirty-five percent island-wide recycling rate by 1996, but this goal was pushed back to 2000, due to a lack of compliance at the SWMA. In turn, the thirty-five percent goal was again moved in 2000 until after 2004 (Caribbean Recycling Foundation, 2001; McPhaul, 2002). Much of the initial problem with this program was the lack of an attempt to actually establish a recycling plan. In recent years, money has been given to the municipalities to help reach the goal, but without guidance on how to create a recycling program, nothing has happened (McPhaul, 2002; Figueroa, 2001; Gigante, 2000).

To further the problem, the lack of recycling processors on the island make implementing a cost effective recycling program difficult. Puerto Rico, unlike the United States, has no plastic recycling plants and only a few metal processing plants. In order for Puerto Rico to recycle its waste, it must export it to recycling plants in the United States, adding considerable cost to the recycled material. In the case of plastics; which have a very low profit margin in recycling, exportation is not commercially feasible. Even with metals, which are generally more lucrative to recycle, exporting seriously hampers the ability of any company to recycle them and make a profit. Without the resources to process recyclables on the island, and in some places, the labor to collect them, the costs associated with recycling make it prohibitively expensive in Puerto Rico (Jorge El-Koury of Energy Answers, personal correspondence, March 2002).

Composting

Composting is another option for managing waste. Composting is a way of recycling organic waste, and the result is a rich fertilizer. This method of waste management has been widely used, but operates best on a small scale. Although large composting plants do exist to recycle communities' organic waste, they are not always successful. Composting plants must have a buyer for their compost product in order to make the plant cost effective. In many countries, compost from large plants is not preferred for two reasons. One is that the compost is of lesser quality than fertilizers which are normally used. Second, the compost is usually almost as expensive as normal fertilizer, which does not make composting a viable alternative for most farmers (Stop the Incinerator, The Other Story). Composting is not currently a solution used in Puerto Rico, and although SWMA has shown interest in composting as a partial solution to the waste problem, it has not been shown to be economically viable in Puerto Rico.

Incineration and Waste-to-Energy

Burning trash has become a more widely used method in the effort to manage waste. Incineration was a practice that started in the 1960s and 1970s when waste emission regulations were not yet in effect (Kreith, 1992; Lea, 1996). Burning waste indiscriminately caused numerous air pollution problems that led to several acts being passed in the United States and Europe to regulate the emissions of incineration plants (Huffman, 1987; Miranda& Hale, 1997). In the early 1990s the Environmental Protection Agency issued mandates that required a huge reduction in emissions (Kreith, 1992). As a result, today's incineration plants are far more efficient and the process can reduce waste while emitting toxic emissions well below acceptable limits.

After the EPA formed its regulations, the incinerator changed more than just its filters; the idea of burning trash to produce energy as well as reduce the volume of waste gave birth to the modern WTE plant. Waste-to-energy plants are most cost effective as a technique for managing waste in places where there is little available land. The technology involved with waste-to-energy becomes less expensive as more garbage is produced because the initial building costs are offset, whereas if more and more landfills need to be built the costs multiply due to the need to purchase more land (Lea, 1996; Miranda& Hale, 1997).

The process of turning waste to energy is used in many places in the United States and Europe. Some countries such as Denmark, Switzerland, Japan, and Sweden utilize fifty percent or more of their waste to generate a useful amount of energy (Miranda& Hale, 1997; Vollebergh, 1997). Of the many countries that employ these techniques to generate energy, most report it as a source of up to one percent in energy production (Miranda& Hale, 1997). Currently there are 102 operating waste-to-energy plants in the United States, that generate energy by burning 97,003 tons of garbage per day (http://www.wte.org).

After burning waste, the energy produced can be used in three ways; from heat, either directly as hot water or steam; or as electricity produced from either (Miranda& Hale, 1997; Kreith, 1992). Hot water is the simplest and most direct use for the heat (energy) produced after incinerating the waste; a plant in Uppsala generates ninety percent of its energy in the form of hot water (Miranda& Hale, 1997). As an example, this hot water might be pumped through pipes to heat peoples' homes. Producing electricity is sometimes the least efficient use of the heat from waste incineration, because energy is lost in the process of converting hot water to steam and then to electricity using turbines (Miranda& Hale, 1997).

Each plant uses different methods of preparing waste for energy. These methods include mass-burn, gasification, and refuse-derived fuel (RDF) plants (Miranda& Hale, 1997; Kreith, 1992; http://www.wte.org). The mass-burn method incinerates everything as it comes into the plant without pre-sorting the garbage. The burning process at mass-burn facilities can be inefficient because of the inconsistency of the waste. Byproduct ash that is formed can also have inconsistent composition and quality. Generally, mass-burn facilities create more toxic emissions than other methods of waste-to-energy conversion. This is because items that create these emissions are not removed from the waste stream.

Gasification, another method of waste-to-energy conversion, begins by compressing trash to ten percent of its initial volume (www.interstatewastetechnologies.com). In a high temperature and pressure environment, chemical reactions break down garbage, producing methane and other gases. The results of gasification are methane gas and carbonized ash. Heavy metals and sulfur are sorted out separately during the process. Although gasification appears to work in theory, it has experienced many problems in implementation (Casellas, 2001; Dahlkamp, 2000). These problems include toxic emissions over the acceptable limits and illegal dumping of hazardous residues.

The third method of incineration, refuse-derived fuel (RDF), separates recyclable materials and then shreds the rest of the waste into a fine fuel (Miranda& Hale, 1997; Kreith, 1992). This fuel is then incinerated in a process similar to mass-burn. The byproducts include two types of ashes, bottom ash and fly ash. The quality and composition of these ashes are consistent on a daily basis. The toxic emissions from an RDF plant are typically much lower than EPA standards (www.wte.org; EAC).

In 1993, the Puerto Rico SWMA formed a plan to build two waste-to-energy incinerators that would burn 1,200 tons of waste a day each, thus reducing waste going into landfills. This would have been equal to a twenty-five or thirty percent of the waste created each day by the people of Puerto Rico (McGraw-Hill Engineering News-Record, 1994; Financial Times Energy Newsletters – Power in Latin America, 1998). As with the recycling initiative, however, the idea to build waste-to-energy plants has gone through many revisions in the past few years. First, the plan was cut back to two plants that could process six hundred tons of garbage each, then upgraded to three plants of the same capacity (McGraw-Hill Engineering News-Record, 1994). Eventually, the whole idea changed again when the Puerto Rico Electric Power Authority (PREPA) projected a shortfall of electricity by the year 2002 due to continued steady growth in electricity demand.

Energy use has been increasing almost four percent a year for the past few years putting a strain on PREPA's ability to provide electricity (Financial Times Energy Newsletters – Power in Latin America, 2000; 1999; James, 1999; Department of Energy: Energy Information Administration, 2001). Even though oil prices soared at the beginning of this millennium, over double the price of 1999, energy consumption levels have continued rising. In the late 1990s, PREPA projected that with the continued three to four percent electricity growth rate it would run out of capacity by 2002 (Financial Times Energy Newsletters – Power in Latin America, 2000). To meet this growing demand, PREPA has looked for some new answers to its energy problem.

PREPA has been very reliant on oil-fired power plants to power the island. With the great increases in price in 2000 and 2001, it became obvious that fuel diversity was needed to keep energy prices down for the local people. Suggested solutions to the problem include a natural gas fired generator, a coal power plant, and the refurbishing of two existing power plants (Department of Energy: Energy Information Administration, 2001; James, 1999; Financial Times Energy Newsletters – Power in Latin America, 2000; James, 1999). PREPA also upgraded the capacity of the desired waste-to-energy power plants to 2,500 tons or more of garbage daily (Financial Times Energy Newsletters – Power in Latin America, 1999; James, 1999). The two waste-to-energy power plants, still currently in the planning stages will help to alleviate some of the electricity problems on the island. One plant proposed by Caribe Waste will use a gasification technology to reduce waste and produce energy. It will be able to handle 3,300 tons of garbage per day (Chemical Business News, 1998; Gigante, 2000). Another WTE plant proposed by Energy Answers will use the refuse-drive fuel method to incinerate about three thousand tons of trash a day.

Energy Answers built one waste-to-energy plant, SEMASS, in 1989. This plant, located in Rochester, Massachusetts, recycles 2,700 tons of waste every day (http://www.wte.org; http://www.ref-fuel.com). This waste is carefully processed and sorted using the RDF method to create the maximum amount of power; ten percent of the energy produced is used to power the plant itself and the rest of the power is used to power up to 75,000 homes per year (http://www.ref-fuel.com/technology.htm). All of the emissions at SEMASS are well below industry standards and are also low compared to alternative methods of waste disposal and energy production. The plant Energy Answers is planning for Puerto Rico will have a similar design.

2.2 The RENOVA Project

Energy Answers Corporation is a waste management company that is looking for better waste management solutions. These solutions, using waste-to-energy as a cornerstone, try to meet the company's goal of zero-disposal. The RENOVA Project is Energy Answers waste management plan for Puerto Rico, which includes an eco-industrial park and a waste-to-energy plant. However, there is one by-product of the WTE process that is keeping Energy Answers from achieving its goal, fly ash. The uncertainty about how fly ash can be used has created some problems for the RENOVA Project, such as a siting debate and a long delay in the start of the project. In this section, we describe the RENOVA Project in detail.

The goal of Energy Answers is to create waste-to-energy plants that have no unusable byproducts. Energy Answers has taken a new approach and designed the RENOVA project. The RENOVA project is an eco-industrial park with a WTE plant at the center. An eco-industrial park (EIP) is a network of businesses sharing resources for mutual advantage. Companies do not usually depend on each other for materials or share the costs of disposal. However, in an EIP, the waste from one company in the park can be used as the raw materials for another (The Eco-Industrial Park: A New Path to a Sustainable Economic Future, 1995). This ensures a new source of profit for the company that creates the waste, because the costs of disposal and transportation of that waste are minimal. The receiving company has a convenient source for raw material and avoids import costs. This arrangement is mutually beneficial to the companies, allowing them not only to conduct business less expensively, but also to keep the environment cleaner by recycling wastes. The moral standards formed by the reduction of garbage and the focus on environmental issues in an EIP are a new approach to business that takes into account the environmental consequences of industrial practices (The Eco-Industrial Park: A New Path to a Sustainable Economic Future, 1995).

The waste-to-energy plant at the center of an eco-industrial park is a new method of reaching zero disposal. This plant will incinerate the unusable waste of the communities and businesses around it and provide raw materials and energy for those businesses in the EIP. These surrounding businesses could include a recycling plant, a concrete products plant, a steel mill, agricultural support industries, metals processing plants, a paper mill, and an aquaculture greenhouse. Any waste that can be recycled will leave the waste stream to go to the recycling plant before incineration. Other trash will continue through the process, where metals will be removed and sent to the metals processing facilities. Bottom ash will then go to concrete manufacturers in the park. Energy produced by the WTE plant will be used to power the businesses, as well as the plant itself, and extra energy will be sold to PREPA. This EIP will be a self contained environment in which all of the waste is used for energy and the businesses receive all or a part of their raw materials from each other or the WTE plant.

However some products such as the fly ash currently have no use. Therefore to achieve zero disposal, a use will have to be found. Currently, fly ash produced in the RDF process is generally placed in mono-fills, a landfill containing only fly ash or regular municipal solid waste landfills (Miranda& Hale, 1997; Kreith, 1992).

Concerns about fly ash and WTE as a waste management solution have played a large part in shaping the current RENOVA project. In Arecibo, the town where the first potential site for the waste-to-energy plant and EIP was located, there has been a large outcry from the government and the citizens against the waste-to-energy plant and the fly ash it will produce (Rosario, 2001; Sánchez, 2001). After a recent change in municipal government administration, RENOVA has been put on hold at the site in Arecibo. The new officials believe by building a waste-to-energy plant, recycling within the community will become non-existent and pollutants such as fly ash will fill the air and ground (Bob, 2001; Colón, 2001; Mulero, 2001; Rosario, 2001; Sánchez, 2001; Santos, 2001; Solo, 2001). Such beliefs may stem from lectures and reports by Dr. Paul Connett, director of Work on Waste, an advocate of recycling and composting as the answer for controlling and reducing waste, and others like him that have published pamphlets and lectured about the dangers of incineration (Bob, 2001; Rosario 2001; Sanchez 2001; Stop the Incinerator, The Other Story). These officials, who have read the reports may not take into account that these publications use old data and have been cited by other scientists and activists for the omission of facts that do not support their cause (Stop the Incinerator, The Other Story). The new proposed site for RENOVA, located in Caguas, has a government that is supportive of waste-to-energy plants. Concerns there are less focused on whether the plants will hurt recycling efforts and more on what to do with the by-products produced (Casellas, 2001).

2.3 Municipal Solid Waste Fly Ash

Fly ash produced during the waste-to-energy process is one of the main challenges Energy Answers faces in implementing the RENOVA Project. Long debates over the safety of using fly ash and the fact that little experimentation has been done on municipal solid waste (MSW) fly ash are impediments to RENOVA. The debate about fly ash is described in this section. We list some of the known uses of fly ash from the waste-to-energy process, as well as uses of coal fly ash for which MSW fly ash could be used. A comparison of coal fly ash and MSW fly ash is also included.

Fly Ash Safety Concerns

The safe use of fly ash has long been a debate among the power industry, concerned citizens, environmentalists, and the government. Power plants have been advocating the use of fly ash as a safe, reliable resource. While some environmentalist groups refute that opinion, other environmentalists support it wholeheartedly. The U.S. government has taken a proactive role; it has ruled waste fly ash non-hazardous after it passes the Toxic Characteristic Leaching Procedure (TCLP). The public has a mix of varying feelings from scared to supportive of recycling fly ash.

The Environmental Protection Agency decided over twenty years ago that fly ash is a non-hazardous substance after passing the TCLP and has only confirmed that ruling since that time (Coal in the News, 1993; Lowman, 1998; Murray, 2000; Resolving the clash over ash, 2000). All long-term studies done by the government have shown that fly ash presents no risk to human health or the environment, when testing for hazardous substances in fugitive dust and ashes, health problems that could result from fugitive dust, and the leaching of heavy metals from ash (Wiles, C. & Shepard, P., 1999). According to RCRA, fly ash can be landfilled along with regular municipal solid waste. Fly ash is often exempted from state hazardous waste regulations as well.

The power industry has a slightly different view of the situation. Many power plant officials hold that fly ash is a safe and viable resource (Coal in the News, 1993; Lowman, 1998; Murray, 2000). They contend that the only reason people are opposed to fly ash is that they do not know what it is or how it can be used. One power plant representative even goes so far as to claim it has the same properties as soil (Murray, 2000). This same power plant is voluntarily monitoring its landfill sites to help increase the credibility of its belief that there is little impact on human health or the environment from fly ash (Murray, 2000).

Environmentalists are of mixed opinion on the matter of fly ash. Some groups of environmentalists and citizens contend that fly ash poses a problem for ground water contamination by heavy metals, and others that dioxin levels from the smoke stacks of plants are so high that acceptable levels can not even be set (Resolving the clash over ash, 2000; Ruiz, 1999). Another group feels that by mixing fly ash into cement, it will help to limit the greenhouse effect by reducing the CO_2 production associated with making cement (Deal Between CRH and ESB, 1999; Rosenbaum, 1998). However, with little evidence as to whether fly ash will create or solve problems, some groups are waiting to decide their opinions. They are conducting studies on the leaching of ash, as well as the health risks that may stem from handling ash, to determine the safety of fly ash and decide if its regulation is truly a concern (Murray, 2000; Rosenbaum, 1998).

Communities also appear to have mixed feelings on the use of fly ash in their neighborhoods. The public, while demanding environmentally responsible solutions for the use of fly ash, is reluctant to accept the proposed uses unreservedly (Canning, 1999; Fleming, 1999; Hopey, 2001; Siegel, 1999; Walsh, 1998). In Maryland, a seventeenyear dispute occurred when residents feared the dumping of ash into a landfill. They did not, however, oppose the use of the same ash as a filler under cement (Coal in the news, 1993; Murray, 2000; Siegel, 1999). Another community that feared a power plant might possibly open a landfill near their town immediately began steps to stop the plant on that rumor alone (Hopey, 2001). Plant officials stated they never had plans to landfill there and were planning on selling their ash for structural fill. One suggested project using ash under an airport runway caused a conflict in a community in Pennsylvania. Some believed using ash would be a win-win situation, recycling the ash and lowering the construction costs. The opposition thought that the ash would pollute the groundwater and would not be structurally sound (Walsh, 1998). Communities are likely to continue to hold uncertain views on the use of fly ash until its effects, both long and short term, are better understood.

Many of the debates about fly ash stem from the possible environmental and health effects that fly ash may present. The most often cited risks are possible leaching of heavy metals and soluble salts, inhalation of particulates, and dioxins that may be present in fly ash. Studies and experiments have been done to gage the validity of these risks.

The leaching of heavy metals and soluble salts from fly ash is one of the most noted hazards. Research studies throughout the past have tried to determine how materials will leach from the ash, how much, and if these amounts are dangerous to health (Gielecki, 1997; www.wte.org; Wiles, C. & Shepard, P, 1999). Three main conclusions have been drawn from these experiments. For one, cadmium and lead are the two heavy metals of the greatest concentration, but are below set standards and can be managed. Two, the leaching of metals depends upon the field conditions and cannot be predicted with a single test. Three, while leaching of both soluble salts and metals can occur, management options can control the amounts that are above the acceptable limits. Nonetheless, some still think that leaching represents the greatest potential danger to the environment and human health (Gielecki, 1997; www.wte.org; Wiles, C. & Shepard, P, 1999).

The second risk associated with fly ash production is possible danger from spreading and inhaling airborne particulates. Due to the small size and low density of fly ash, risk assessments have been done on the possibilities of fugitive dust affecting workers' health and safety. The findings of these studies show that when handled in a fashion similar to other aggregates it does not pose unacceptable environmental or health risks. Controlling techniques, like those used to handle any lightweight particle should also be used. However, if handled incorrectly or uncontrolled, fly ash could present a risk from inhalation (Jones et al., 1999; Wiles, C & Shepard, P. 1999).

The last risk that is a concern when handling fly ash is the dioxin content. Dioxins are organic chemicals found in ash that are produced during incineration. Dioxins can cause skin disorders and in extreme cases may be carcinogenic. The studies done on fly ash measure the amount of dioxins that are formed and if this amount is potentially dangerous. The studies also show that older WTE plants produce more dioxins than newer plants, and that the level of dioxins in bottom ash is well below the amount found in normal soil. The main source of dioxins in the WTE process is the filter residues, however, the danger of these amounts is still under debate. Most believe the amounts will prove to be not hazardous, but this is not a certainty (europa.eu.int; www.wte.org; Wiles, C. & Shepard, P, 1999).

Using fly ash has been called a great recycling project, but until now it has been hard to determine its environmental consequences. As a better understanding of what fly ash can do emerges with more experimentation, communities, the government, and environmentalists will be better able to form opinions on whether it is a resource that can be used or one that has too many environmental costs.

Uses of Fly Ash

Experiments have shown that fly ash produced from coal or municipal solid waste (MSW) can be used in a wide variety of ways from road embankments to concrete admixtures to eco-friendly bricks. These uses reduce waste production, save resources such as land, water, and coal, and fill a need for hard to find resources. However, while the applications and benefits for using fly ash appear to be many, globally only twenty-five percent of fly ash produced from coal is used and even less from MSW (Battarcharjee & Kandpal, 2002).

There are several reasons why it is difficult to recycle fly ash. Problems involving the inconsistent quality of production are one obstacle. Varying compositions of both coal and MSW fly ash make it difficult to apply the same technologies and achieve satisfactory results. A second reason recycling fly ash is not done on a large scale is that cost effective technologies have yet to be researched extensively, only pilot projects have been done (Battarcharjee & Kandpal, 2002, McCarthy & Dhir, 1999). Further research may break through these barriers and allow any composition of fly ash to be used in a variety of products.

Compared to ash from coal plants, there is little information on the use of ash produced from waste-to-energy plants (EAC; Valenti, 1999). One company in France has found a way to condition MSW fly ash and recycle plastic at the same time. Replacing forty to seventy percent of pure mineral filler in a process used to create a synthetic plastic, the fly ash is mixed with recycled plastic. This process creates a material known as Plastibloc, which is used for landfill barriers (Valenti, 1999).

Another process that has been explored to increase the use of MSW fly ash is vitrification. Vitrification is a technology that involves melting waste fly ash at extremely high temperatures. Fly ash subjected to the vitrification process forms glass and glass-ceramic materials that trap heavy metals (Barbieri & Bonamartini & Lancellotti, 2000; Kobylecki et al., 2001; www.vitrification.com). This glass, which is similar to volcanic rock (i.e. basalt), can be used as glass-ceramics and poses no threat to the environment from heavy metals. This glass can and has gone into products such as floor and roof tiles, road barriers, fill, grit blasters, cook ware, sewer pipes, and railroad ties (Barbieri et al., 2000; www.vitrification.com).

With so little information on MSW ash, we studied some of the uses for coal fly ash. Coal fly ash, which is used in a variety of products, has some similar characteristics to waste fly ash. We first compared coal fly ash to MSW fly ash, then chose some uses which might be compatible with MSW fly ash.

Fly ash can have a wide variety of compositions. Most fly ash contains varying amounts of silicates, aluminates, and calcium deposits, along with some heavy metals such as nickel, iron, cadmium, chromium, and zinc. Coal fly ash is produced from coal thermal power plants and contains high levels of silicates and aluminates. MSW fly ash varies slightly in content from coal fly ash. While much of the literature does not specify what its composition is, MSW fly ash is known to have lower percentages of silicates and aluminates and higher percentages of heavy metals than coal fly ash.

Table 1: Summary of Ash Differences (adapted from Summary of Ash Differences)

Measured Property	SEMASS MSW Fly Ash	Coal Fly Ash
Bulk Density, lb/ft^3	36	77
Microscopic Appearance	Fuzzy Shapes and some spheres	Clean, shiny spheres
Ph	11.8	10.6
Calcium (CaO)	40%	10%
Chlorine	21%	(<5%)
Sulfur (SO_3)	5%	0.8%
Silicon (SiO_2)	10%	55%
Aluminum (Al_2O_3)	8%	22%
Water Content @ambient	2%	0.1%
Soluble Salts	~30%	No

Source: Summary of Ash Differences (2000, March 3): Appendix F

In Table 1, fly ash produced at the SEMASS waste to energy plant is compared to coal fly ash produced at a coal power plant. SEMASS uses the same combustion techniques that Energy Answers plans to use in Puerto Rico, so the fly ash is similar to the fly ash that will be produced in Puerto Rico. One thing that is not shown on this table is the fact that the SEMASS fly ash does contain trace heavy metals, such as lead and cadmium. This is one of the main environmental concerns, as heavy metals can contaminate ground waters and cause harm to the health of people and animals.

One of the big differences between the fly ashes is that the SEMASS fly ash is less than half the density of coal fly ash. This may have a serious effect on the use of MSW fly ash, since double the volume of the fly ash would have to be used to make up the same weight in a substance that used coal fly ash. Also, the MSW fly ash is slightly more basic in pH than the coal fly ash. Heavy metals leach at extreme pHs, especially acidic ones. The base quality of MSW fly ash could help prevent metal leaching (Efrain Carreras of Grupo Carmelo, personal correspondence, 2002; Tahar El-Korchi of WPI civil engineering department, personal correspondence, 2002; Wiles. C & Shepard, P., 2001). Calcium content of the MSW fly ash is high, which explains why, when mixed with water, MSW fly ash forms a very hard, almost concrete-like material or pollazzan. This high calcium content should make MSW fly ash useful in products which must be hard. The relatively high chlorine content in MSW fly ash could cause problems when it is mixed with water. We believe that this will make hydrochloric acid, which could harm any metals that come in contact with it. This makes MSW fly ash use in reinforced concrete or any metal fiber composite unlikely. The silicate and aluminate concentrations in MSW fly ash are much lower than in coal fly ash. In coal fly ash, these materials can create crystalline structures which help produce a variety of strong materials (Choi et al., 2001; Querol et al., 1991). We can see from this that although MSW fly ash may produce crystals as well, there may not be a high enough concentration to be useful. Finally, the high content of soluble salts could also be a barrier for use of MSW fly ash in products, as salt is not usually a desired material.

Taking the differences of composition in mind, we studied the uses of coal fly ash. So far use of fly ash from coal-fired power plants has gone mostly into production as cement admixtures and aggregate replacements. Coal fly ash can be added to concrete being used for any purpose, but is mostly used in jobs where low slump is required: for architectural purposes and pre-cast concrete products (Manz, 1999; McCarthy & Dhir, 1999). Coal fly ash increases the pumpability of the concrete and allows for easier finishing with trowels (Manz, 1999; Businessworld, 2001). Concrete that is mixed using fly ash with high lime content has the benefits of high strength and high performance because of its capabilities to perform as a binder and not just an aggregate (Manz, 1999; McCarthy & Dhir, 1999). In Europe and the United Kingdom, the widest use of ash in concrete involves low lime ash as an aggregate rather than a binder, although its binding properties are being researched and utilized more often (McCarthy & Dhir, 1999). In the United States, fly ash is substituted for as much as seventy percent of binding material in some projects and is used to create dams, walls, girders, pavements, parking lots, and stadiums (Manz, 1999; Siegel, 1999). In the Philippines, specially blended bags of coal fly ash and Portland Cement are sold commercially for plastering, rendering, and the bedding and pointing of blocks and bricks. Each blended bag can be spread thinner than an unmixed bag of Portland cement, allowing the use of less cement in construction (Businessworld, 2001).

Sanitary landfills have used coal fly ash as a barrier. Leaching of toxic materials has been a problem in landfills for many years and has led to the use of sanitary landfills (Cornell & Naiman, 1996; Prashanth et al., 2001). Sanitary landfills require barriers to be erected to minimize the migration of toxic waste. These barriers are created from all sorts of materials: synthetic as well as from natural materials such as clay, shale, bitumen, and soil (Cornell & Naiman, 1996; Prashanth et al., 2001). Fly ash mixed with lime can be used as a liner due to its low permeability. The ash, once laid on the ground, has concrete-like properties that cause it to harden with little shrinkage and virtually no volume change (IWSA; Prashanth et al., 2001; Resolving the clash over ash, 2000). This hardening reduces the potential for rainwater to enter the landfill system and create leachate. Ash landfill studies have shown that leachate from ash landfills has metal contents at approximately the same level as drinking water (IWSA; Resolving the clash over ash, 2000; Wiles, C. & Shepard, P., 1999). This technology has been used throughout the United States in Maryland, Minnesota, Pennsylvania, Massachusetts, Tennessee, and New York (IWSA; Hopey, 2001; Lowman, 1998; Walsh, 1998).

Coal fly ash, which is commonly considered a mineral aggregate, is also used as a variety of filler materials. It is considered a safe, reliable component in structural fill and construction material. Filler applications for which fly ash have already been used include road embankments, backfill, land development, and airport runway extensions (Battarcharjee & Kandpal, 2002; Hopey, 2001; Lowman, 1998; Murray, 2000; Walsh, 1998). Other proposed filler options include using it in strip mines and under housing developments (Hopey, 2001; Murray, 2000). Use of fly ash filler saves soil and other mineral aggregates that would otherwise be mined, quarried, and moved to building sites, which is expensive and can cause harmful environmental impacts (Battarcharjee& Kandpal, 2002; Walsh, 1998). Worldwide, fly ash has been used as fillers in India, the United States, and Israel just to name a few (Battarcharjee & Kandpal, 2002; Hopey, 2001; Shaul, 2001; Walsh, 1998).

Bricks from coal fly ash have been explored extensively in Australia and India and some research is also being conducted in Maryland. Fired clay bricks are used for the majority of houses and civil works buildings in India. The use of soil to create these bricks had caused a strain on the environment by depleting the land volume and topsoil acceptable for agricultural use (Battarcharjee & Kandpal, 2002). Bricks made of fly ash and clay, fly ash and sand lime, or fly ash, sand lime, and gypsum are being produced in order to reduce soil usage and recycle fly ash (Battarcharjee & Kandpal, 2002). In Australia, the main use of fly ash bricks comes from two brothers who have mixed their product with some concrete to form hollow concrete blocks that are lighter and stronger than conventional "cinder blocks" (Garlick, 2001; Olsson, 2000; McCullough, 2001). These bricks, known as SmartBlock, have been used for building fences, swimming pool surrounds, and a house. (Garlick, 2001; Olsson, 2000; McCullough, 2001) Other bricks made from fly ash are now being explored around the world.

Other building products on the market made from coal fly ash are composite wood beams and plywood. One product known as "Other Than Wood" (OTW) is a lightweight material made of cement, fly ash, and polyester fibers (Nystrom, 1998). This product and the other composites made from fly ash are used in a less traditional way than real wood. The houses built with OTW use steel to frame the house, rather than wood. The producers claim the product has great noise reduction, is well insulated, and is both hurricane and earthquake resistant. This product is already being used in the United States, Mexico, and Thailand (Nystrom, 1998). Another similar product is called Century-Board. This product is up to seventy percent fly ash and is especially good for lumber being used for outdoor and marine exposure (Innovative Uses for Fly Ash, 1998).

Other applications of coal fly ash for industrial purposes are being researched. Experimentation has shown that zeolites can be formed from fly ash in a variety of ways.

A zeolite is a crystal formed of SiO_2 and AlO_4 with many applications (Choi et al., 2001; Querol et al., 1991; http://mineral.galleries.com). Experimentation and use of these products is occurring in Spain and Korea, as well as in Pennsylvania. Many authors believe pursuing the zeolitization of fly ash will lead to a massive recycling campaign and use for further purposes (Choi et al.; 2001, Querol et al., 1991; http://www.fetc.doe.gov/newsroom/media_rel/mr_pennst.html)). Zeolites can work as ion filters, water softeners, sorbents, and can even be added to livestock feed. The authors agree that as industrial sorbents, zeolites from fly ash have a bright future because of their ability to remove ions and molecules in solution, not to mention their ability to be used over and over again for this purpose (Choi et al., 2001; Querol et al.; 1991, http://www.fetc.doe.gov/newsroom/media_rel/mr_pennst.html).

It has already been established that coal fly ash can remove contaminants from water as zeolites; while further research sponsored by the United States Department of Energy has implied that fly ash can be used in the powdered form as a drinking water filter (Hartman, 2001). Mixing fly ash with high-alkaline chemicals caused the fly ash to stick together allowing water to pass but not heavy metals (Hartman, 2001) This research is fairly new and has not yet been completely confirmed.

Coal fly ash is also being considered beneficial as a soil and as a fertilizer. Volcanic ash, a natural re-fertilizer of soils, has many similar properties to fly ash, leading researchers to use fly ash as a soil conditioner (Konkes, 2000; Shaul, 2001). It has been shown in some Australian farms to remove some salinity from the soil and trap phosphorus, preventing it from entering waterways. Unlike synthetic fertilizers, no problems with leaching of heavy metals have been shown to affect waterways close to farms using fly ash. (Konkes, 2000) Other uses as fertilizer in India included mixing the ash with sewage sludge and composted weeds to create a highly fertile soil. The weeds and sewage provide nitrogen, while the ash provides rich minerals such as zinc, cadmium, cobalt, and magnesium, a perfect mix to nurture plants (Fly ash recycling breakthrough, 2000; Shaul, 2001; Young, 1994). The only problem with this method seems to be the correct proportioning of materials to avoid over abundance of heavy metals. This problem has been solved by using the fertilizer to grow crops for fibers, fuel, and building materials, rather than for food. (Shaul, 2001; Young 1994)

In summary, the possible uses of both MSW and coal fly ash have been greatly explored over the past few years. Applications in many fields from construction to sanitation have been revealed and could be applied in the coming years to help Energy Answers to achieve its goal of zero disposal.

3 Methodology

One of the largest challenges that Energy Answers faces in its plans for the creation of a WTE plant in Puerto Rico is recycling the fly ash byproduct. There is concern from the government and environmentalists in Puerto Rico about the risks associated with using fly ash, which is one reason Energy Answers may have a hard time meeting its goal of zero disposal. A second reason recycling fly ash will be difficult is there are not many known uses for fly ash from municipal solid waste incinerators. In order to address these two problems, we have provided Energy Answers with information regarding the safety and possible uses of fly ash in the form of a review on environmental and treatment regulations from around the world. In addition, we identified products for which fly ash might possibly be used in Puerto Rico.

3.1 Risk Assessment

To analyze the risks associated with fly ash, we reviewed the regulations for fly ash in a number of countries in Europe and Asia. Second, we reviewed how ash was treated in the United States and what WTE facilities were doing with their ash. In order to provide this information, we relied on environmental agency web sites and technical reports published by the Department of Energy.

After obtaining information on the use and legislation for fly ash around the world, a comparative analysis was done to evaluate the safety issues. From our findings, we were able to describe what is done with fly ash in other countries. We believed that the legislation and regulations that govern fly ash present the most comprehensive picture of how much risk is deemed acceptable in other countries. There have been hundreds of studies and experiments looking at hazards that could be associated with ash, and ash disposal and use, these regulations reflect the information that has been learned through these studies.

3.2 Potential Products from Fly Ash

In addition to educating Energy Answers on the safety issues associated with fly ash, we also sought to find products in which fly ash could be used. We researched uses of coal fly ash in order to compile a list of possible products that could use MSW fly ash. MSW fly ash and coal fly ash have some similar characteristics as shown in the Table 1 in section 2.3. From this list, we found a few promising ideas that, if feasible, would allow the safe and constructive use of MSW fly ash. We also gained ideas for possible uses from current uses of combined bottom and fly ash from MSW.

After compiling our ideas, to determine which uses would be the most feasible, we studied the possible products and the processes that are used to create them. To accomplish this, we looked into the historical uses of the product through company websites and journal articles. We then identified a few makers of the products in Puerto Rico by interviewing Energy Answers employees and looking on the Internet for trade websites. Interviews with producers of the products introduced some potential problems that would be associated with the integration of fly ash. If at all possible, we tried to include companies that already were partners in the RENOVA project in order to eliminate the problem of not being able to obtain information from the company because it was proprietary.

We also did a chemical comparison with help from the producers of each product. It consisted of comparing the chemical and physical makeup of fly ash with the material that it would replace to determine if the differences in the makeup will have any effect on the final product. This first order analysis was very limited and could only really tell us if experimenting with fly ash for that specific product was reasonable.

Next, after collecting data on the physical feasibility of using fly ash in products, we then performed a cost analysis to determine the economic feasibility. For comparison, we found what the costs would be if Energy Answers landfilled the fly ash in a municipal landfill. This was the base cost and the alternatives had to be close to or less than this cost in order for them to be considered feasible.

Lastly, we estimated the cost of using fly ash for each product. For the most part, we assumed that Energy Answers would be selling the fly ash for a fraction of the original costs. The only cost to Energy Answers was then to transport the fly ash from the RENOVA project site to the company that would be using the fly ash. The truckers union has a set price for transportation between different municipalities, so by finding how far the trucks would have to go, we determined the transportation costs. For each product, we compared these transportation costs to the base cost of landfilling the fly ash, in order to conclude whether the product would be economically feasible for Energy Answers.

The final step in this analysis was to decide whether using fly ash was economically feasible for the producer of the product by using cost data provided by companies that produce each product. The cost of the material that fly ash would replace was compared to the cost of fly ash to the producer, which in most cases was much less.

We then estimated how much of the fly ash could be used in that particular product and the total change in price. This use and cost data for each product allowed us to find a total cost change for the producer per year. From this analysis, we can present a first order approximation of how much the use of fly ash would save the company. This plan could include more than one use of fly ash, determined by the amounts of fly ash used in each product.

Although these methods provided a good framework for finding ways to use municipal solid waste fly ash, the conclusions reached in this study were only first level analysis of these problems. More information is needed to make sure that the use of fly ash in any of the products is safe and feasible. Nevertheless, the first order analysis presented here can provide Energy Answers with a more focused plan for using fly ash.

4 Results and Analysis

In this chapter, we present the findings based on our review of treatment regulations and research on the possible uses of fly ash. We begin by discussing the regulations and legislation of various countries and the reasoning behind them. We also present the products we studied for the possibility of using fly ash in Puerto Rico. We include a description of the products that can be made, the benefits of using fly ash in each product, the possible risks, and a cost analysis. The products that were investigated include road base, concrete, landfill liner, and products that have been vitrified.

4.1 Regulations and Health Issues for Fly Ash

Controversy over the safety and regulation of fly ash appears to be an issue not only in the United States, but also throughout the world. Fly ash can contain varying amounts of heavy metals, such as lead, cadmium, mercury, arsenic, copper, and zinc, and other soluble salts. These materials can present a danger to environmental and public health, if they leach into the environment. The argument concerning the safety of landfilling or using fly ash does not dispute the presence of these materials, but the possibility of hazardous amounts leaching from the fly ash before or even after stabilization. Treatment options and regulations in the United States and around the world are included in this section.

Treatment

For the most part, ash from incineration is treated before it is considered safe for use and disposal. One reason fly ash is treated is to neutralize the pH of the ash. Most metals leach at extreme pH values, especially the more acidic ones. By maintaining the pH of the ash, the likelihood of metals leaching from the ash is greatly reduced. The second reason ash may need treatment is the high quantity of soluble salts present. Soluble salts may reduce the strength of ash when used in products and can increase levels of salt found in the ground (Valenti, 1999; Wiles C. & Shepard, P, 1999).

There are several ways to treat ash that have the effect of neutralizing the pH and eliminating soluble salts. The treatments for lowering pH consist of adding lime, phosphoric acid, by-product dust products from cement kilns, and other chemicals that include calcium and sodium cations. Mixing ash with Portland cement is also a frequently used method to neutralize pH due to the calcium content (Solid Waste Management Sourcebook, 2000; Wiles C. & Shepard, P, 1999). The most common way to treat ash for soluble salts is to "age" it. Aging consists of stockpiling ash for a certain amount of time, usually for two or three months, to allow soluble salts to hydrate. After this occurs, the salts are no longer considered a problem. Many facilities, where the ash is quenched as part of the process, do not need to age their ash because the salt content is greatly reduced during that process (Wiles C. & Shepard, P, 1999). Vitrification is another accepted way of treating ash. Vitrification is an ash melting procedure that creates stable compounds from the chemical components of ash. Vitrification programs are currently on the rise due to the fact that the process is believed to stop the leaching of metals and salts completely (Valenti, 1999; Wiles C. & Shepard, P, 1999).

Although there are many treatment options for incinerator ash, no one treatment has been determined to be definitively better than others. The treatment that is chosen usually depends on the availability of materials and what is economically feasible.

Vitrification has been identified as possibly being one of the better treatments, but its expense is still too high to be considered for use in most places.

Classification

Researching treatment options lead us to the classification of fly ash around the world. Fly ash is usually classified in three categories by legislation; it can be considered a hazardous waste, a special domestic waste[1], or regular municipal solid waste. Table 2 briefly explains the classification of ash in select countries and the toxicity tests that are used to classify ash for disposal and use.

Table 2: Ash Classification Methods in Select Countries

Country	Classification	Toxicity Tests Used
US[a]	Non-hazardous if the TCLP test is passed	TCLP test
Italy[b]	Non-hazardous after treatment; Lime is not considered sufficient stabilization; addition of cement is also required	NA
France[c]	Non-hazardous after treatment	Leaching test is NFX31-210, separates bottom ash into three categories
Netherlands[c]	Non-hazardous after treatment	NEN 7343 and NEN 7345; tests used estimate 100 year leaching rate; soil criteria and utilization on land and water are evaluated as part of test
Denmark[d]	Fly ash is mixed with flue gases is considered a special domestic waste	NA
Sweden[c]	Non-hazardous after treatment	NA
UK[c]	Fly ash is mixed with flue gases is considered a special domestic waste	Currently choosing a method to test
Taiwan[e]	Non-hazardous	Use TCLP
Japan[c]	Special domestic waste due to metal content	NA
Bermuda[c]	Non-hazardous	Tests for untreated ash leaching into environment using ocean water and rainwater; determine effects on marine organisms; emissions modeling of leachate is done

NA-Not Avaliable
Flue gases refers to air pollution control residues
References:
a: Complete bibliographies are at the end of the document. United States information is from About Waste to Energy and articles/reports by, Berenyi, Eileen (1998).Wiles, C. & Shepard, P. (1999). Gielecki, Mark (1997).
b: Source for Italy information Schroppe, T. (1999) and Pollastro, Fabrizio (2000).
c: Information sources for France, Netherlands, Sweden, United Kingdom, Bermuda, and Japan are Wiles, C & Shepard, P. (1999)
d: Sources for Denmark are Wiles, C & Shepard, P. (1999) and Husen, Rabbeck, Nielsen, & Scheim (1999)
e: Sources for Taiwan information Solid Waste Equipment market (1998) and Yu-tzu, Chiu (2002).

[1] Municipal waste that is treated under certain specifications

There was a long debate in United States on how to classify the fly ash produced during the waste-to-energy process. Beginning in the early seventies, fly ash was regulated the same way as municipal solid waste. The logic behind this was that if the municipal solid waste was not hazardous, the fly ash produced from the incineration process was also non-hazardous (Gielecki, 1997). Changes in regulations began in the early 1990s, and culminated in 1994 with a US Supreme Court decision that required fly ash to be regulated under Subtitle C of RCRA, which regulates hazardous waste. Fly ash is subjected to the Toxicity Characteristic Leaching Procedure (TCLP) to classify it as hazardous/non-hazardous waste. The test is applied at the point directly before ash would be introduced to the environment. This test uses acetic acid to promote leaching of select metals[2] in the ash, if the ash leaches more metals than the "acceptable" limits, it is deemed hazardous. If the ash passes the test, it is then regulated under Subtitle D regulations for non-hazardous waste. Most sources state that ash very rarely, if ever fails the TCLP test and ash that has failed can be reprocessed through the facility to pass the test (Gielecki, 1996; Ruth, 1998; Wiles, C. & Shepard P., 1999; www.wte.org). The TCLP test is also known to overestimate the leaching of materials because the pH conditions of the test would most likely never occur in field conditions. This means that there may be even less metals leaching from fly ash than the current tests estimate (Wiles, C. & Shepard, P, 1999).

In Europe and Asia, with a few exceptions, ash is usually designated as non-hazardous waste after treatment. Table 2 shows that countries that do classify the ash as hazardous usually mix other filter residues such as flue gases with the fly ash. However,

[2] As-Arsenic, Ba-Barium, Cd-Cadmium, Cr-Chromium, Hg-Mercury, Pb-Lead, Se-Selenium, Ag-Silver

the majority find that with treatment[3], ash is a non-hazardous waste. Toxicity tests other than the TCLP are also used around the world. These tests are usually used to determine suitability for ash use, rather than to define ash as a waste, as in the United States. Specifics of these tests were not available for us to compare them with the TCLP.

After ash has been classified there are a few options for management and use. In the United States, fly ash is most often landfilled in ash monofills. Landfills containing ash have varying degrees of protective measures. Some ash is put in ash monofills that have synthetic and clay liners, similar to landfills containing regular municipal solid waste (Berenyi, 1998; Ruth, 1998; Wiles, C. & Shepard, P.,1999). At the other end of the spectrum, ash is used as a landfill liner and cap in municipal solid waste landfills (Gielecki, 1997; Wiles, C & Shepard, P. 1999; www.wte.org). Projects using ash as landfill cover are being performed in six states. The decision to place the waste in monofills, use liners, or use ash as liners is left to state legislature. The other most popular uses of fly ash are as roadbed and mixed with asphalt, a technology that has been used in eleven states. Other known uses of fly ash in the US are mostly in bricks/blocks made of concrete and fly ash (Gielecki, 1997; www.wte.org). Many of these uses are limited to projects in the immediate area of waste-to-energy plants or landfills due to the expense of permitting outside these areas.

Regulations on the disposal of fly ash after classification in other parts of the world are similar to the United States in general, but there is a greater emphasis on recycling. Ash that is landfilled can be landfilled in regular landfills after treatment or put into a special hazardous waste landfill. Table 3 shows what the landfilling options are in some select countries.

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[3] Specific treatment options are not always specified, usually include one of the aforementioned options

One of the countries that has more complex classification and disposal legislation is Italy. In Italy, fly ash that is collected is partially recycled to recover un-reacted lime and carbon and the remaining portion is sent to storage silos for further processing. Fly ash that is stored is still classified as a hazardous substance. Ash can be further processed, which involves mixing fly ash with cement, water, and a neutralizing agent and poured in bags, to meet the requirements for non-hazardous waste landfilling (Schroppe, 1999; Pollastro, 2000). Ash in Sweden has similar regulations. After treatment, ash may be landfilled in municipal solid waste landfills. If the ash is untreated it must be landfilled in hazardous waste landfills (Wiles, C. & Shepard, P. 1999). Taiwan, Singapore, Japan, Canada, the United Kingdom, and Denmark also landfill their waste after some stabilization treatment is completed (Solid Waste Equipment market, 1998; Wiles, C. & Shepard, P. 1999;Yu-tzu, 2002).

Table 3: Landfill Options in Select Countries

Country	Ash can be put in a Regular Landfill After Treatment	Ash must be put in a Special Landfill
US[a]	Yes can be landfilled after passing TCLP test	Ash that does not pass the TCLP is landfilled in hazardous waste landfill
France[b]	Must be solidified before disposal	No
Italy[c]	Mixed with cement and neutralizing agent	No
Netherlands[d]	Most fly ash disposed of in regular landfills; as of 1998 must be treated	No
Denmark[e]	No	Temporarily landfilled until treatment technology is decided upon
Sweden[d]	Yes; treatment required	Untreated fly ash disposed of in special landfills or special cells in landfill
Germany[f]	No	Used in mines to fill cavities
Bermuda[d]	Can be landfilled	No
UK[d]	Yes; treatment not yet decided though	No
Japan[d]	Must meet criteria of Environmental Agency; specified treatment techniques include melting and solidification	No
Taiwan[g]	Stabilized then put in landfills	No

NA-Not Available

References:

a: Complete bibliographies are at the end of the document. United States information is from About Waste to Energy and articles/reports by, Berenyi, Eileen (1998). Gielecki, Mark (1997), Wiles, C. & Shepard, P. (1999).

b: Sources for France Wiles, C. & Shepard, P. (1999) and Valenti (1999)

c: Source for Italy information Schroppe, T. (1999) and Pollastro, Fabrizio (2000).

d: Sources for Netherlands, Sweden, United Kingdom, Bermuda, and Japan are Wiles, C & Shepard, P. (1999)

e: Sources for Denmark are Wiles, C & Shepard, P. (1999) and Husen, Rabbeck, Nielsen, & Scheim (1999)

f: Source for Germany are Wiles, C & Shepard, P. (1999) and Yu-tzu, Chiu (2002)

g: Sources for Taiwan are Solid Waste Equipment market (1998) and Yu-tzu, Chiu (2002)

Beneficial Use

Although ash may be landfilled in other countries, ash is reused wherever possible. Many projects exist where fly ash and bottom ash are used for bricks/blocks, road bed, asphalt, and cement. The information presented in Table 4 is a summary of how much ash is put to beneficial use and if known, how much. The use of ash in the United States can be compared to the products being made in other countries and the amounts that are used.

Table 4: Summary of Ash Use in Select Countries

Country	Bottom Ash used	Fly ash used	Combined Bottom and Fly Ash Used	Use and Experimentation required
US[a]	In roadbed, landfill liner and cap, asphalt, aggregate	Pilot projects as landfill cover	6% of ash is used in roadbed, landfill liner, cap, asphalt aggregate	No
France[b]	45% used in civil engineering projects; must meet requirements of Ministry of Environment; aging required	No	No	No
Netherlands[d]	90% as fill in road embankments and as road base; water infiltration must be minimized	Yes can be used as asphalt filler	Uses include asphalt fillers; up to 30% of fly ash produced used in combined ash form	Yes; National Plan covers all options for use and experimentation of better treatment methods
Denmark[e]	80% is used for parking lots, paths, roads, and fill material	Combined and fly ash may be used but must meet established chemical criteria		Use as long as no environment impact is shown
Sweden[d]	Yes; each project must be individually decided upon by city councils for acceptability	No	NA	No
Germany[f]	60% is used as road paving and similar projects; "aging" required	To prevent subsidence of mine cavities	NA	Use is required if economically feasible
Bermuda[d]	Yes	Yes	50% of the ash created is used to make blocks for seawall	No
UK[d]	Not yet; treatment methods and regulating agency are being decided; projects include road base, concrete subbase, resurfacing of car park	No	No	No
Japan[d]	Yes	Yes	3% of ash produced is vitrified and was used as fill material, roadbed, interlocking blocks, and asphalt aggregate (1995)	No
Taiwan[g]	NA	Researching recycling for roads, walls, artificial reefs, and bricks	NA	No

NA-Not Available

References: **a:** Complete bibliographies are at the end of the document. United States information is from About Waste to Energy and articles/reports by, Berenyi, Eileen (1998), Gielecki, Mark (1997), Jones (1999), Wiles, C. & Shepard, P. (1999).
b: Sources for France Larane, A. (1997) ,Wiles, C. & Shepard, P. (1999) and Valenti (1999)
c: Source for Italy information Pollastro, F. (2000) and Schroppe, T. (1999)
d: Sources for Netherlands, Sweden, United Kingdom, Bermuda, and Japan are Wiles, C & Shepard, P. (1999)
e: Sources for Denmark are Wiles, C & Shepard, P. (1999) and Husen, Rabbeck, Nielsen, & Scheim (1999)
f: Source for Germany are Wiles, C & Shepard, P. (1999) and Yu-tzu, Chiu (2002)
g: Sources for Taiwan are Solid Waste Equipment market (1998) and Yu-tzu, Chiu (2002)

The Netherlands is one of the leaders in ash re-use and experimentation (Ruth, 1998; Wiles, C. & Shepard, P., 1999)) . Up to ninety percent of bottom ash and about thirty percent of fly ash is used. Fly ash and bottom ash are combined for use in civil engineering projects, roads, and concrete. Fly ash that is unused is landfilled in non-hazardous landfills after it has been treated (Wiles, C. & Shepard, P, 1999).

In Bermuda, an ash utilization project involves bottom ash mixed with fly ash being used in a land reclamation project in the Castle Bay Harbor. This project is part of a large ash management plan that involved testing to determine the effects of ash on public health, on the environment, and on marine organisms. The combined ash is mixed with sixteen percent cement by weight to form blocks that will construct a wall forty feet deep in the harbor (Wiles, C. & Shepard, P, 1999).

France is also looking at recycling fly ash on a large scale by vitrifying it for use in construction materials. Currently, France uses bottom ash that has been aged, but using fly ash is part of their waste management plan. Only pilot projects for vitrification exist as of now and fly ash is landfilled after stabilization (Larane, 1997; Valenti, 1999).

Germany is one country that is using its ash in an unusual way. Fly ash, as well as salts, are used to backfill mines to prevent subsidence (Wiles, C. & Shepard, P. 1999). This allows them to recycle their fly ash and save room in landfills. However, one source says the reason for placing the ash in mines is not to prevent subsidence, but to prevent leaching metals from coming in contact with the general public (Yu-tzu, 2002).

Health Risks

Other regulations that exist regarding fly ash are to protect employees who work with fly ash and those living in the area where ash is being used in projects. A study done using ash as landfill cover in Hawaii has shown that fly ash meets OSHA standards for use, when properly used (Jones et al. 1999). The study also included estimates for lead content that would be found in workers and surrounding communities blood from contact with the ash. The content was well below established standards. Ash is also considered safe as an unbound filler material in the Netherlands and may be spread throughout the work site, open to the elements without adversely affecting workers. Ash, like other construction materials, cannot be exposed after work is complete though (Potential recycling applications open up for incinerator ash, 2000). Ash, for the most part, is not considered a health risk to workers using the fly ash or to the population having background exposure.

In summary, the health risks to the environment and the population resulting from fly ash are known to result mostly from heavy metals and soluble salts leaching from untreated ash. Although it can not be said that fly ash poses no risk, treatment options greatly lessen the possibilities of these constituents leaching into the environment. Regulations around the world reflect the issues of safety and usability of fly ash. For the most part, un-stabilized fly ash is considered hazardous, while ash that has undergone some treatment is no longer a hazard. The extensive studies and research that have gone into current treatment options and uses strongly indicate that stabilized ash is safe to dispose of in landfills, use in many civil engineering projects, and does not present a great health risk.

4.2 Possible Uses in Puerto Rico

After investigating the regulations and health risks surrounding fly ash, we looked into using fly ash in products in Puerto Rico. Using our initial investigation of coal fly ash products, we selected the most promising uses. We then studied each use to determine the chemical suitability and the economic outlook of MSW fly ash for each product. Some uses were immediately eliminated such as zeolites, filters, fertilizers, and composite wood because we determined they were not chemically compatible with MSW fly ash. The uses we concluded had the most potential were using MSW fly ash in concrete, as a roadbed, as landfill liner, and as products that had been treated by vitrification.

Aggregate in Concrete

Fly ash can be considered for use as an aggregate in concrete. Ash has several qualities that would recommend it for use in concrete; such as its calcium content and its consistent quality. However, some problems might arise from using fly ash in concrete due to other aspects of its chemical composition. It might also be hard to have producers in Puerto Rico accept fly ash as an aggregate if their current materials are less expensive. Current uses of ash in concrete are mostly for combined ash, so some experimentation is also recommended before using fly ash.

Concrete is composed of a mixture of about thirty percent Portland cement and seventy percent graded aggregates. MSW fly ash could be a successful aggregate for several reasons. The high quantity of calcium found in MSW fly ash is one of the best reasons to consider its use in concrete says Efrain Carreras Vice President of Puerto Rican concrete producer Grupo Carmelo (personal correspondence, March 28, 2002).

Portland cement, a material made of almost all calcium carbonate, is used to bind materials together in concrete. Aggregates that contain a large volume of calcium can complement the binding qualities of the cement and make it stronger (Wiles, C. & Stephan, P. 1999; Efrain Carreras, personal correspondence, 2002). MSW fly ash contains a little more than forty percent calcium due to the lime treatment in the incineration process, thus making it a possible candidate for use in concrete.

MSW fly ash could also be considered a good aggregate because of its consistent quality. The refuse-derived fuel process creates fly ash that always has similar quality, texture, and composition (EAC). Quality and composition of aggregates are important because materials found in natural aggregates, such as clay, can weaken the concrete (Efrain Carreras, personal correspondence, March 28, 2002). With MSW fly ash, these types of imperfections would not have to be worried about.

Although fly ash exhibits some strengths of a quality aggregate, there are some features that may cause problems. Chlorine, which has a large concentration in MSW fly ash, could be reason for concern. The chlorine could react with water to produce hydrochloric acid, which is corrosive to metals. This means that concrete made with MSW fly ash should not be used in reinforced concrete. MSW fly ash should only be used in prefabricated concrete products such as blocks, highway barriers, and sea walls. This might have an effect on the quantity of fly ash that can be used and the price of products produced using MSW fly ash. The high concentration of sulfur in fly ash, which could also form a corrosive acid, would have similar effects (Wiles, C. & Stephan, P. 1999, Efrain Carreres, personal correspondence, March 28, 2002).

Another issue involved with using fly ash is that it has not been used by itself in concrete. Many projects using combined[4] and bottom ash have occurred throughout the United States over the past twenty years, but none using only fly ash. Although there are no implications that fly ash used by itself would not work as an aggregate, one of the few guidelines created from these projects is that ash must be mixed with other aggregates due to its low density. The density of the fly ash is lower than that of many aggregates including combined ash. This can be a problem if fly ash is used in too large a percentage of the aggregate because the concrete will be weakened. These projects using ash also stress that glass and soluble salts must be removed from the ash where strength and appearance are important as they can weaken cement and cause pitting (Wiles, C & Stephan, P. 1999).

One challenge to using MSW fly ash in Puerto Rico is providing either cheaper or better aggregates to the concrete producers than those currently used. Producers like to use aggregates that are either the best quality or the least expensive. Many manufacturers in Puerto Rico currently use limestone of varying qualities as aggregate. If fly ash is not of better quality or cheaper than the limestone being used, producers may be wary of exchanging aggregates in their product. However, if fly ash is of consistent enough quality and size it might be favored over fabricated sand aggregates made from limestone, which are expensive. Currently, about eighteen million tons of aggregate is used yearly in concrete in Puerto Rico (Efrain Carreras, personal correspondence, March 28, 2002). Even if fly ash makes up a very small percentage of aggregate, all the fly ash can be used if the transportation costs of delivering it to various producers can be met.

[4] Combined ash is a mixture of fly ash and bottom ash.

In the case of concrete, we were able to find enough information to make a preliminary calculation of the amounts of fly ash that could be used. Grupo Carmelo uses 600,000 tons of aggregate every year. In that aggregate, about forty two percent is sand or silt, which is what fly ash could replace. In the following analysis, as well as the cost analysis, all percentages of concrete aggregate are expressed as a percentage of the sand in the aggregate. We assumed that fly ash would have to be mixed in small percentages in order to minimize the effects of density and the chlorine and sulfur compositions on the concrete. We analyzed the use of fly ash by assuming different mixtures of fly ash with the current aggregate from 0 percent, which would be all of the fly ash landfilled, up to 5, 10, 15, 25, 50 and 100 percent.

Table 5: Fly Ash landfilled per Percent Mix of Concrete Aggregate

Percent Mix	Tons of fly ash Landfilled
0%	109,500.00
5%	96,873.75
10%	84,247.50
15%	71,621.25
25%	46,368.75
50%	0.00
100%	0.00

In Table 5, the amount of fly ash that would be landfilled minus the amount that could be used as an aggregate is displayed as a function of what percentage of the aggregate consists of fly ash. It illustrates the drastic reduction in the landfilling of fly ash that would occur if fly ash could be used in concrete based on aggregate information given to us by Grupo Carmelo. If Grupo Carmelo used fly ash in a fifteen percent mix of sand in all of their bricks, almost 40,000 tons of the fly ash produced at the RENOVA project site every year would be used.

Fly Ash as a Road Bed

A second possibility for the use of fly ash is as a road base. Road base is the material that goes underneath the road to make an even surface and provide a foundation for asphalt. Usually aggregates used for road base are similar to that of aggregates used for concrete, but of lesser quality.

A good road base material is one that is both loose like gravel and will not change in volume when exposed to water. Use of fly ash as a road base aggregate could be more feasible than as a concrete aggregate because the chemical composition would not be as significant a factor. For example, there are no metal reinforcements that would be affected by chlorine or sulfur contents. In fact, some places within the United States have already used MSW fly ash, when combined with the bottom ash as a road base. California has been using the combined ash for a road base in the Puente Hills Landfill in Whittier, while Pennsylvania has approved the use of ash as a road base for roads on the Lanchester Landfill in Honeybrook (Gielecki, 1999). Since these places have found a use for combined ash as a road base, it may be a possibility in Puerto Rico.

Even though fly ash use in road base would not have as many of the chemical problems associated with fly ash use in concrete, a new host of questions were apparent to us. One of the biggest questions is how much fly ash would change in volume when water was added to it. If fly ash was to be used as a roadbed it could not be subject to a large change in volume when water is present. Water could be introduced to fly ash road base when underground water rises to the surface. Most road bases do not harden when mixed with water, but fly ash does, although it is not clear whether this would cause a problem. The low density of the fly ash would be another questionable trait. Most road bases have a density much higher than the 36-lbs/ft^3 density of fly ash (Jones et al, 1999). Although this seems to be major problem, the road base would be compacted before use with a roller, which would increase the density. More research would be needed to determine whether these concerns would actually cause a major problem in the use of road base.

For road base, we were also able to make some preliminary calculations on the amounts of fly ash that could be used. Fly ash would have to be used in small percentages in road base to avoid problems with volume change and density, similar to concrete. We analyzed the use of fly ash the same way we did for concrete, by assuming different mixtures of fly ash with the current aggregate from 0%, which would be all of the fly ash landfilled, up to 5, 10, 15, 25, 50 and 100 percent.

Table 6: Fly Ash landfilled per Percent Mix of Road Base Aggregate

Percent Mix	Tons of fly ash Landfilled
0%	109,500.00
5%	106,069.87
10%	102,639.73
15%	99,209.60
25%	92,349.33
50%	75,198.65
100%	40,897.30

In Table 6, the amount of fly ash that would be landfilled minus the percentage that could be used as an aggregate in road base is displayed. The information is based on road base projects undertaken by the Highway Transportation Authority (HTA) over the past decade. It should be noted that local municipalities also use road base and those projects were not investigated in this analysis. Also, because there are a lot of companies which produce road base aggregate, we assumed a fifty percent market penetration of fly ash in order to stay conservative. Based on these assumptions, if fifteen percent of fly ash could be used in road base, almost 15,000 tons of fly ash would be used annually.

Fly Ash Landfill Liners and Caps

The final uses we looked at for MSW fly ash are landfill liners and caps. In this section, properties of good landfill liners are discussed and fly ash is compared for use as an alternative. Some of the best documented and the most recent projects involving fly ash and combined ash for this purpose are also discussed here. The problems with implementing fly ash as a liner in Puerto Rico are also addressed.

Landfill liners and caps are used in sanitary landfills to help prevent toxic water from leaching into the surrounding areas. In the United States, RCRA stipulates the guidelines for use on landfill liners and caps. For a landfill to be in compliance with RCRA, it must have a virtually non-permeable liner and must be covered daily with a cap. The most common liners and caps are composite plastics as well as various types of clay.

Fly ash has many properties that would be conducive to its use as a landfill cap or liner. The first and most important is that when mixed with water, fly ash becomes hard and virtually non-permeable. This is the most important trait of a landfill cover (Sonya Feliciano of the EQB, personal correspondence, April 16, 2002). MSW ash also has a history of being used as a landfill cap in different projects in the United States. Combined bottom and fly ash has been used as a daily landfill cap in at least four states and has been used as a final landfill cover in at least as many (Gielecki, 1999; Jones et al, 1999). Although these projects are using combined ash, some are using more fly ash in the mixture than bottom ash. One such example is the H-Power facility in Hawaii, where the National Renewable Energy Laboratory is doing research on the uses of ash. The study concluded that using fly ash as a landfill cover was safe and saved money and space when compared to landfilling the ash (Jones et al, 1999). Since the use of combined and fly ash as a landfill cover has been demonstrated numerous times in the U.S., we believe it could be a good candidate for use in Puerto Rico.

There are some issues that arise in trying to use fly ash for a landfill cover in Puerto Rico. One of these issues is that at the moment almost all of the landfills in Puerto Rico are not lined or capped on a daily basis (Mr. Rivera of the SWMA, personal correspondence, April 5, 2002; Sonya Feliciano of the EQB, personal correspondence, April 16, 2002). This means that right now there is virtually no market for landfill liners or caps in Puerto Rico. Landfills in Puerto Rico can continue to be non-compliant with RCRA due to a grandfather clause that allows landfills to stay open until they are full. This means landfills will not need a daily cap for the next five to ten years (Mr. Rivera of the SWMA, personal correspondence, April 5, 2002).

When the older landfills close in Puerto Rico, new landfills will need to meet the regulations of being lined and capped daily. Besides meeting regulations imposed by the RCRA, liner and cap material in Puerto Rico must also meet regulations set by the Environmental Quality Board (EQB). The EQB has set the guidelines for caps and liner materials in anticipation of the future need. For liners, non-permeable plastics must be used, which eliminates the possibility that fly ash could be used. Landfill caps, on the other hand, are going to be made of clay, sand, and other natural aggregate materials, so fly ash could be used as a landfill cap. The only major necessity for the use of fly ash as a landfill cap is that a permeability of $1*10^{-5}$ cm/sec or less is required (Sonya Feliciano of the EQB, personal correspondence, April 16, 2002). The study being done in Hawaii indicates that fly ash has a permeability that should meet this requirement, but because fly ash from different facilities varies slightly fly ash from the RENOVA project would have to be tested (Jones et al. 1999).

Vitrification Practices

Many stabilization techniques have been tried to increase the use of fly ash, including vitrification. Vitrification is an ash melting technology that produces a highly stable product that can be used for tile, ceramics, and aggregate. Use of this technology is increasing and may be beneficial in Puerto Rico due to the controversy over ash safety. The process of vitrification, the products that can be created, and where the technology is being used are all described in this section. Advantages and problems of using a vitrification technology in Puerto Rico are also included.

Vitrification is a process by which a material is melted and then flash cooled to create a glass-like substance. The process begins when waste materials are fed into a pit that is heated to more than 2,000 degrees Fahrenheit by various types of electric arc systems. In most vitrification systems, the high temperature created by the arc will create a plasma near the electrodes (www.vitrification.com). The melted material becomes a molten glass. Below in Figure 1 is an example of a vitrification system for MSW, which is very similar to the system for MSW fly ash. This particular system uses an AC current to heat the MSW to a temperature in which it is without any crystalline form or vitreous. When the MSW is extracted as the molten glass it has become, it is cooled. The end result is a material that closely resembles marble or granite.

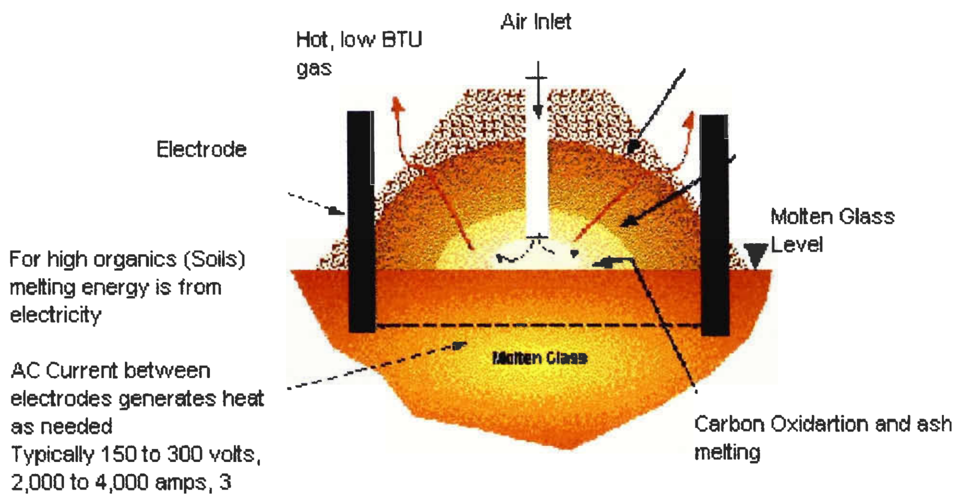

Figure 1: Vitrification Process (adapted from Waste Vitrification: Principles pf Processing)

Source: Waste Vitrification: Principles of Processing: www.vitrification.com

The process of vitrification was originally designed to stabilize nuclear wastes and was then used to treat hazardous materials (Valenti, 1999). Recently, it has also started to become cost effective to vitrify non-hazardous wastes in order to make the waste easier to use in commercial products. The glass type material that is the byproduct of this process resembles volcanic glass, which is produced in a similar fashion in nature. This byproduct could be used for many different applications. Since the glass material, called slag, outwardly resembles marble or granite in appearance, it could be used as an elegant stone in countertops, sculptures, and stonewalls. The slag can also be made into smaller particles and used in concrete aggregate or filler for roadbeds. In construction that requires high strengths, slag could be used as it is a high strength material as shown in Table 3. The bending strength and hardness of the slag produced in RENOVA would be similar to the slag shown in the table because the slag was produced from fly ash from a refuse-derived fuel plant. This stone could also be used as an attractive construction component as well for high end houses. All in all, the vitrified ash would have many possible uses in Puerto Rico.

Table 7: Properties of Vitrified Fly Ash Slag (adapted from The Plasma Treatment of Incinerator Ashes)

Property	Recrystallised Slag	Marble	Granite
Bend Strength / kg cm-2	500	100	150
Bulk Density / g cm-3	3	2.7	2.7
Mobs Hardness	6 - 7	3	5 – 6
Acid Resistance / %	0.1	10.3	1
Thermal Expansion Coefficient / MK-1	6.7	8	8.3

Source: The Plasma Treatment of Incinerator Ashes; www.tectronics.com

In many countries, such as Japan, vitrification is one of the most important ways to dispose of incineration fly ash. Japan has more than 1900 MSW incinerators, which is one of the highest counts of any country in the world (http://www.unep.or.jp). Vitrification is viable in Japan because the government subsidizes the use of products that contain vitrified ash from incinerators. There is a difference though in the vitrification processes between the plants in U.S. and Europe and the plants in Japan. In Japan, the molten ash is heated in excess of 3,000 degrees Fahrenheit, which is higher than most of the vitrification processes in the U.S., and a few hundred degrees higher than most of the European plants (http://www.unep.or.jp/CTT_DATA/WASTE/WASTE_4/html/Waste-141.html; /Waste-167 /Waste-137.html;/Waste-143.html). The reason for the different temperatures used is not apparent. Vitrification efforts in Japan have also included work toward the use of the vitrified ash as aggregates in a variety of construction materials, such as tiles and bricks (http://www.unep.or.jp/CTT_DATA/WASTE/WASTE_6/html/Waste-167.html).

France is another country that is on the leading edge of vitrification technology. France produces about 300,000 tons of fly ash annually (Valenti,1999). Most of the fly ash produced in France is stabilized using chemical stabilization techniques, but growing concern about eliminating all the health issues of fly ash has caused vitrification to become a viable option. Many vitrification plants on the order of thirty to fifty tons per day capacity have been built in the past few years in France and throughout Europe (Valenti, 1999; Larane, 1997). One trend that is apparent in the vitrification industry is that most countries where vitrification is widely used subsidize the vitrification companies.

This subsidizing underlies one of the largest problems with vitrification, the fact that it may be prohibitively expensive. Given that the space needs in Europe and Japan are much more urgent than in the United States, landfilling is much more expensive there. The cost of vitrification in Europe ranges from between $300 to $600 per ton, while the costs in Japan are sometimes as high as $1,000 per ton ((Larane, 1997; Valenti, 1999). This would make vitrification prohibitively expensive in Puerto Rico even if the final vitrified product was sold as a commercial product.

Cost Analysis

Besides considering how easily the fly ash could be incorporated into a product, we also investigated approximate cost information. We analyzed the prices per ton on the various products compared with landfilling the fly ash. We also tried to determine how much fly ash would be used in each product. The result of this analysis is a preliminary report on the possible cost savings to both Energy Answers and the producers of the potential products.

In order to determine the costs of each use, we took into account two things. First, we included a transportation cost which Energy Answers may have to pay in order to send the fly ash to the producers. We included this cost because we tried to make this analysis as conservative in the benefits to Energy Answers as possible and we were not certain whether Energy Answers would have to pay this cost. Secondly, there was the gain Energy Answers would make by selling the product. In order to stay conservative, we assumed Energy Answers would sell the fly ash for a third of the price of materials that could be replaced. After both of these costs were determined, subtracting the sales price from the transportation cost gave us the total cost to Energy Answers.

One of the most important things to analyze was the overall cost per ton of using fly ash per ton for each product. We started by finding costs for landfilling the fly ash in a regular municipal landfill. Although Energy Answers had some information on this price, we verified a price of $20.00 per ton of fly ash for the tipping fee (Juan Rodriguez of BFI, personal correspondence, April 22, 2002). In addition to this cost was the cost of transportation to the landfill, which was approximately $15 per ton (Jose Soto of BFI, personal correspondence, April 22, 2002). This figure is the cost to transport from the Caguas municipality to the Humacao landfill, where all of the waste in Caguas is currently disposed. This cost was used to compare the cost to landfill all of the fly ash to using it in various products.

Figure 4 compares the cost per ton of landfilling to the cost of using fly ash in the various possibilities we have suggested. This is the cost to Energy Answers and it includes paying for a $15.43 per ton transportation cost, which is a good estimate of transporting fly ash on the east side of the island (Efrain Carreras, personal

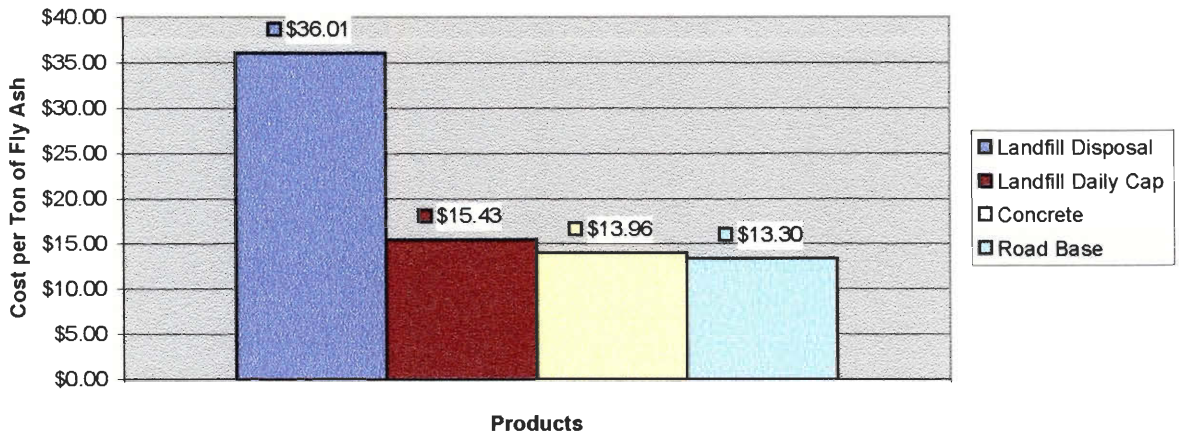

Figure 2: Total Cost to Energy Answers per Ton of Fly Ash Used: Including Transportation Costs

correspondence, March 28, 2002). All of the information we received from producers was analyzed to determine the sale price of fly ash. From our research on how easily fly ash could be used with different products, we determined that in order to sell fly ash it would have to be much cheaper than currently used materials. This is because fly ash should compete with lower quality materials. We attempted to make this analysis a conservative appraisal of the benefits to Energy Answers. Therefore, we determined that selling fly ash for one third of the cost of the current material would be a reasonable estimate, although much more in-depth analysis of each product would be necessary to establish the best price for selling fly ash.

The second bar displayed in Figure 2 is the cost of using fly ash as a daily cap, this would be the second most expensive option for Energy Answers. There were many challenges in obtaining the cost of a landfill cap in Puerto Rico. Most notably is the fact that almost none of the landfills use a daily cap. Teddy Diaz of BFI (personal correspondence, April 23, 2002) informed us that many landfills that use a daily cap used the dirt they had dug up to make room for the trash, although it is important to note that this dirt may not meet the permeability requirements of the EQB. This may severely limit the use of fly ash as a daily cover in Puerto Rico as nothing is paid to obtain this cap, but future caps will definitely have to meet these requirements and they may be more expensive.

Even though Energy Answers would not be able to charge money to use fly ash as a landfill cover, it may save the landfill owners money by paying for transportation of the fly ash to the landfills. This is the $15.43 cost per ton that is depicted in Figure 2. For the landfill owners, the normal cost of labor and machinery to transport and compact the dirt is about $5.00 per cubic yard (Juan Rodriguez, personal correspondence, April 22, 2002). This cost could be reduced slightly if Energy Answers paid for all the transportation costs of fly ash to the landfill site.

The second product we analyzed costs for was fly ash as concrete aggregate. As in our analysis of other products, the cost to transport the fly ash was factored into the final price. According to Ramon Lopez of Grupo Carmelo (personal correspondence, April 22, 2002), the cost of concrete block aggregate is $4.22 per ton. Grupo Carmelo is one of the companies who have invested in the RENOVA project eco-industrial park, so they would be the most likely buyers of the fly ash for concrete purposes. Using our pricing method of taking one third of the current cost, we determined that this would allow Energy Answers to sell the fly ash for about $1.50 per ton. The total costs to Energy Answers including the cost of transporting to the Grupo Carmelo plant would be approximately $13.96 per ton, the transportation costs less the price of fly ash. The cost to Grupo Carmelo for aggregates would also be reduced by almost seventy percent from $4.22 per ton to $1.50.

The final product we investigated was the cost for road base. We obtained road base cost information on many of the road base projects undertaken in the last ten years from the Highway Transportation Authority (HTA) of Puerto Rico. This information included the total cost of the road base project, as well as the amount of material used in the project. Jose A. Fernandez of the HTA (personal correspondence, April 18, 2002) informed us that we could determine the material costs by dividing the total costs in half. This is because half of the cost is usually material, while the other half is profit, labor, and machinery.

For our cost analysis, we assumed that forty percent of the total cost was material cost in order to keep a conservative estimate. This means that we tried to assume the lowest cost for materials. The HTA uses cost estimates per volume of material rather than weight, we used the density of fly ash to calculate the cost estimates per weight of material. The average cost in a road base project from the HTA was $5.93 per cubic meter of material used. According to our calculations, this cost would be $6.38 per ton of material of the same density as fly ash. This would allow Energy Answers to sell fly ash at a price of nearly $2.15 per ton and still be three times less expensive than the usual road base material. This means the final cost to Energy Answers would be $13.30 per ton. One problem that may be encountered in trying to use road base material is that the market for it seems to be very fragmented and it may be very hard to penetrate enough of the market to make the effort useful to Energy Answers.

In the description of our uses earlier in this section we analyzed the amount of fly ash that could be used in concrete or as a road base. Below in Figure 3 is a representation of all of the costs to Energy Answers if those numbers were to be realized. One thing that must be noted is that the costs presented include both the cost to use the fly ash, as well as the cost to landfill all of the fly ash that is still unused. For every ton of fly ash used, Energy Answers will save the $20.00 tipping fee. Also, for the cost assessments a fifteen percent mix of fly ash in the aggregates is assumed. At fifteen percent, we felt that the composition of fly ash would not adversely affect either the road base or the concrete. More research would be needed to determine the best percentage mix for fly ash.

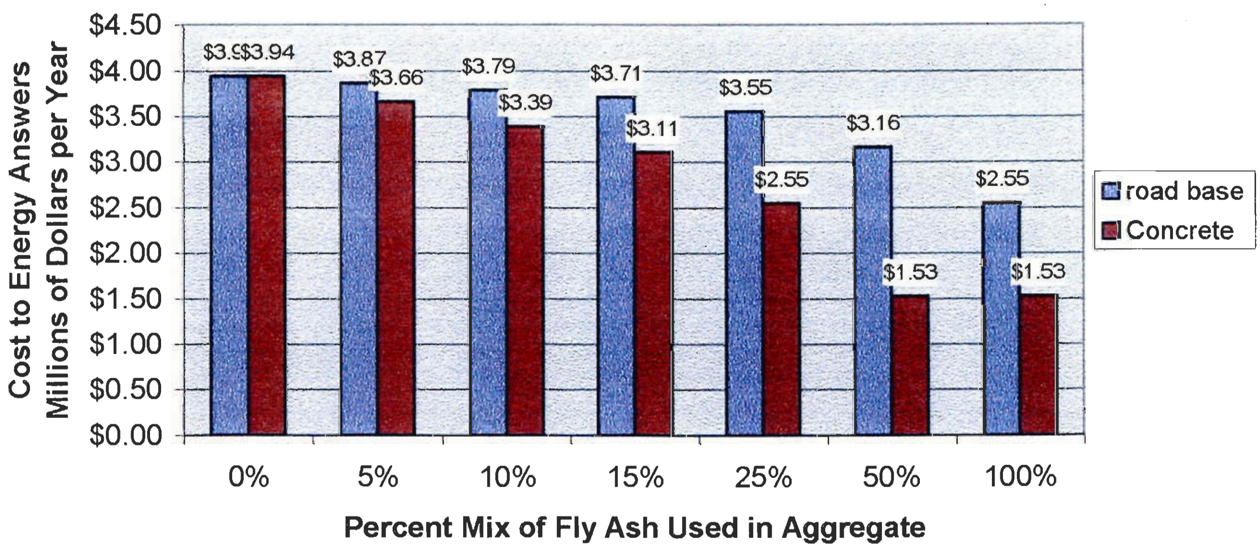

Figure 3: Fly Ash Use in Concrete vs. Road Base

Figure 3 shows if neither the road base nor concrete are used, the price is the cost to landfill the ash. This base cost comes out to $3,940,000 per year and is the price to transport and landfill all of the fly ash. As you can see, if just fifteen percent of the concrete aggregate contains fly ash, Energy Answers could potentially save almost $800,000 a year. Even though the gains from using road base are not as high, Energy Answers would still save over $200,000 a year.

One thing that is not calculated here is the cost savings to the producers. In Figure 4, savings to the producers is displayed. These savings assume that the selling price of the final product stays the same as their cost of materials go down. Continuing with our assumption of a fifteen percent mix of fly ash, Grupo Carmelo would save over $100,000. Road base manufacturers would save over $40,000 per year if they were to use a fifteen percent mix. These costs are substantial enough to judge that fly ash, if suitable, would be a good cost saving investment for producers to investigate fully.

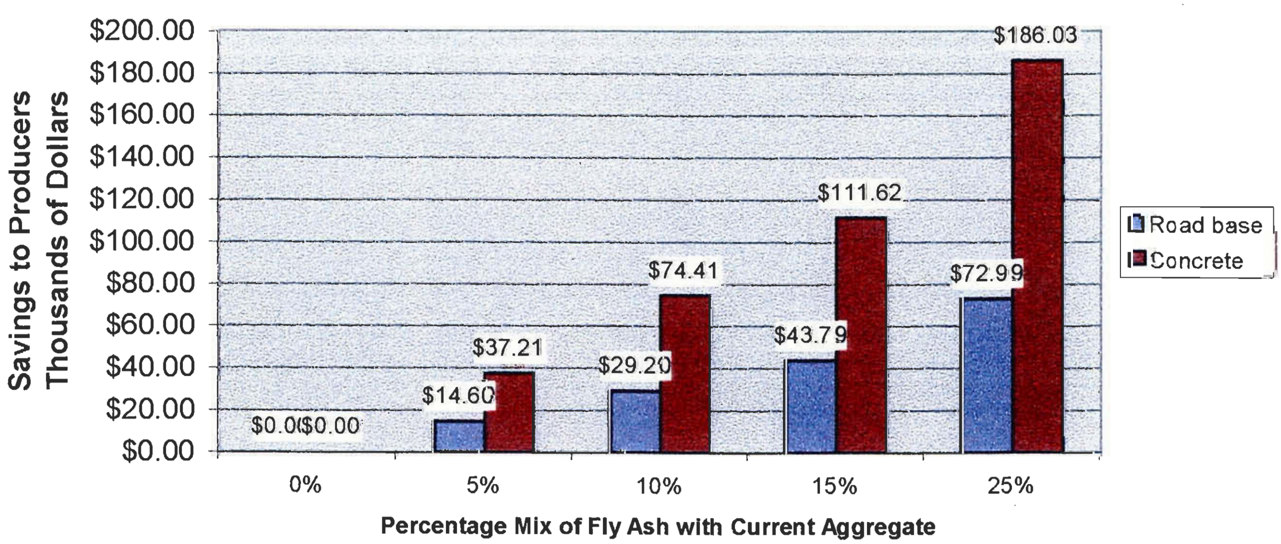

Figure 4:Savings to Producers vs. Percentage Mix of Fly Ash Used

Before now, we have not discussed the costs associated with vitrifying fly ash before using it. From information we obtained from the Scandinavian company ScanArc, a vitrification plant on the order of 26,000 tons per year could be built for a cost of $15 million. It would cost about $117 per ton to vitrify fly ash and would consume about 3.8 MW of electricity, or about five percent of all of the electricity that will be generated at the RENOVA site. The price per ton does not include the cost of all of the electricity used by the plant. We have done research that indicates that the byproduct of the vitrification process could be sold as a replacement for granite and marble. The average price of granite is about $260 per ton. In Figure 5 below, we assume that the black granite material produced in vitrification can be sold for a third of the average cost of granite.

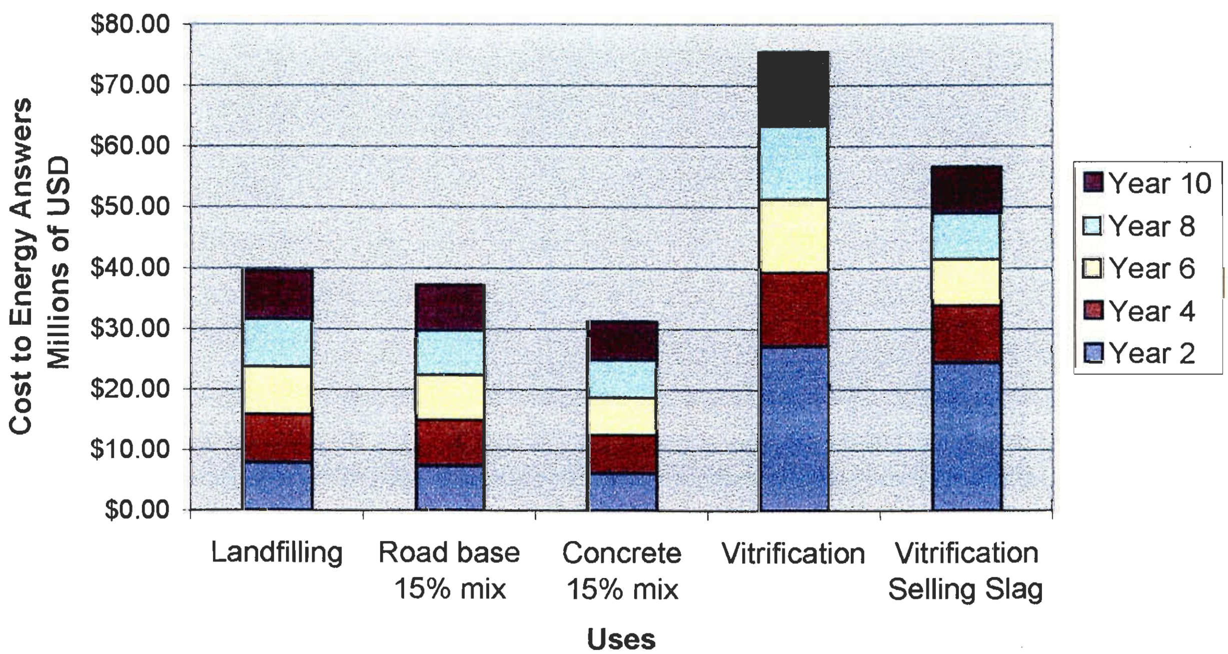

Figure 5: Cumulative Cost to Use Fly Ash in Various Products

In Figure 5, the cumulative costs to Energy Answers are displayed over a ten-year period. These costs include the cost of using the fly ash for a specific product plus the cost to landfill any unused portion of the fly ash. The cost of fly ash as a landfill cap is not included because we were unable to attain enough use data. As can be seen, a vitrification plant of about 26,000 tons per year would be much more expensive than landfilling it. This is true even if all of the slag is sold as a granite replacement at about $80 per ton. Over a ten year period using fly ash in concrete would save almost $10,000,000 and almost $2,500,000 would be saved if fly ash was used in a road base. These savings over the next 10 years are more than enough to justify an attempt by Energy Answers to use their fly ash for these purposes.

The use of fly ash as an aggregate or landfill liner will have large economic benefits to Energy Answers as well as producers of concrete and road base. For all of those involved, savings will be on the order of at least $30,000 - $40,000 per year, and Energy Answers will be able to save hundreds of thousands of dollars per year by using their fly ash.

5 Conclusions and Recommendations

From our research, we were able to analyze the risks associated with fly ash and possible uses for the ash in Puerto Rico. In this chapter, we give the major points of our findings and the final recommendations on how to use the most fly ash at the least cost.

5.1 Risk Assessment

In order to determine whether fly ash was a risk to human health and the environment, we reviewed fly ash legislation worldwide. We made the assumption that a country reflects its beliefs on how much risk is acceptable in its legislation and regulation. From our findings, we have shown that no country considers treated fly ash a hazardous waste after it has been stabilized to hydrate soluble salts and bind metal ions in compounds. It has also been shown that there is an increased use of combined ash and that experimentation for using fly ash by itself has also increased. Lastly, toxicity tests in the United States have consistently shown treated fly ash to be non-hazardous. We believe that we can reasonably conclude that treated fly ash does not pose a great health or environmental risk in Puerto Rico from the information we have presented.

5.2 Uses for Fly Ash in Puerto Rico

To recommend options for the use of fly ash, we had to determine whether fly ash was physically and chemically compatible as well as economically feasible as a material in each product. In looking at the physical and chemical compatibility of fly ash with various products, we were able to get a preliminary idea of the challenges associated with using fly ash. After addressing these two issues, we were then able to recommend what products Energy Answers should focus on further. These products are concrete aggregate, road base, and landfill liners. We also looked at vitrification as a treatment option that could increase the amount of fly ash that could be used.

Concrete Aggregate

Advantages

- The calcium content of the fly ash may compliment the binding qualities of the cement, resulting in stronger concrete.
- MSW fly ash is does not vary in quality, texture, and composition.
- Many projects using combined and bottom ash have been undertaken in the past twenty years in the United States.
- The amount of concrete aggregate sold per year solely by Grupo Carmelo would be enough to utilize a third of fly ash, if a fifteen percent fly ash mix was used. If fly ash can be used in small percentages and dispersed to many different concrete block makers, it will be relatively easy to use one hundred percent of the fly ash.
- The savings to Energy Answers could be almost $1,000,000 if the concrete aggregate was composed of more than fifteen percent fly ash. Depending on the percent of fly ash used in the aggregate, Grupo Carmelo could save between $100,000 - $200,000.

Disadvantages

- High chlorine and sulfur contents of MSW fly ash could be reason for concern if used in reinforced concrete. This is because when mixed with water, they can form acids which are corrosive to metals.
- The low density of fly ash may weaken concrete by increasing the volume. As discussed in our analysis, this may be overcome by using a small percent of fly ash in the aggregate.

Road Base

Advantages

- The chemical requirements of loose aggregate are not as important as in other uses because there are no bindings or reinforcements that may break down.

- Combined ash has been used in California and Pennsylvania as a road base.
- Cost per ton to Energy Answers will very likely be less than any of the other alternatives at $13.30 or less per ton.

Disadvantages

- Fly ash may cause a problem if it changes volume when it comes in contact with ground or rainwater
- The density of fly ash falls well below that of a normal road base aggregate.
- Fly ash use as a road base may have the most ecological repercussions, due to its unbound state.
- Only about ten percent of the fly ash produced could probably be used in road base on a commonwealth-wide scale. More research into road base use at the municipality level may reveal a bigger market for road base.

Landfill Liners and Caps

Advantages

- Combined ash and fly ash have been used successfully as a daily cap in more than four states in the United States. This is the most extensive and documented use of fly ash and we know it will be physically feasible to use ash as landfill liner.
- When mixed with water, fly ash becomes hard and virtually non-permeable. According to other studies, the hydraulic-permeability of solidified fly ash from similar RDF plants is lower than the necessary 1*10-5 cm/sec.

Disadvantages

- Most landfills in Puerto Rico are not currently lined or capped, which limits the market for a landfill cover in Puerto Rico.
- Cost savings to the landfill owners and Energy Answers will be less than that of the other products that we have researched.

Vitrification

Advantages

- The use of vitrification is considered a better stabilization technique in some countries around the world including France and Japan. This may alleviate fears of opponents to the RENOVA project.
- Byproducts are more widely used than fly ash in countries where vitrification is used.

Disadvantages

- Initial cost would be at least $15,000,000 to build a plant which would vitrify about a quarter of the fly ash produced at the RENOVA site.
- Cost per ton to vitrify fly ash is at least $100.
- Electric consumption is about 3.8 MW. This is about seven or eight percent of the total electricity produced at the RENOVA site.
- Companies who have experience in vitrification techniques are mostly European or Japanese, little large scale vitrification has been done in the United States.

Recommendations

Our recommendations consist of further research we believe Energy Answers should undertake in order to determine how fly ash could be used in Puerto Rico. Vitrification has been shown to be too expensive and we don't recommend any further research into that process:

- **Analyze in more detail the chemical and physical composition of fly ash**.
  - Analyze the physical properties of fly ash in powdered form and after it is solidified. Physical properties that have shown importance in determining whether fly ash could be used are density, hydraulic permeability, and volume change, between solidified and non-solidified form.
  - Analyze the chemical make-up of fly ash in order to determine to what extent acids are formed when water is added
- **Work with Grupo Carmelo to obtain information on fly ash use in concrete.**
  - Send a fly ash sample to their research department. In our meeting with Grupo Carmelo they indicated that they would do research on using fly ash as an aggregate in their product.
  - Obtain better cost information for the sand in their aggregate. The small particle size of fly ash means it could be used as a partial replacement for sand in an aggregate. This information could give Energy Answers a

better insight into the price that fly ash could be sold for when used in concrete.

    - Determine whether Energy Answers would have to pay to transport the fly ash to the Grupo Carmelo plant.
    - Find information on other concrete producers in Puerto Rico, such as their interest in using fly ash and the prices of their products.

- **Research the use of fly ash as a road base.**
    - Determine if the public reaction toward using fly ash in a road base is negative. Even if using fly ash in a road base were feasible, a harsh reaction from the public would bar fly ash use.
    - Determine whether a volume change takes place when fly ash solidifies and how much water can be introduced before the volume change becomes too extreme.
    - Identify the producers of road base in Puerto Rico and contact them for information regarding use and cost data. The HTA should has this information, but if not contractors listed in Appendix G would know who produces road base.
- **Continue research on fly ash as a landfill daily cap**.
    - Obtain information from the EQB on the specific regulations regarding landfill liners and how to petition for the use of a material as an sanctioned daily cap.
    - Review NREL study *Utilization of Municipal Waste Combustion Ash,* which describes current research using fly ash as a landfill liner.
- **Analyze fly ash use as an asphalt aggregate as well.**
    - Review studies done using ash in asphalt.
    - Identify the companies that make asphalt and obtain cost and use data from them. This information could probably be found at the HTA.
    - Research EQB requirements for asphalt aggregates. Much of this paperwork is included in Appendix H.

The information presented within is the result of a first order analysis into the risks and possible uses associated with fly ash in Puerto Rico. If the recommendations are further researched, fly ash may be found to have a feasible use. That could allow Energy Answers to save money as well as begin to fulfill their goal of zero disposal.

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7 Appendices

A. Mission and Organization of Energy Answers Corporation

Energy Answers Corporation (EAC) was established in 1981 to help develop solutions for the disposal of municipal solid wastes. The company is dedicated to reducing waste and finding a way to reach "zero disposal". They want to be able to minimize waste using methods such as incineration and recycling. EAC's employees see themselves as environmentalists with solutions; a collection of experts who are working together to come up with solutions for the disposal of municipal solid waste. EAC has won numerous awards since its inception, such as the 1993 ***Corporate Citizen Award*** by the Plymouth [Massachusetts] County Development Council and the ***Public Water System Letter of Recognition*** by the Commonwealth of Massachusetts. These awards are listed at http://www.energyanswers.com/awards.htm. The company philosophy is as follows; they believe that many of society's problems can be solved by innovation and hard work. If employees effectively use their skills to achieve the goal of EAC, they believe they can make zero waste a reality.

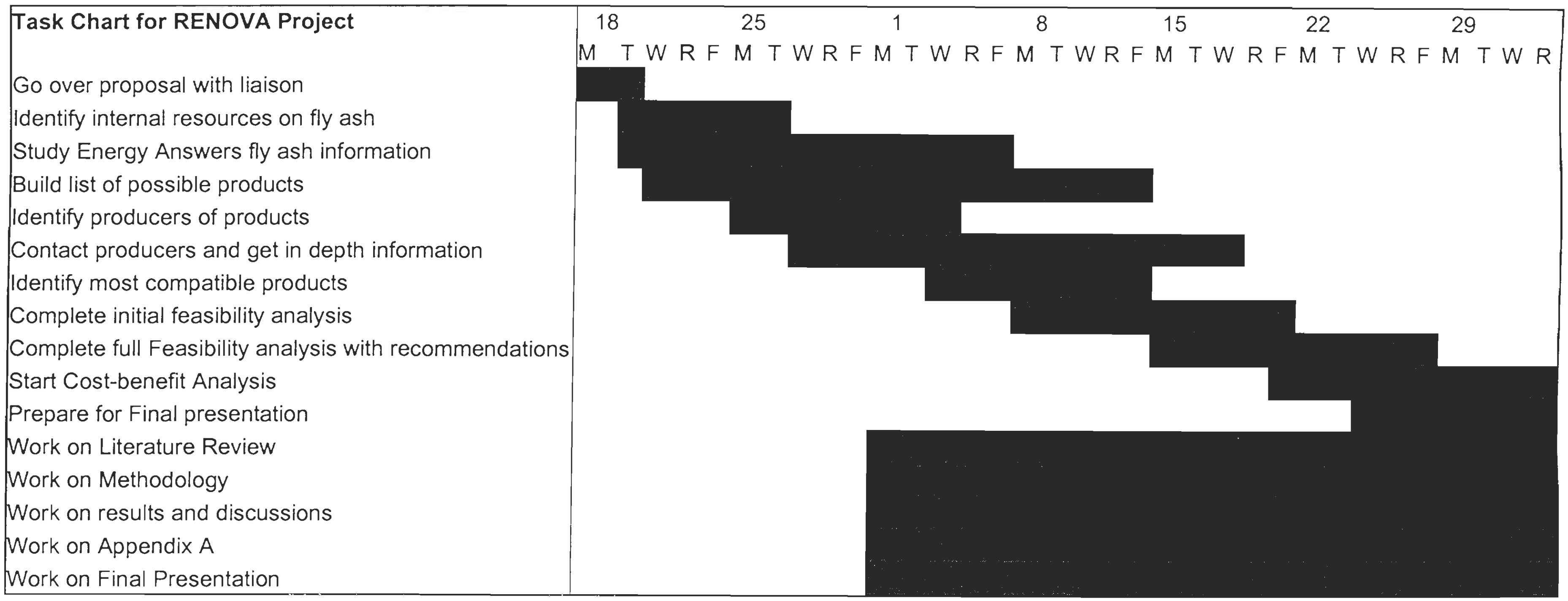
EAC's project benefits all communities world wide, their techniques, if perfected could be used to develop plants everywhere so that close to one hundred percent of waste could be disposed of without the need to store garbage in landfills. The plant they built in Rochester, MA services several communities in the area and they plan to build a similar one in Puerto Rico to help with the waste and energy problems. There is also a plant in Agawam, Massachusetts that sells electricity to the local electric company. There are several facilities in the country run by EAC to help communities to recycle their waste and generate additional electricity.

Organization:

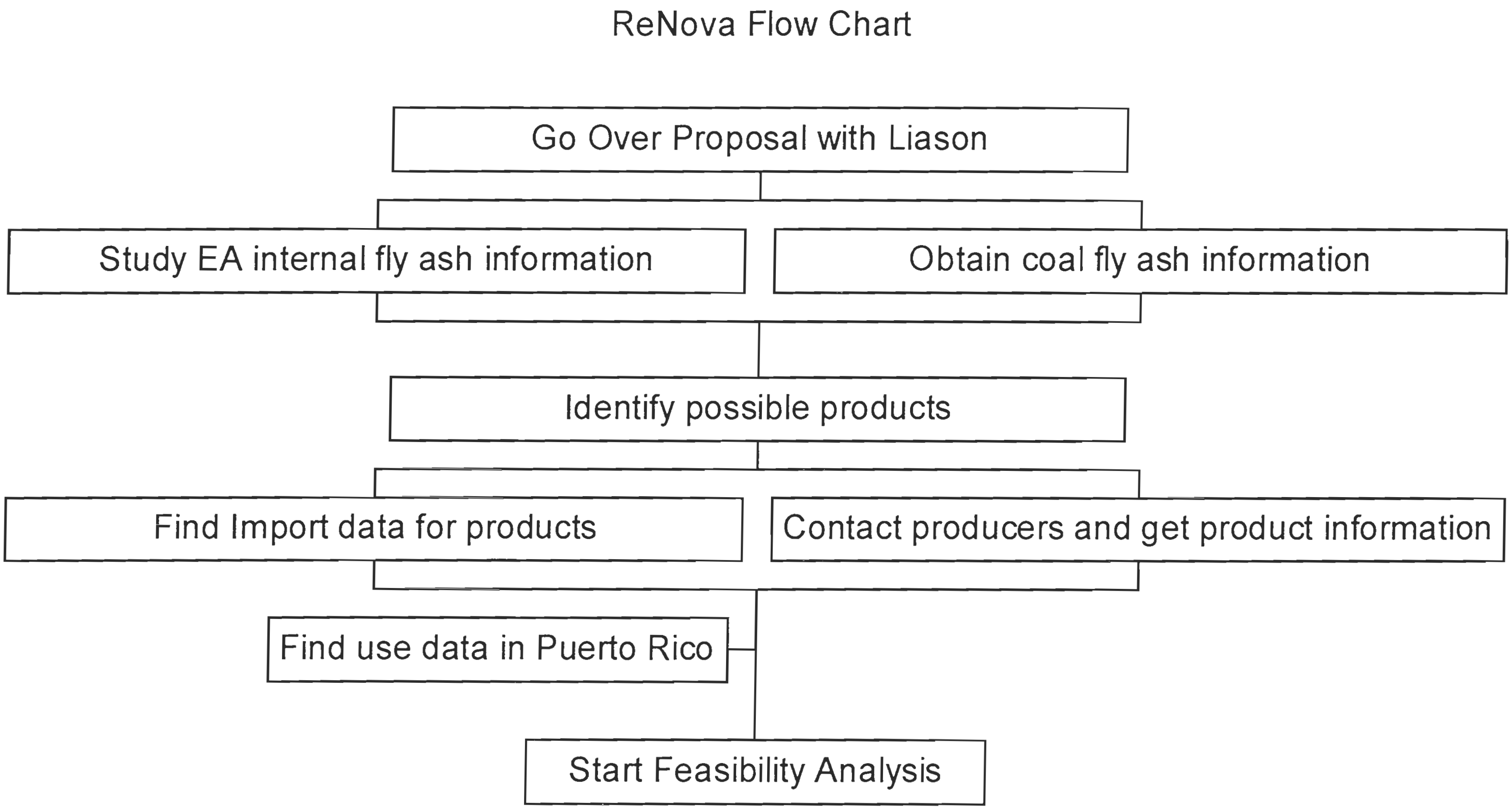
The structure of the officer and directors in the EAC organization:

- Cynthia G. Colin - Director-Energy Answers Corporation; Senior Vice President/Financial Consultant, Salomon Smith Barney
- S. William Green, Esq. - Director-Energy Answers Corporation; former U.S. Congressman
- Patrick F. Mahoney - Director, Chairman and Chief Executive Officer
- Gordon L. Sutin - Director, Vice Chairman and Executive Vice President
- Larry D. Richardson - President, EAC Operations, Inc.
- Open - Vice President, EAC Operations, Inc., Operations
- E. Larry Beaumont - Vice President, EAC Operations, Inc., Technologies
- William H. Ralston - General Counsel

B. Task Chart


Task Chart for RENOVA Project
18
25
1
8
15
22
29
M T W R F M T W R F M T W R F M T W R F M T W R F M T W R F M T W R
Go over proposal with liaison
Identify internal resources on fly ash
Study Energy Answers fly ash information
Build list of possible products
Identify producers of products
Contact producers and get in depth information
Identify most compatible products
Complete initial feasibility analysis
Complete full Feasibility analysis with recommendations
Start Cost-benefit Analysis
Prepare for Final presentation
Work on Literature Review
Work on Methodology
Work on results and discussions
Work on Appendix A
Work on Final Presentation

C. Flow Chart


ReNova Flow Chart
Go Over Proposal with Liason
Study EA internal fly ash information
Obtain coal fly ash information
Identify possible products
Find Import data for products
Contact producers and get product information
Find use data in Puerto Rico
Start Feasibility Analysis

D. *Interview Question and Faxes*

In this appendix, prepared questions for interviews and faxes to companies asking for specific information are included.

Questions for Concrete Manufacturers in Puerto Rico

1. What do you currently use for aggregate material?
2. Where does this material come from? Is it imported?
3. Where does your cement come from? Do you make it or is it bought?
4. What is the concrete used for (i.e. Houses, roads, seawalls, hotels, sidewalks).
5. How much concrete do you sell yearly? What percentage of this is aggregate?
6. How much concrete would you expect to sell from the RENOVA project site?
7. What are the costs of the aggregates you use? Would cutting costs here be important?
8. What overall chemical properties make a good aggregate? What chemical properties make a bad aggregate?
9. Give them chemical makeup of MSW fly ash. Does anything on this sheet make you more or less able to use MSW fly ash?
10. Do you do research and development?
11. Would it be necessary to do testing on the fly ash before using it as an aggregate? Would you be willing/able to do this research?
12. Would you be willing to try MSW fly ash for use in your aggregate if it was offered at a lower price than current aggregate?
13. If affirmative – about how much MSW fly ash would you approximate that you would use per day or year?

Questions for the Environmental Quality Board

1. How are landfills currently taken care of?
2. What are you using for landfill covers and liners? Are you covering them everyday?
3. What materials are being used or will be used as the cover/liner?
4. What requirements are there for landfill liner?
5. What are you using to cap the San Juan Municipal Landfill?
6. How much material is used each day/week for lining or covering landfills in PR?
7. How much does the material cost that is being used?

Questions for Clay Walton of Energy Answers

1. There are some products here in the office, such as tile, composite wood (recycled plastic) concrete blocks (boiler aggregate not fly ash) Where did these items come from?
2. Who made them and what kind of testing was done to determine if using fly ash for these products was feasible?
3. Are there plans for any of these products to be produced on a larger scale at this point?
4. In general what kind of problems have you had using the fly ash?
5. Have you found the fly ash to be hazardous in any way?
6. Are there certain materials that fly ash should not come in contact with?
7. Any information you might have on the composition of the fly ash would be helpful.
8. Do you know anything about environmental regulations on fly ash in other countries? Japan?

Questions for the Solid Waste Management Authority

1. Tell them we are an Independent agency doing research on fly ash uses for the RENOVA project.
2. What are your current recycling plans?
3. How are landfills currently taken care of? Are they in compliance with the EPA?
4. What are you using for landfill covers and liners? Are you covering them everyday?
5. What materials are being used as the cover/liner?
6. What properties of the material make it good for a cover?
7. How much material is used each day/week for lining or covering landfills in PR?
8. How much does the material cost that is being used?
9. Would you be interested in using a fly ash material as landfill cover as a cheap alternative to the current cover materials?
10. If not why not? What factors make fly ash a bad candidate for cover?

Fax to Landfill Operators; BFI, LM Waste, Waste Management

We are students from Worcester Polytechnic Institute in Massachusetts, U.S. doing a research project on the uses of waste incinerator fly ash in Puerto Rico. This research is primarily a first order analysis of the uses of fly ash and the associated costs. One of the uses we have come across is the using fly ash as a landfill liner. Fly ash has

From: O'Malley Barton, Carlos Perez, Vinayak Rao

RE: Municipal Solid Waste Fly Ash Use in Concrete

On Friday, March 28, 2002, we met to discuss using Municipal Solid Waste (MSW) fly ash as an aggregate in concrete. We reviewed what Grupo Carmelo currently uses for aggregate, how much aggregate is used, and the possibility of replacing some of it with MSW fly ash. In addition to using MSW fly ash as an aggregate for concrete blocks, the possibility of using it as an aggregate in asphalt or as a road base was mentioned. The composition of the fly ash caused minor concern as an aggregate due to its sulfur and chlorine content and its density. Determining the extent of the problems this composition might cause will require testing of the fly ash. Also, the cost of using fly ash versus current materials was addressed. The main cost of using the fly ash would be transportation costs, since the actually production of the fly ash would be a by-product of the waste-to-energy plant.

We would like to obtain some additional information from you at your earliest convenience. This would include the production costs of your current aggregate and a breakdown of percentages of the composition of your aggregate. The final piece of information we need is the reason that the sulfur content of the fly ash causes concern, we forgot to ask for this information during the meeting.

We will arrange to obtain a sample of the SEMASS fly ash as soon as possible. If you could give us the amount needed for testing as well as the procedure for submitting the materials to you or your lab, it would be greatly appreciated.

Memo of SWMA Meeting

Date: 4/30/02

To: Patrick Mahoney

Cc: Jaime Pabon, Jorge El-Kouri

From: O'Malley Barton, Carlos Perez, Vinayak Rao

RE: Municipal Solid Waste Fly Ash Use in Concrete

On Friday, April 5, 2002, we had the chance to talk with a Mr. Rivera at the SWMA executive offices in San Juan. It was our intention to obtain information on the landfill situation in Puerto Rico. In particular, we were interested in knowing if fly ash could be used as a landfill liner or cap and what materials are currently being used.

We were given some information which we were unaware of when trying to obtain answers to these questions. For one, Mr. Rivera explained to us that there were no plans in the next five to ten years to cap any landfill daily as required by the RCRA. Apparently, there is a loophole in the regulations that allow the landfills that were open before the passage of the RCRA bill to stay open until they reach their maximum capacity. When enough of the landfills have reached capacity, he told us that they would be reopening old landfills and lining and capping them according to the regulations. We did not quite understand what this meant by this. We assumed that they were going to been used as a component for landfill liner in the states and we would like to know some information on what is currently being used in Puerto Rico.

We would appreciate the following information, what material is being used as a landfill liner, which landfills are using them, are they being capped daily, how much it costs to cap and line the landfills, and what are the important factors in using a landfill liner. Also information on the cost to landfill a ton of trash as well as the cost of transporting trash on the island would be appreciated. Thank you for your time in this matter.

O'Malley Barton

Carlos Perez

Vinayak Rao

Fax to Vitrification Plants

We are students from Worcester Polytechnic Institute in Massachusetts, U.S. doing a research project on the uses of waste incinerator fly ash in Puerto Rico. This research is primarily a first order analysis of the uses of fly ash and the associated costs. One of the uses we have come across is vitrification technology. We have come across information about ScanArcs Vitroarc technology and would like to know a bit more about it.

The company we are doing this research for is Energy Answers Corporation. The waste to energy plant that they are proposing to build in Puerto Rico will produce 300 tons of fly ash per day. The WTE plant would use Refuse Derived Fuel method of incineration. The major components of fly ash would be about 40 % calcium and 20 % chlorine. We will be recommending to Energy Answers ways to use their MSW fly ash or dispose of it in a more environmentally friendly way. We would like to know approximately how much it would cost to build a VitroArc plant to vitrify fly ash. Also, we would like to know approximately how much it would cost per ton of ash to operate and how much electricity it would require. The solution we are looking for would have a capacity of more than 50 tons per day. We are looking for this information to give us a first order analysis of the costs associated with the vitrification process. Any general information you might have on approximate costs would help us immensely. If you have any other questions for us, please call us at 787-758-1899 in the U.S.A.

We greatly appreciate your help,
Carlos Perez
O'Malley Barton
Vinayak Rao

Memo to Grupo Carmelo

Date: 4/30/02

To: Melba Figueroa, Efrain Carreras

Cc: Jaime Pabon

reopen some of the landfills that had been closed in the mid-90's that weren't complying with RCRA at the time, but we aren't certain.

He also explained to us that the tipping fees for landfilling in Puerto Rico range from 40 to 65 dollars, which Jorge has said that estimate is much too high. Our last question about the landfill capping materials he did not know, and he referred us to the EQB to find out this information. One thing that we noted was that Mr. Rivera did not seem at all enthusiastic to help us and at times attempted to dodge our questions. He was unhelpful until we made it clear to him that we were university researchers doing an independent analysis of the problems associated with fly ash.

TO OMalley Barton
Carlos Perez
Vinayak Rao

Worchester Polytechnic Inst. in Massachusetts US

Assumptions:

VitroArc Plant 4 ton/hour
26000 tons per year on 5 shift operation
1 USD = 10 SEK
El consumption 950 kWh/ ton flyash

Investment cost 15 MUSD incl:
- Raw material feeding
-Thermal treatment
-Gas and Water treatment
- Energy recovery
-Utilities
-El.Power & Process Control
-Civil works

Cost of operation.

Variable cost	52	
Manpower* 27	30	
Capital	35	
TOT	117	USD/ton flyash

*Cost 32000 USD/ man year

Best regards
Borje Johansson

ScanArc Plasma Technologies

E. Letter to Request Interviews

RENOVA

RECUPERANDO RECURSOS

GENERANDO ENERGIA

RENOVANDO EL AMBIENTE

March 21, 2002

Mr. Federico F. Sánchez
President Interlink

Dear Mr. Sánchez:

In addition to my duties as Director of Conserva el Encanto, I have taken over the position of liaison between University researchers and Energy Answers of Puerto Rico. We are currently working with students from Worcester Polytechnic Institute in Massachusetts (Interdisciplinary and Global Studies Division) on possible uses for MSW fly ash in Puerto Rico.

The students have been researching this for a couple of weeks and are now in our office ready to go forward with the project. As you know, MSW fly ash is the only aspect of the RENOVA project that we still need to address to make this technology one of "zero disposal". One of the possible uses of the fly ash, proven to work in other countries, is to use it in the production of concrete. The students are now ready to interview some of the key players in this arena and we were hopeful that you could provide some assistance in getting us a meeting with somebody from PR Cement and Bloques Carmelo. This person should preferably be someone that is familiar with the composition and production of concrete (see attached student questions). If it is possible, a tour of the plant would also be of great help in their learning/research experience.

At this point we are willing to meet with them ASAP considering the conference that will be held at Caguas at the end of April. Having an economic/environmental/social solution and use for the MSW fly ash will make the RENOVA project even more attractive for the government and other partners. We appreciate any help that you could give us. If you need to contact me you may do so at our office 787-758-1899 or at my cell phone 787-319-2352.

Sincerely,

Jaime Pabón

cc. Patrick Mahoney, Energy Answers

Villas de San Francisco Plaza
Ave. De Diego # 87 Suite 114
San Juan, Puerto Rico 00927
(787) 758-1899
(787) 758-2272 • Fax

RECOVERING RESOURCES • GENERATING ENERGY • RENOVATING THE EARTH

F. Summary of Fly Ash Differences (Fax from Larry Beaumont)

ATT: LARRY BEAUME

What Did We Learn About the Difference Between Semass Fly Ash & Boiler Aggregate?

In the Ecomat lumber system the BA and grd BA are very useful fillers. These appear to be technically and economically ready to exploit in lumber. What is the problem with the FA? The difference between BA and FA is huge. The chart below summarizes the differences between the two, and hopefully leads to an understanding of the difference, and eventually, how to make the FA more acceptable in the lumber system.

Since BA works close to the way coal ash works - and Semass FA does not -- should give us a clue. There are many differences between coal FA and Semass FA. Which are important, which govern the performance and loadings in the Ecomat resin system?

Certainly the bulk density is a part of this mystery. But what causes this is not defined, although the fuzzy ash particles in the Semass FA is part of this. The differences in chlorine, sulfur and silicon content are also clear, as is the high level of soluble salts in Semass FA, but what is the relative influence, and how do they cause this problem?

Summary of Ash Differences

Both the Coal and Boiler Aggregate Ashes work well in the Lumber System

Measured Property	Semass Fly Ash	Coal Fly Ash (Mohave)	Semass Boiler Aggregate
Bulk Density, pcf	36	77	
Density in Acetone	136	131	
Microscopic Appearance	Fuzzy shapes & some spheres	Clean, shiny spheres	Clean glassy chunks
pH	11.8	10.6	
Carbon (LOI)		0.6%	
Calcium (CaO)	40%	10%	24%
Chlorine	21%	(<5%)	1%
Sulfur (SO3)	5%	0.8%	2.8%
Silicon (SiO2)	10%	55%	31%
Aluminum (Al2O3)	8%	22%	11%
Water Content @ Equilibrium/Ambient	2.0%	0.1%	0.2%
Water Pick-up in Boards, 45% Ash	7.2%	1.5%	----
Main particle size, microns	53-63	45-38	4000
Max. Loading in Polyol	49%	75%	74%
Soluble Salts?	~30%	No	No?
Sintering During Burn?	No	Some?	No

G. Road Base Specifications from the HTA

301-1 DESCRIPTION

301-1.01 Scope - This work shall consist of furnishing, placing and compacting a subbase course on a prepared subgrade in accordance with these specifications and in reasonably close conformity with the lines, grades, thicknesses and typical sections shown on the plans or established by the Engineer.

301-2 MATERIALS

301-2.01 Materials Requirements - Material for subbase courses shall be a **well graded granular soil or soil-aggregate mixture** classifiable as an A-1 or **A-2-4 material as per AASHTO M 145. The subbase material shall be free of any stone or rock fragments measuring over** fifteen (15) centimeters in **their greatest dimension.** It shall also be free from vegetable matter, **balls or lumps** of clay and other deleterious substances; and shall be of such nature and gradation that it can be **compacted readily to form a firm, stable subbase that can be fine graded** to the required tolerances.

301-2.02 Sampling and Testing -

a. The contractor shall advise the Engineer as to the exact location of the sources of the materials that he proposes to provide, at least four weeks in advance of their actual use, so that samples may be obtained and tested for conformance with this specification. No material shall be hauled to the roadway until the Engineer has approved its source.

b. Throughout the construction operations, the Engineer will take random samples of the materials in place for testing. **The Contractor shall have available for the use of the Engineer in taking samples of in-place material, a powered 4 in. auger capable of sampling** to depths of **at least 1.20 meters (4 feet) in accordance with the procedures of AASHTO T-203.**

c. Sampling will be performed as follows:

(1) The subbase course will be divided into 400-square meter segments. One random sample will be taken from each area segment and the test results of this sample taken as representative of the entire segment.

(2) To avoid contamination of the sample by subgrade material, the boring will extend no deeper than 10 centimeters above the bottom of the subbase course.

(3) If the sample of an area segment fails to meet the specification requirements, two additional random samples will be taken for testing. If these also fail, the reduction in unit price provisions determined as specified under Article 301-5.01 will be applied using the average value of the three (3) samples.

(4) The Contractor may request further resampling and retesting at his expense in which case the samples will be increased to four per area segment. The price reduction formula will be applied using the average value of all the samples taken.

d. **When the plasticity index (PI) of the in-place material exceeds 10 but is not over 15, the material may be accepted** at the discretion of the Engineer but subject to a reduction in unit **price determined in accordance with the procedure included under Section 301-5 of this specification. All in-place material with a PI in excess of 15 shall be removed and replaced with material meeting the specification requirements.**

e. **When the fraction of the in-place material passing** the 200 sieve **exceeds 35% but is not over 40%, the material may be accepted at the discretion of the Engineer but subject to a reduction in unit price determined in accordance with the procedure included under Section 301-5 of this specification. All in-place material with a fraction passing the 200 sieve in excess of 40 shall be removed and replaced with material meeting the specification requirements.**

f. The reduction in unit price shall be applicable to the volume of in-place material that is determined to be outside the specification requirements as to PI or fraction passing the 200 sieve, or both. The Contractor may elect to remove any deficient material and replace it with material meeting the specification requirements at the Contractor's expense.

301-2.03 **On Site Material** - When the contract calls for a pay item of subbase course under this specification and material meeting the requirements of this specification is available within the roadway areas, the Contractor may obtain it from this source subject to the provisions of Article 104.08 of the General Provisions.

301-3 CONSTRUCTION REQUIREMENTS

301-3.01 Placing and Spreading -

a. The material for subbase shall be delivered to the roadbed as a uniform mixture and shall be deposited in layers or windrows. Segregation shall be avoided and the material shall be free from pockets of coarse or fine material.

b. **The layers or windrows of subbase material shall be shaped to such thickness that after watering, if required, and compacting, the completed subbase shall be in reasonably close conformity to the required grade, thickness and cross section and within the specified tolerances.**

c. The subbase course material shall be placed and spread on the repared subgrade and compacted in layers not exceeding 30 centimeters in ose thickness or as shown on the plans. The maximum loose layer thick-ess in confined areas, as defined by the Engineer, shall be 20 centi-eters. When more than one layer is required, each layer shall be shaped d compacted before the succeeding layer is placed.

d. No subbase course will be allowed to be placed on the subgrade til the latter is reasonably dry, graded as required and accepted by the gineer.

e. If after a layer of subbase course material has been placed and read, it is found to lack reasonable uniformity, it shall be thoroughly ade-mixed to its full depth by alternately blading the entire layer to e center and back to the edges of the road. Traveling mixers may be sed in lieu of blade-mixing. If necessary, the material shall be watered ring mixing to attain the required moisture content for proper compac-ion. When uniform, the material shall again be spread and shaped to the quired cross section.

)1-3.02 Compaction -

a. All subbase courses shall be constructed with moisture and den-ity control.

b. All subbase material shall be compacted to not less than 95% of ximum density which shall by determined by AASHTO T 180 Method D. Cor-ction for coarse particles in the material being tested using AASHTO T 4 will be made when appropriate. However, when the subbase material ing furnished is such as to retain 67% or more in the #4 sieve, then the mpaction and density requirements shall be as specified for aggregate se course in Article 304-3.04 of Specification 304 - Aggregate Base urse, and paragraphs c., d. and e. below will not apply.

c. The subbase material shall have the moisture content required to tain the specified density after compaction. The Contractor shall be sponsible for determining the required moisture content and for control-ing it within the proper limits as the work progresses. When water must e added to the material, it may be added on the lift or at the borrow it. However, when added on the lift, it shall be applied with an proved pressure distributor. Water added shall be thoroughly incor-orated into the material to attain uniform distribution.

d. When the moisture content of the material in a lift exceeds the quired amount, the compaction shall be deferred until the material has ried to the proper amount. If necessary, the material shall be manipu-ated and aerated to attain the required moisture content.

e. The Engineer will, during the progress of the work, make such ests as he considers necessary to ascertain the density of each compacted ayer. Tests will be made in accordance with AASHTO T 191, T 204, T 205, r T 238. If the density tests indicate that the obtained density is less han the required density, additional rolling, and moisture control if

necessary, shall be performed by the Contractor until the specified density is obtained.

f. Any irregularities or depressions that develop under rolling shall be corrected by loosening the material at these places and adding or removing material until the surface is smooth and uniform.

g. Along walls, and at all places not accessible to the roller, the subbase course material shall be tamped thoroughly with mechanical tampers or compactors.

h. Compaction and moisture control, whether adding or removing moisture, by whatever methods are used, shall be an obligation of the Contractor under this specification with the cost included in the contract unit price for the subbase course.

301-3.03 Proof Rolling - When called for in the contract and immediately prior to the final trimming of the subbase surface, all areas of subbase surface within the roadway limits that are indicated on the plans or ordered by the Engineer shall be proofrolled according to the requirements of Article 203-3.06 of Specification 203 - Excavation and Embankment.

301-3.04 Testing of the Finished Surface -

a. After compaction, and proof rolling when included, the finished subbase surface shall conform so nearly to that required by the plans that it will nowhere vary by more than 1.5 centimeters when tested with a 3-meter straight edge applied parallel to, and perpendicular to, the center line of the road. The Contractor shall provide a light weight aluminum straight edge for this testing as part of his obligations under this pay item. This testing tool will remain the property of the contractor.

b. The finished surface shall be rolled as necessary to maintain a smooth, even, uniformly compacted subbase until any pavement or treatment that may be provided for in the same contract is placed thereon.

c. Such portions of the completed subbase course which are defective in finish, density or composition, or not complying in all respects to the requirements of these specifications and of the plans shall be corrected at the Contractor's expense, including any contamination or damage caused by the Contractor's operations or equipment.

301-4 METHOD OF MEASUREMENT

301-4.01 Subbase Course - The quantity of subbase course to be paid shall be the number of cubic meters placed, compacted and accepted in final position computed from the payment lines shown on the plans or, where changes have been ordered, from the payment lines established by the Engineer.

304-3 CONSTRUCTION REQUIREMENTS

304-3.01 Preparation of Surface -

a. The subgrade or subbase on which the base course is to be placed shall have been completed and the surface finished in accordance with the requirements of Specifications 203, 204 or 301 as applicable. Immediately before placing base course material, the subgrade or subbase shall be checked as to conformity with grade and cross section.

b. No base course shall be placed on the subgrade or subbase unless it is reasonably dry and free from impounded water, and the surface finish accepted by the Engineer.

304-3.02 Placing -

a. The base course material shall be spread on the prepared surface and compacted in layers not exceeding 15 centimeters in thickness. When more than one layer is required, each layer shall be shaped and compacted before the succeeding layer is placed.

b. Placing shall be from spreader boxes or from vehicles equipped to distribute the material in a uniform layer or windrow without segregation of size. The layer or windrow shall be of such size that when spread and compacted, the layer shall have the required thickness. Spreading may be by motor grader.

304-3.03 Mixing and Spreading -

a. If after the layer of base course material has been placed and spread as indicated above, it is found that it is not uniform, it shall be thoroughly mixed to its full depth by means of power graders, traveling mixers or other mixing equipment approved by the Engineer. During the mixing, water shall be added in the amount necessary to provide the optimum moisture content for compaction.

b. When mixed, the material shall be spread smoothly to a uniform thickness and in the case of the top course, to the cross section shown on the plans. Spreading and compaction shall be completed within 24 hours after mixing.

c. Filler material, when added on the roadbed, shall be thoroughly mixed into the aggregate layer as in paragraph a. above.

304-3.04 Compaction

a. Immediately following spreading and smoothing, each layer shall be compacted to its full width. Compaction effort shall continue until the base aggregate material reaches a density of at least 83 percent of its solid volume density. The solid volume density of the aggregate shall

be computed on the basis of its bulk specific gravity as determined by AASHTO T 84 and T 85, and the dry weight of the aggregate. The in-place density of the compacted aggregate base shall be determined by the use of AASHTO T 191, T 205 or T 238.

b. The surface of each layer shall be maintained during the compaction operations in such a manner that a uniform texture is produced and the aggregate firmly keyed. If required, water shall be uniformly sprinkled over the base materials during compaction in the amount necessary for proper consolidation.

c. Any irregularities or depressions that develop under rolling shall be corrected by loosening the material at these places and adding or removing material until the surface is smooth and uniform.

d. Along curbs, headers, and walls, and at all places not accessible to the roller, the base course material shall be thoroughly compacted with mechanical tampers.

304-3.05 Thickness Requirements -

a. The thickness of the completed base course shall not vary by more than 1.25 centimeters from that called for in the plans. Test holes shall be dug, at the discretion of the Engineer, at the center and sides of the base course to determine if its compacted thickness is within the allowed tolerance. Any areas not within the allowable tolerance shall be corrected by removing or adding material as necessary and shaping and compacting it as specified.

b. The Contractor shall refill the test holes in such manner as to leave the finished surface compacted, smooth and uniform, to the satisfaction of the Engineer.

304-3.06 Surface Finish Requirements

a. The finished surface of the base course shall conform so nearly to that required by the plans that it will nowhere vary by more than 1.25 cm. when tested with a 3-meter straightedge. Straightedges shall be furnished by the Contractor at no extra cost and shall remain the property of the Contractor.

b. Any areas where the surface variation exceeds the 1.25 centimeter tolerance shall be reworked by the Contractor until the variation falls within this limit.

c. The finished surface shall be rolled as necessary to maintain a smooth, even, uniformly compacted base until any surface or treatment that may be provided for in the same contract is placed thereon.

304-4 METHOD OF MEASUREMENT

304-4.01 Aggregate base course, including filler, will be measured by the cubic meter of material in place in the completed course, computed on the basis of the thickness shown on the plans. No additional thickness over that shown on the plans will be considered for measurement.

304-5 BASIS OF PAYMENT

304-5.01 The volume of compacted base course material, determined as provided above, placed, compacted and accepted will be paid for at the contract unit price per cubic meter of the class and grading called for in the contract documents. Such price and payment will be full compensation for furnishing and placing all materials, including any necessary filler and water, and for all labor, equipment, tools and incidentals necessary to complete the work as specified.

304-5.02 Payment will be made under:

Pay Item	Pay Unit
Aggregate Base Course..............................	Cubic Meter

305-1 DESCRIPTION

305-1.01 Scope - This work shall consist of constructing a lean concrete base in accordance with these specifications and in conformity with the lines, grades, dimensions and typical sections shown on the plans or established by the Engineer.

305-2 MATERIALS

305-2.01 Lean concrete shall consist of a mixture of portland cement, fine and coarse aggregates, and water. Air entraining, water reducing, set retarding or superplasticizer chemical admixtures may be added at the option of the contractor but subject to the prior approval of the Engineer.

305-2.02 The following materials shall meet the applicable requirements of the specifications indicated:

Material	Specification
Portland Cement....................................	701-1
Fine Aggregate.....................................	703-1
Curing Materials...................................	711-1
Air Entraining Admixtures..........................	711-2
Chemical Admixtures................................	711-3
Water..	712-1

305-2.03 **Coarse Aggregate** - Shall conform to the requirements of Article 703-2 of Specification 703 - Aggregates but subject to the following:

a. Aggregate shall be of designated sizes 2" to 1", 1 1/2" to 3/4" or 1" to No. 4, at the option of the Contractor, shown in Table 703-2 but the grading distributions shown in this table are only suggested and not mandatory, provided the limiting maximum and minimum size values are complied with. However, once a designated size and grading is selected, it shall not be changed without the Engineer's written approval.

b. The maximum percentage of wear when tested as per AASHTO T 96 shall not exceed 45.

c. The minimum polishing value requirement does not apply.

305-2.04 **Proportioning of Concrete** - The Contractor shall design the lean concrete mix in accordance with all the applicable requirements of Article 501-2.07 of Specification 501 - Portland Cement Concrete Pavement except that it shall provide for a minimum compressive strength of 1000 psi at 28 days.

b. Suggested gradings are shown in Table 703-2.

c. Deleterious substances shall not exceed the limits of Class Designation B (Table 1 in M 80) for architectural concrete and bridge decks, of Class Designation C for concrete pavements and sidewalks, and of Class Designation D for concrete not exposed to the weather. The sodium sulfate soundness requirements do not apply.

d. The coarse aggregate in Portland Cement concrete mixes for pavements, bridge decks and any other concrete that will serve as a surface for vehicular traffic shall have a minimum polishing value of 48% as determined by ASTM D 3319.

703-3 Aggregates for Hot Plant-Mix Bituminous Pavement

703-3.01 Aggregates for hot plant-mix bituminous pavements shall conform to the grading requirements shown in Table 703-3 for each specified mix.

703-3.02 Coarse aggregate (not passing the No. 8 sieve) shall be crushed stone or crushed gravel meeting the following requirements:

a. It shall be free from soft and disintegrated pieces, clay, organic or other deleterious matter.

b. The maximum percentage of wear when tested as per AASHTO T 96 shall not exceed 40.

c. Aggregate for surface courses shall have a minimum polishing value of 48% as determined by ASTM D 3319.

d. The coarse aggregate shall have the following minimum percentages of fractured faces:

Fractured Faces	Course Designation Surface	Leveling	Base
One face	75	50	50

e. Maximum number of pieces with elongated faces shall not exceed 15%. An elongated face is one where the ratio of the longest dimension to the shortest dimension exceeds 5.

f. The grading of the coarse aggregate shall be such that when it is combined with other required aggregate fractions in proper proportion, the resultant mixture will meet the gradation required by the composition of the particular mix specified in the contract.

TABLE 703-3

AGGREGATE GRADINGS FOR HOT PLANT-MIX BITUMINOUS PAVEMENTS

Sieve Designation	Percentages by Weight Passing Square Mesh Sieves (AASHTO T-27) Base Courses		Leveling Courses		Surface Course
	B-1	B-2	L-1	L-2	S-1
1-1/2"	100	-	100	-	-
1"	80-100	-	80-100	-	-
3/4"	70-90	100	70-90	100	100
1/2"	-	80-100	-	80-100	85-100
3/8"	55-75	70-90	55-75	70-90	70-90
No. 4	45-62	50-70	45-62	50-70	50-70
No. 8	35-50	35-50	35-50	35-50	35-50
No. 30	19-30	18-29	19-30	18-29	18-29
No. 50	13-23	13-23	13-23	13-23	13-23
No. 100	7-15	8-16	7-15	8-16	8-16
No. 200	0-8	4-10	0-8	4-10	4-10
Recommended Minimum Compacted Depth in Centimeters for each Individual Course:					
	7.5 - 10.0	3.8 - 7.5	7.5 - 10.0	2.5 - 5.0	5.0

703-3.03 Fine aggregate (passing the No. 8 sieve) shall consist of natural sand, stone screenings, or a combination thereof and shall conform to the quality requirements of AASHTO M 29 except that the soundness test is not required. It shall be of such gradation that when combined with other required aggregate fractions in proper proportion, the resultant mixture will meet the gradation requirements of the particular mix specified in the contract.

703-3.04 Mineral filler for bituminous paving mixtures shall conform to the requirements of AASHTO M 17.

703-4 Aggregate for Base Course

703-4.01 Aggregate for untreated aggregate base course shall consist of hard durable particles or fragments of crushed stone or crushed or natural gravel conforming to the grading requirements shown in Table 703-4 for the grading class specified in the contract and meeting the following requirements:

a. Material shall be free from lumps of clay, vegetable matter or other objectionable matter.

b. The coarse aggregate not passing the No. 8 sieve shall have a percentage of wear, when tested by AASHTO T 96, of not more than 45.

c. Maximum number of pieces with elongated faces shall not exceed 15%. Elongated faces are defined in paragraph 703-3.02 e.

d. The fraction passing the No. 200 sieve shall not be greater than two-thirds (2/3) of the fraction passing the No. 40 sieve.

e. The fraction passing the No. 40 sieve shall have a liquid limit not greater than 25 and a plasticity index not greater than 6.

f. When crushed aggregate is specified, not less than 50 percent by weight of the particles retained in the No. 4 sieve shall have at lease one fractured face.

TABLE 703-4

GRADINGS FOR AGGREGATE BASE COURSE
(Percentage by Weight Passing Square Mesh Sieve)

Sieve Designation	Grading Class		
	A	B	C
2"	100	-	-
1 1/2"	-	100	-
1"	50 - 80	-	100
1/2"	-	40 - 75	-
No. 4	20 - 50	30 - 60	40 - 75
No. 10	-	-	25 - 60
No. 200	5 - 12	5 - 12	5 - 12

703-5 Bed Course Material

703-5.01 Bed course material for sidewalks, curbing, and paved waterways shall consist of sand, gravel, crushed stone or other approved material of such gradation that all particles will pass through a sieve having 1/2 inch square openings and not more than 12 per cent shall pass a No. 200 sieve.

703-5.02 Bed course material for slope paving shall be a porous material consisting of sand, gravel, crushed stone or other approved free-draining material. This material shall be uniformly graded and of such size that 100 per cent of the material will pass through a sieve having 1 1/2 inch square openings.

703-6 Aggregates for Bituminous Surface Treatments

703-6.01 Aggregates for bituminous surface treatments, including seal coats, shall consist of crushed stone on crushed gravel conforming to the grading requirements shown on Table 703-5 for each specified grading class.

703-6.02 The coarse portion of the aggregate not passing the No. 8 sieve shall meet the following requirements:

a. It shall be free from soft and disintegrated pieces, clay, organic material and other deleterious material.

b. A minimum of 75 percent of the material shall have at least one fractured face.

c. The maximum number of pieces with elongated faces shall not exceed 15%. Elongated faces are defined in paragraph 703-3.02 e.

d. The maximum percentage of wear when tested as per AASHTO T 96 shall not exceed 40.

e. Aggregate for seal coats and for the top layer of other bituminous surface treatments shall have a minimum polishing value of 48% as determined by ASTM D 3319.

f. The aggregate shall have a retained bituminous film cover of no less than 95 percent when tested for coating and stripping under AASHTO T 182. Subject to approval by the Authority, a chemical additive may be used to aid in meeting this requirement.

703-6.03 Sand and fine screenings shall consist of natural sand, stone screenings, or a combination thereof and shall conform to the quality requirements of AASHTO M 29 except that the soundness test is not required. It shall be of such gradation that when combined with other required aggregate fractions in proper proportion, the resultant mixture will meet the gradation requirements of the particular class specified in the contract.

703-7 Blotter Material

703-7.01 Blotter material shall be non-plastic rock screening or sand conforming to the gradation requirements of Size No. 10 of AASHTO M 43, and free from organic matter, clay or other deleterious material.

TABLE 703-5

AGGREGATE GRADINGS FOR BITUMINOUS SURFACE TREATMENTS
(Percentage by Weight Passing Square Mesh Sieve)

Sieve Designation (AASHTO T 27)	Grading Class			
	A	B	C	D
1"	100	-	-	-
3/4"	90-100	100	-	-
1/2"	0- 35	90-100	100	-
3/8"	0- 12	0- 35	85-100	100
No. 4	-	0- 12	0-35	85-100
No. 8	-	-	0- 8	0- 20
No. 200	0- 1	0- 1	0- 1	0- 1

705-1 Concrete Joint Fillers

705-1.01 Poured joint sealants shall be of the types called for in the contract documents and shall conform to the following requirements:

a. Hot poured elastic type shall conform to the requirements of AASHTO M 173.

b. Hot-poured, one-component, elastomeric type shall conform to AASHTO M 282.

c. Silicone joint sealant shall be furnished in a one part silicone formulation meeting the requirements specified in Table 705-1. Acid cure sealants are not acceptable. If required by the manufacturer, a primer for bonding the sealant to the concrete shall be used.

d. The Contractor shall submit certified test reports from the manufacturer for each lot of sealant material furnished to a project. These reports shall indicate the results of tests performed as required by this specification and shall include a certification that the material conforms with this specification.

705-1.02 Preformed expansion joint fillers shall be of the types called for in the contract documents and shall conform to the following requirements:

a. Bituminous type shall conform to AASHTO M 33 (ASTM D 994).

b. Sponge rubber and cork types shall conform to AASHTO M 153 (ASTM D 1752).

c. Non extruding resilient types shall conform to AASHTO M 213 (ASTM D 1751).

d. Elastic joint seals of the elastomeric open-cell compression type shall conform to AASHTO M 220.

e. The filler for each joint shall be furnished in a single piece for the full depth and width required unless otherwise authorized by the Engineer. When the use of more than one piece is authorized for a joint, the abutting ends shall be fastened securely and held accurately to shape by stapling or other positive fastening method satisfactory to the Engineer. The filler shall be punched to admit dowels where called for on the plans.

705-2 Pipe Joint Mortar

705-2.01 Pipe joint mortar shall consist of one part portland cement and two parts approved sand with water added as necessary to obtain the required consistency. The mortar shall be used within 30 minutes after its preparation.

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401-1 DESCRIPTION

401-1.01 Scope -

a. This work shall consist of constructing one or more courses of hot plant-mix bituminous pavement on a prepared foundation in accordance with these specifications, and in conformance with the lines, grades, thickness and typical cross sections shown on the plans or established by the Engineer. Courses will be identified as base, leveling and surface.

b. The work shall also include the application of any required tack and prime coats as specified in Specifications 407 and 408 respectively.

401-2 MATERIALS

401-2.01 Bituminous Materials - The bituminous material shall be asphalt cement meeting the requirements of Section 702-1 of Specification 702 - Bituminous Materials. Asphalt cement shall be viscosity grade AC-20 or AC-30, at the option of the Contractor, unless otherwise specified in the contract documents. The Contractor shall submit temperature/viscosity charts, on the asphalt cements to be used.

401-2.02 Aggregates - Aggregates, including mineral filler, shall meet the requirements of Section 703-3 of Specification 703 - Aggregates. **The job mix formula plus and minus the gradation tolerances must remain within the overall gradation requirements of Section 703-3. If the job mix plus or minus the gradation tolerances exceed the Section 703-3 limits, then the Section 703-3 limit shall constitute the absolute permitted limit.**

401-2.03 Hydrated Lime - Hydrated lime shall meet the requirements of Section 712-3 of Specification 712 - Miscellaneous Materials. Contractor shall submit certified laboratory reports on tests of the hydrated lime to be used showing its compliance with the specifications.

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401-2.04 Other Additives - Anti-stripping agents, when required, may be liquid additives to the asphalt cement or pulverent solids such as fly ash, hydrated lime added to the aggregates. The proposed additives shall be submitted to the Authority for approval prior to use.

401-2.05 Composition of Mixtures -

a. General - The bituminous plant mix shall consist of a mixture of aggregates, asphalt cement, and Anti-stripping additives, if required. The various mixes are as indicated below. The number in parenthesis refers to the applicable number of hammer blows to be used in the Marshall Test (AASHTO T 245) for each mix as called for in the contract documents. If the number of hammer blows is not specified, a value of 75 shall be used for all mixes on primary and secondary roads, and a value of 50 for municipal and tertiary roads.

(1) Base Courses - B-1 (50 or 75), B-2 (50 or 75)
(2) Leveling Courses - L-1 (50 or 75), L-2 (50 or 75)
(3) Surface Course - S-1 (50 or 75), S-2 (50 or 75)

b. Job-Mix Formula - The Contractor shall submit in writing for the Engineer's approval, at least three weeks in advance of the date he intends to start paving operations, a job-mix formula for each type of mixture to be used in the project. Each job-mix formula shall be supported by certified laboratory test data and the design charts used. The submission shall also identify the proposed sources of the asphalt cement, aggregates and the specific additives, if any, to be used. When requested by the Authority, the Contractor shall submit samples of any of the materials proposed for use in the mix for checking the mix design. The three-week lead requirement may be waived where the Contractor proposes to use a job-mix and mix components which have been previously approved by the Authority. The submittal shall show the compliance of the proposed job-mix formula with the requirements specified below.

c. Mix Requirements - Each mix shall be designed according to the Marshall Mix Design Method as described in the Asphalt

Institute Manual MS-2 and shall meet the following requirements:

(1) Stability as determined by AASHTO T 245 - 1200 lbs. minimum for 50 blows, 1500 lbs. minimum for 75 blows, and 3500 lbs. maximum for all mixes except that for the B-1 and L-1 mixes the maximum shall be 4500 lbs. For the purposes of this specification, the last sentence of Section 1.1 of AASHTO T 245 shall be disregarded and the Marshall Test will be applicable to all mixes (B-1, B-2, L-1, L-2, S-1, S-2) regardless of maximum aggregate size specified.

(2) Flow, 0.01 inch (25 mm) as per AASHTO T 245 - 8 minimum to 16 maximum.

(3) Residual stability as determined by Specification 719 - 75% minimum. If the mix fails to meet this residual stability requirement, the aggregate source shall be changed or hydrated lime, or other anti-stripping agent, shall be added to attain the 75% requirement.

(4) Percent air voids in the mix as determined by AASHTO T 166, T 209 and T 269 - 3% minimum to 8% maximum for B-1 and L-1 mixes, and 3% minimum to 5% maximum for other mixes.

(5) Voids in the mineral aggregate (VMA) as determined by the Asphalt Institute Method shall be as follows:

Nominal Maximum Size of Aggregate in Mix (inches)	Minimum Voids in Percent
1/2	15
3/4	14
1	13
1 1/2	12

(6) Dust-asphalt ratio, computed by dividing the percentage of material passing the 200 sieve by the percent of asphalt cement in the mix, both determined from extraction tests made on mix samples - 1.2 maximum.

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(7) Mixing temperature - the temperature at which the asphalt will have a viscosity of 170 ± 20 Cs as determined from the temperature/ viscosity chart for the asphalt to be used. **This mixing temperature will be for laboratory use only.**

(8) Compacting Temperature - the temperature at which asphalt will have attained a viscosity of 280 ± 30 Cs. **This compacting temperature will be for laboratory use only.**

d. Mix Values - Each job-mix formula submitted shall propose definite values for:

(1) Single percentage of aggregates passing each required sieve size.

(2) Single percentage of asphalt cement to be added based on total weight of the mixture.

(3) The kind and percentage of additives to be used, if any.

(4) The kind and percentage of mineral filler to be used, if any.

(5) The plant mixing temperature and the temperature at which the mixture is to be delivered at the point of placement.

(6) The laboratory density of the bituminous mixture.

e. Mix Tolerances - After the job-mix formula is approved, all mixtures furnished for the project shall conform to the following ranges of allowable deviations from target values:

(1) Aggregate passing the 3/4", 1/2" or 3/8"... ± 5%

(2) Aggregate passing the No. 4 sieve .... ± 5%

(3) Aggregate passing the No. 30 sieve .... ± 4%

(4) Aggregate passing the No. 100 sieve .... ± 3%

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(5) Aggregate passing the No. 200 sieve .... ± 2%

(6) Amount of asphalt cement .... ± 0.4%

(7) Mixing temperature .... ± 20°F

f. Mix Changes - Should a change in sources of materials occur or be proposed, or should a job-mix formula prove unsatisfactory as determined by the Engineer, a new job-mix formula shall be developed and submitted by the Contractor for approval prior to production and use. **Acceptance of any tonnage of bituminous mix produced under an approved job mix is subject to appropriate behavior of the mix in the field. Failure of the approved mix to exhibit appropriate behavior in the field will be cause for its rejection.**

401-2.06 Sampling and Testing -

a. All sampling and testing will be performed by the Authority, **except as noted below.** Samples will remain in the custody of the Authority at all times. The Contractor or his authorized representative may be present, if so desired, when these sampling and testing operations are being performed. All testing will be done at a laboratory of the Authority. However, the Authority may, at its discretion, perform the testing at the producer's plant laboratory provided it meets the requirements specified in paragraph 401-2.06c below to the satisfaction of the Authority's Materials Testing Office.

b. The Contractor shall provide the following sampling and testing equipment **and their operators:**

(1) Coring machine and personnel at the project site to take full depth 4" diameter cores from the in-place bituminous pavement as required for testing and acceptance.

(2) Scoops, insulated working gloves, plain kraft paper, string or tape for the taking, packaging and transporting of samples of the mix taken at the plant for testing by the Authority

at its laboratory.

(3) A nuclear density meter, capable of measuring the density of compacted bituminous mixes and of limiting the depth of reading to the required layer thickness, an operator to use it, licensed if so required by the type of meter to be used. The meter shall be calibrated using standard blocks. This nuclear density meter will be used to check the density of the in-place compacted bituminous concrete when paving operations are in progress, to guide the Contractor on the adequacy of his compaction efforts. **The Authority may require the Contractor to demonstrate the calibration of the nuclear gage by using the Authority's standard blocks located at the Authority's Central Laboratory.**

c. The Contractor shall provide at the mixing plant, for quality control, a laboratory and all the equipment, tools, supplies and other apparatus required for sampling the mix, preparing specimens and testing for compliance of the mix being produced and its components with all the requirements specified in Article 401-2.05.

(1) The equipment listed below shall be provided as a minimum at the plant laboratory. This equipment shall comply with the requirements of the AASHTO or ASTM specification indicated, or be equal or similar to the specific equipment indicated.

(a) Automatic Bituminous Compactor - ASTM D 1559
(b) Specimen Ejector - ASTM D 1559
(c) Asphalt Centrifuge Extractor with Filter Disks- AASHTO T 164, **modified for the use of biodegradable solvents (terpene)**
(d) Oven (392 degrees F) - Soiltest L-5B
(e) Compaction Molds (4 inches) - ASTM D 1559
(f) Paper Disks for Compaction Molds - ASTM D 1559
(g) Water Bath - ASTM D-1559, **at its discretion the Authority may require the bath to be enclosed in an approved cage with padlock.**
(h) Marshall Test Set - AASHTO T 245
(i) Asphalt Flow Indicator - ASTM D 1559

(j) Triple Beam Scale (with clamp and rod support for specific gravity weighing) - AASHTO M 231
(k) 12 inch Standard Sieve Set (2 inch to #200) - ASTM E 11
(l) Wet Sieve Set - ASTM E 11
(m) Six Stainless Steel Pans - 20" X 12" X 4" deep
(n) Six Stainless Steel Mixing Bowls - 5 qts.
(o) Round Mouth Scoop
(p) Laboratory Tongs
(q) Heat Resistant Gloves
(r) Trowel
(s) Spatulas (10" L X 1 1/4" W)
(t) Calipers
(u) Laboratory Thermometers (temp. range 0 - 200 degrees F) - Soiltest G-171 or G-178
(v) Armored Thermometer (temp. range 0 - 500 degrees F) - Soiltest G-185 or G-191
(w) Aprons
(x) **Biodegradable solvents for asphalt (terpene)- AASHTO T 164**

(2) The plant laboratory testing equipment shall be calibrated and certified at least once a year by an independent laboratory qualified to perform such calibration.

(3) The plant laboratory shall be available to the Authority, upon request, to perform such tests on the mix being prepared, or being delivered to the project, as may be considered necessary by the Engineer.

d. The Authority will take, at its discretion, random samples of the asphalt cement and the aggregates at the plant, prior to and during mix production, to test for the compliance of these materials with their specifications requirements. If at any time the results of these random tests show a failure of the asphalt cement or the aggregates to meet the requirements of the specification, the Authority reserves the right to refuse further deliveries of mixes from the plant until the deficiencies have been corrected including the submission of a new job-mix formula, if required.

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e. Samples of the mix material being produced for delivery to the project will be taken by the Engineer at the plant for testing by the Authority for compliance with the aggregates grading and asphalt content and, at its discretion other specification requirements. The control unit for sampling, testing and acceptance purposes will be a lot which is defined as 300 tons of bituminous mix or fraction thereof. **At the discretion of the Authority, lot fractions may be incorporated into previous lots.** Samples will consist of 3 specimens of at least 2000 grams each taken at random from each lot. The Authority may, at its discretion, take samples of the mix being delivered to the project site for testing.

(1) The specimens will be taken from the delivery trucks and wrapped in kraft paper for delivery to the Authority's laboratory, as soon as possible, for testing by Authority personnel.

(2) Extraction tests will be performed on one of these specimens, selected at random, to determine aggregate sizes, percentage of asphalt in the mix and at the discretion of the Authority, the viscosity of the recovered asphalt. Testing for percentage of aggregate passing the No. 200 sieve will be at the discretion of the Authority.

(3) If the tested specimen meets all requirements of the specification, the other two specimens will be disposed of without testing.

(4) If the tested specimen fails in any of the specification requirements, the other two samples will be tested and the average results of all three specimens of the lot will be used for comparing with the specification requirements for acceptance purposes.

f. Ten (10) nuclear density readings will be taken at random locations for each 300-ton lot, or fraction thereof, of bituminous mix placed and compacted for testing for compliance with the density requirements. **The Contractor's nuclear gage operator and**

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the inspector will witness the nuclear gage readings and report and certify their veracity by signing the appropriate forms provided by the Authority for such purposes. This lot will not necessarily coincide with the 300-ton specified in paragraph "e" above. In addition, a core will be taken **by the Contractor under Authority's supervision** at one of the nuclear density readings location selected at random.

(1) The core shall be 4" in diameter and extend for the full depth of the pavement layer being tested. It shall not be taken until at least 72 hours have elapsed since placing the mix but not later than 144 hours after placing. **At his risk, the Contractor may elect to take cores prior to the minimum 72 hours period established.**

(2) The computed density of the core will be compared with the nuclear density meter reading for verification purposes.

(3) The other nuclear readings will be corrected as required and an average of all the corrected readings will be computed. This average will be used to compare the density of the lot being tested with the laboratory density. **At its discretion and after a statistical analysis of the veracity of the nuclear meter and operator, the Authority may waive the testing of the core and base acceptance of the lot solely upon the nuclear readings.**

g. Leveling courses of less than 3.8 centimeters thickness will be exempt from coring and nuclear density testing.

401-2.07 **Basis of Acceptance -**

a. The acceptability of the quality of the hot plant-mix bituminous pavement will be based on the results of the sampling and testing performed as called for in Article 401-2.06 above as compared to the mix requirements for aggregates, asphalt content and compacted density specified in Article 401-2.05 and the tolerances and conditions provided in subsequent paragraphs herein.

b. Asphalt Content - Mixes with asphalt cement content exceeding the specified tolerance of ± 0.4% will be rejected.

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However, at the discretion of the Authority, mixes within ± 0.52% of the approved job-mix formula asphalt content may be accepted but subject to payment at a reduced unit price as specified in Articles 401-5.01 and 401-5.02. Mixes with asphalt content deviating in excess of ± 0.52% of the specified asphalt will be rejected and shall be removed from the project at the Contractor's expense and replaced. However, the Contractor may propose corrective measures to be made at his expense for consideration by the Authority. If these are accepted by the Authority the mix may remain in place subject to such price reductions as may be determined by the Authority but not to exceed 90%. If the corrective measures are not accepted, the deficient mix shall be removed at the Contractor's expense and replaced with acceptable mix.

c. Aggregate Grading - Mixes with aggregates grading exceeding the range of allowable deviations from the job-mix formula specified in paragraph "e" of Article 401-2.05 will be rejected. However, at the discretion of the Authority, mixes with aggregate within the ranges of deviation indicated below may be accepted but subject to payment at a reduced unit price as specified in Articles 401-5.01 and 401-5.02. Mixes exceeding these deviations will be rejected and shall be removed from the project at the Contractor's expense and replaced with suitable material. However, the Contractor may propose corrective measures to be made at his expense for consideration by the Authority. If these are accepted by the Authority, the mix may remain in place but subject to such price reductions as may be determined by the Authority but not to exceed the maximum values specified in paragraph 401-5.02b. If the corrective measures are not accepted, the deficient mix shall be removed at the Contractor's expense and replaced with acceptable mix.

Aggregate Passing	Deviation from Target Value
3/4" Sieve	± 7.0% (B-1 & L-1)
1/2" Sieve	± 7.0% (S-2)
3/8" Sieve	± 7.0% (B-2, L-2 & S-1)
No. 4 Sieve	± 7.0% (All mixes)
No. 30 Sieve	± 6.0% (All mixes)
No. 100 Sieve	± 3.8% (All mixes)

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d. When it is determined from the test results that the in place mix has such deficiencies in asphalt content and/or aggregate grading that it should be removed, the Authority may at its discretion, when so requested by the Contractor, evaluate the mix to determine whether it may allow it to remain in place but at a reduced payment **to be established by the Authority, which deduction will be at least 50 percent.**

e. Mix Density - The compacted bituminous mix shall have a density of at least 97% of the laboratory density for the specified job-mix. Compacted mixes that fail to attain this 97% value but have at least 92% of the density will be accepted, if otherwise acceptable, but subject to a reduced payment as specified in Article 401-5.02. Compacted mixes with less than 92% of the laboratory density will be rejected and shall be removed from the project at the Contractor's expense and replaced. However, the Authority may, at its discretion, allow such failing mixes to remain in place but at a payment of only 75% of the contract unit price.

f. Hardening of Asphalt Cement - Mixes in which the recovered asphalt cements, by AASHTO T 170, have viscosity values at 140°F in excess of 10,000 poises for AC-20 and 15,000 poises for AC-30 will be rejected at the discretion of the Authority.

g. Thickness - Acceptance for thickness will be as provided in Article 401-3.14.

h. Retesting - When an in-place mix is accepted subject to reduced payment or is rejected and ordered removed under the above provisions, the Contractor may request retesting of the rejected lot. Such request must be made in writing within 30 days of notification by the Authority of the mix deficiencies. Such retesting will be conducted as follows:

(1) Three squares of the full depth of the pavement layer and weighing approximately 3,000 grams will be saw cut out by the Contractor, at his expense, under the supervision of the Engineer for each 300 ton lot being retested.

(2) Extraction tests will be performed by the Authority on each specimen to determine the asphalt content and the aggregate grading. These values will supersede and replace the values previously obtained for the initial specimens taken under the provisions of paragraph d of Article 401-2.06.

(3) The average of the results of the three new specimens will be compared with approved job-mix values for acceptance purposes under the requirements of paragraphs b and c of this Article 401-2.07.

(4) Retesting for compliance with the density requirements will be performed by repeating the nuclear testing and core extraction, at the Contractor's expense, described in Article 401-2.06f at ten new locations selected at random. These values will supersede and replace the initial readings. The average of the new readings, corrected as may be necessary, will be compared with the laboratory density for acceptance purposes under the provisions of Article 401-2.07e.

i. The results of the retesting made under paragraph "h" above will be considered final for acceptance purposes and no further retesting will be performed.

401-2.08 Sampling Repairs - The Contractor shall, at his expense, refill all core holes and other sampling cuts in the pavement courses with mix of the appropriate type, placed and compacted to the satisfaction of the Engineer. On roadways open to traffic, the repairs shall be made on the same day the cuts and cores are taken.

401-3 CONSTRUCTION REQUIREMENTS

401-3.01 Bituminous Mixing Plant - Plants used for the preparation of bituminous mixes shall conform to AASHTO M 156 modified and supplemented as follows:

a. For verification of weights and measures, character of materials and determination of temperatures used in the preparation

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of the paving mix, the Engineer, or his authorized representative, shall have access, at all times, to all portions of the mixing plant, aggregates plant, storage yards, and other facilities for producing and processing the mix materials.

b. Scales shall be inspected and sealed as often as the Engineer may deem necessary, but not less than once a year, to assure their continued accuracy, by the Division of Weights and Measures of the Commonwealth Department of Commerce. Any cost involved in the inspection and sealing of the scales shall be at the Contractor's expense.

c. All projects involving 2,000 Tons or more of bituminous mixture shall be served by a plant having automatic controls which coordinate the proportioning, timing and discharge of the mixture.

d. All plants shall be equipped with air pollution control devices which meet the requirements of the Environmental Quality Board.

e. The completed bituminous mixture shall be weighed on approved scales furnished by the Contractor at his expense. **The scales shall be inspected and calibrated at least once a year by an independent entity.**

f. As specified in Article 401-2.06 c, the plant shall have a laboratory adequately equipped and staffed to perform AASHTO T 245 and all other testing required for quality control. The producer's laboratory technician shall be present during periods of mix production. **The producer's technician may participate in the testing under the supervision of Authority's personnel. If he participate, the producer's technician will sign the appropriate test reports along side the Authority's representative. Refusal to sign on the part of the producer's technician will disqualify him from participating in the testing and sampling procedures and may only be present as an observer.**

401-3.02 Hauling Equipment - Trucks used for hauling bituminous mixtures shall have tight, clean, smooth metal beds which have been thinly coated with a minimum amount of paraffin oil, lime solution or other approved material to prevent the mixture from adhering to the beds. Each truck shall have a cover of canvas or other suitable material of such size as to protect the mixture and for use during hauling operations.

401-3.03 Delivery Trucks - Before unloading at the site of the work the bituminous mix supplier shall furnish to the Engineer a delivery tickets containing the following information concerning the bituminous mix in the truck:

a. Name of bituminous mixing plant
b. Serial number of ticket
c. Date, time and truck number
d. Name of Contractor
e. Specific designation of job (name, number and location)
f. Type of mix
g. Weight of mix in the truck
h. **Space for signatures of Authority's inspectors at the paving site and at the scales**

401-3.04 Bituminous Pavers -

a. Bituminous pavers shall be self-contained, power-propelled units with a vibrating or tamper screed and strike-off assembly covering the full laydown width, heated if necessary, and capable of spreading and finishing courses of bituminous plant mix material which will meet the specified typical section, thickness, smoothness, and grade. Pavers used for shoulders and similar construction shall be capable of spreading and finishing courses of bituminous plant mix material in the widths shown on the plans.

b. The paver shall have a receiving hopper of sufficient capacity to permit a uniform spreading operation. The hopper shall be equipped with a distribution system to place the mixture uniformly in front of the screed. The screed and strike-off assembly shall effectively produce a finished surface of the required evenness and texture without tearing, shoving, or gouging the mixture.

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c. The paver shall be capable of operating at forward speeds consistent with satisfactory laying of the mixture.

d. The paver shall be equipped with a grade and slope control system capable of automatically maintaining the screed elevation as specified herein. The control system shall be automatically actuated from either a reference line or surface through a system of mechanical sensors or sensor-directed mechanisms or devices which will maintain the paver screed at a predetermined transverse slope and at the proper elevation to obtain the required surface. When directed, the transverse slope control system shall be made inoperative and the screed shall be controlled by sensor directed automatic mechanisms which will independently control the elevation of each end of the screed from the reference lines or surfaces. The controls shall work in conjunction with the following attachments:

(1) Ski-type device, floating beam of not less than 30 feet (9.14 m) in length or as directed by the Engineer.
(2) Short ski or shoe to match adjoining lanes either fresh or old.
(3) Taut stringline wire set by the Contractor to the specified grade.

e. The Contractor shall furnish the long ski and the short ski or shoe, or furnish and install all required stakes and wire for a taut stringline. Should the automatic control system become inoperative during the days work, the Contractor will be permitted to finish the day's paving work using manual controls. However, work shall not be resumed thereafter until the automatic control system has been made operative.

f. The Contractor may be exempt from the use of the automatic control system at locations where the Engineer determines that pavement geometry or widths makes its use impracticable.

401-3.05 Rollers - Rollers may be of the vibratory or tandem steel wheel type. Pneumatic-tired rollers may be used in conjunction with either of the steel wheel types. Rollers shall be in good condition, be capable of reversing without backlash, and shall be operated at speeds slow enough to avoid displacement of the bituminous mixture. The number, type, and weight of rollers shall be sufficient to compact the mixture to the required density without detrimentally affecting the compacted material. For leveling courses, at least one pneumatic tire roller shall be used.

401-3.06 Weather Limitations - Bituminous plant mix shall not be placed on any wet surface or when weather conditions prevent the proper handling or finishing of the bituminous mixture.

401-3.07 Preparation of Surface to be Paved -

a. The surface to be paved shall be true to line and grade, dry and free from loose or deleterious material immediately before the placing of bituminous mixture. If necessary, the surface shall be cleaned by brooming or other approved means.

b. When the surface of an existing pavement or old base to be paved is irregular, it shall be brought to uniform grade and cross section by a leveling course as directed, which shall be compacted to the satisfaction of the Engineer before placing subsequent paving courses.

c. When a leveling course is not required, all depressions and other irregularities shall be patched or corrected in a manner satisfactory to the Engineer. All fatty and unsuitable patches, excess crack or joint filler, and all surplus bituminous material, shall be removed from the area to be paved. Blotting of excessive deposits of asphalt with sand or stone, will not be permitted.

d. Where the area to be paved is an untreated soil or aggregate, it shall be compacted to the required density and then primed in accordance with the provisions of Specification 408 - Bituminous Prime Coat. The prime coat shall be allowed to cure properly in accordance with the provisions of Specification 408 before any further operations are permitted on the primed area. No prime coat will be required for single bituminous mix course 7.5 cm. or more in compacted thickness.

e. Before spreading the mixture upon a portland cement concrete surface or a bituminous surface older than 3 months or excessively dirty, a tack coat in accordance with the provisions of Specification 407 - Bituminous Tack Coat shall be applied. No tack is required on bituminous surfaces which are less than 3 months old if they can be cleaned to the satisfaction of the Engineer.

f. Contact surfaces of curbing, gutters, manholes, and other structures shall be painted with a thin, uniform coating of bituminous material as specified for the tack coat prior to the bituminous mixture being placed against them.

401-3.08 Preparation of Bituminous Material - The bituminous material shall be heated to the temperature specified in Table 702-1 of Specification 702 - Bituminous Materials. The bituminous material shall be heated in a manner that will avoid local overheating and provide a continuous supply of the bituminous material to the mixer at a uniform temperature. Asphalt cement shall not be used while it is foaming nor shall it be heated above 350°F at any time after delivery to the plant.

401-3.09 Mixing -

a. The aggregates shall be combined in the mixer in the amount of each fraction of aggregates required to meet the job-mix formula. The bituminous material shall be measured or gauged and introduced into the mixer in the amount specified by the job-mix formula. The materials shall be mixed until a complete and uniform coating of the particles and a thorough distribution of the bituminous material throughout the aggregate is secured.

b. All mixes shall be delivered at the paving site at a temperature of no less than 225 degrees F.

401-3.10 Transporting, Spreading and Finishing -

a. The mixture shall be transported from the mixing plant to the paving site in vehicles conforming to the requirements of Article 401-3.02. The required protective cover shall be placed over the mix prior to departing the plant and retained in place

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until the mix is delivered.

b. The bituminous mixture shall be laid upon an approved clean surface, spread and struck off to the established grade and elevation. Bituminous pavers shall be used to distribute the mixture either over the entire width or over such partial width as may be practicable.

c. The longitudinal joint in one layer shall be offset from that in the layer immediately below by approximately 15 centimeters; however, the joint in the top layer shall be at the center line of the pavement if the roadway comprises two lanes of width, or at lane lines if the roadway is more than two lanes in width, unless otherwise directed. **Failure of the Contractor to observe the above dispositions and the placement of the longitudinal joint at any wheel path will allow the Authority to reject the mix or to accept the same at a 50% reduction in price.**

d. On areas where irregularities or unavoidable obstacles make the use of mechanical spreading and finishing equipment impracticable, the mixture may be spread and finished by hand tools. For such areas the mixture shall be dumped, spread and screeded to provide the required section and compacted thickness. The Contractor shall provide suitable heating equipment for keeping hand tools free from asphalt. The temperature of the tools when used, shall not be greater than the temperature of the mix placed. Only heat shall be used for cleaning hand tools. The use of petroleum oils or volatiles will not be permitted.

e. The mixtures shall be placed in layers as indicated on the plans. No single layer shall exceed 10 cm. (4") in compacted thickness.

401-3.11 Compaction -

a. Immediately after the bituminous mixture has been spread, struck off and surface irregularities adjusted, it shall be thoroughly and uniformly compacted by rolling. The surface shall be rolled when the mixture is in the proper condition and when the rolling does not cause undue displacement, cracking or shoving.

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The number, weight and type of rollers furnished shall be sufficient to obtain the required compaction while the mixture is in workable condition. The sequence of rolling operations and the selection of roller types shall be such as to provide the required pavement density of at least 97% of the laboratory density. However, the use of pneumatic tire rollers is mandatory for compacting L-1 and L-2 leveling courses.

b. Unless otherwise directed, rolling shall begin at the sides and proceed longitudinally parallel to the road center line, gradually progressing to the crown of the road. Trip overlaps of the roller shall not exceed 6 inches (15 cm.). When paving in echelon or abutting a previously placed lane, the longitudinal joint shall be rolled first followed by the regular rolling procedure. On super-elevated curves the rolling shall begin at the low side and progress to the high side by overlapping of longitudinal trips parallel to the center line.

c. Rollers shall move at a slow but uniform speed with the drive roll or wheels nearest the paver except when rolling an incline, then the procedure is reversed.

d. Any displacement occurring as a result of the reversing of the direction of a roller, or from other causes, shall be corrected at once by the use of rakes and addition of fresh mixture when required. Care shall be exercised in rolling not to displace the line and grade of the edges of the bituminous mixture. To prevent adhesion of the mixture to the rollers, the wheels shall be kept properly moistened with water or water mixed with very small quantities of detergent or other approved material.

e. Along forms, curbs, headers, walls and other places not accessible to the rollers, the mixture shall be thoroughly compacted with mechanical tampers. On depressed areas, a trench or small vibratory roller may be used, or cleated compression strips may be used under the roller to transmit compression to the depressed area.

f. Any mixture that becomes loose and broken, mixed with dirt, or is in any way defective shall be removed and replaced with fresh hot mixture, which shall be compacted to conform with the surrounding area. Any area showing an excess or deficiency of bituminous mix material shall be corrected to the satisfaction of the Engineer.

401-3.12 Joints, Trimming Edges and Cleanup -

a. Placing of the bituminous mix shall be as continuous as possible. Rollers shall not pass over the unprotected end of a freshly laid mixture unless authorized by the Engineer. Transverse joints shall be formed by cutting back on the previous run to expose the full depth of the course. When directed by the Engineer, a brush coat of bituminous material of the type being used in the mix shall be used on the contact surfaces of transverse joints just before additional mixture is placed against the previously rolled material.

b. At the beginning or end of a project connecting to an existing pavement the feathering of the new surface course to match the existing grade of the old pavement will not be permitted. To transition and match the grades, the old pavement shall be undercut to a depth equal to the compacted depth of the new surface course being connected to it. This work shall be a subsidiary obligation of the Contractor under the new pavement pay items.

c. Material trimmed from the edges and any other discarded bituminous mixture shall be removed from the roadway and disposed of by the Contractor outside the project limits or in an approved area out of sight from the road.

401-3.13 Surface Requirements -

a. The Contractor shall provide a 3-meter (10-foot) rolling straight edge, to be operated by the Engineer, that automatically marks, in colored dye, the length of surface variations which exceed a tolerance of 0.5 centimeter (3/16 inch) in 3 meters (10 feet) for testing the top surface of pavements in a longitudinal direction, or a similar instrument, acceptable to the Authority, that will identify surface variations. In addition, the Contractor shall provide a 3-meter portable aluminum straightedge for testing surfaces transversely and for testing base course surfaces, ramps, frontage roads and other miscellaneous surfaces.

b. The surfaces of new **aggregate and bituminous** base courses will be tested with a 3-meter straightedge. Any depressions in excess of 1.25 cm. (1/2") shall be corrected with leveling or surface course material.

c. Each lane of new **surface** course placed on pavement and over a base course of uniform **thickness** will be tested longitudinally, approximately along the lane **wheel path**, with the rolling straightedge to determine the length of surface variations which exceeds the permissible tolerance of 0.5 centimeter in 3 meters. The percent of defective length in the total lane measured length will be computed.

d. The top surface course of pavement will be accepted as is when the percentage of defective length does not exceed 4.0% in any 300-meter sections selected by the Engineer. When the percentage of deficient surface length in a lane in such sections exceeds 4.0%, the deficient sections shall be removed or shall be corrected to the satisfaction of the Engineer at the Contractor's expense.

e. The top surface of ramps, frontage roads, and miscellaneous travel ways other than the main line lanes will be tested by the Engineer at random locations using the rolling straightedge or the portable 3-meter straightedge to check for conformance with the 0.5 centimeters surface variation tolerance.

f. During placement of the surface course, random control testing will be performed with the 3-meter straightedge to ascertain the capability of the paving equipment and operations to meet the surface requirements.

401-3.14 Testing Pavement Thickness -

a. The Contractor shall take three cores per lane per kilometer of each bituminous pavement course at random locations selected by the Engineer for determining the thickness laid.

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b. For surface courses no core shall be deficient by more than 0.6 cm. and the average of all cores must be not less than the thickness specified in the plans.

c. Base courses shall be checked in the same manner as for surface course in paragraph "a" above, except that the tolerance shall be 1.2 cm. for thicknesses in excess of 10 cm.

d. In addition, if the average total thickness for each course exceeds the plan thickness by more than 15%, the excess tonnage equivalent to the excess in average thickness over 115% of plan thickness will not be compensated.

e. Material which is used for a leveling course will not be considered in pavement thickness determinations.

401-3.15 Protection of Pavement - Sections of newly finished work shall be protected from traffic of any kind until the mixture has become properly hardened by cooling. In no case will traffic be permitted less than 6 hours after completion of the pavement unless a shorter period is authorized or directed by the Engineer in emergencies or in reconstruction work.

401-4 METHOD OF MEASUREMENT

401-4.01 Plant-mix bituminous pavement courses will be measured by the ton of compacted mixture placed in the accepted work, as called for in the contract documents. Measurement will be by weighing the delivery trucks at approved scales. Batch weights will not be accepted as a method of measurement.

401-4.02 Any excess tonnage due to excess thickness, determined as provided in Article 401-3.14d, will be deducted from the measurement for payment.

401-4.03 Due to possible variations in the specific gravity of the aggregates, the tonnage used may vary from the contract quantities and no adjustment in the contract unit price will be made because of such variation.

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401-4.04 Work prescribed under Article 401-3.07, Preparation of Surface to be Paved, except for the leveling course and mix material used for patching and correcting irregularities in old surfaces, will not be measured directly for payment, but will be considered as a subsidiary obligation of the Contractor under the various items of hot plant-mix bituminous pavement. Hot plant-mix material used for patching and leveling in this work will be measured for payment under the respective unit prices.

401-5 BASIS OF PAYMENT

401-5.01 The completed and accepted quantities of each class of hot plant mix pavement, measured as provided above, will be paid for at the contract unit price per unit of measurement except as specified in Article 401-5.02 below. Such prices and payment shall constitute full compensation for the cost of preparation of the surface to be paved; the furnishing and placing of any required prime or tack coat; and the furnishing, placing, compacting and finishing of all required materials for the pavement; and for all labor, equipment, tools and incidentals necessary to complete each item of work as required by the plans and specifications.

401-5.02 Pavement found to be deficient as to asphalt content, aggregate gradation or compacted density but allowed to remain in place under the provisions of Article 401-2.07 will be paid for at a reduced unit price as follows:

a. For asphalt content:

Deviation in Asphalt Content from Design Value	Percent Reduction in Unit Price
± 0.4 %	0
± 0.41 to 0.44%	3
± 0.45 to 0.48%	6
± 0.49 to 0.52%	10
Over ± 0.52%	See Arts. 2.07b and d

b. For aggregate grading:

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Sieve Size	Deviation in % Passing from Design Value	Percent Reduction in Unit Price
3/4" (B-1, L-1)	± 5.0	0
or	± 5.1 to 5.5	2
3/8" (B-2, L-2,	± 5.6 to 6.0	4
& S-1)	± 6.1 to 6.5	7
or	± 6.6 to 7.0	10
1/2" (S-2)	Over ± 7.0	See Arts. 2.07c and d
No. 4	± 5.0	0
	± 5.1 to 5.5	2
	± 5.6 to 6.0	4
	± 6.1 to 6.5	7
	± 6.6 to 7.0	10
	Over ± 7.0	See Arts. 2.07c and d
No. 30	± 4.0	0
	± 4.1 to 4.5	2
	± 4.6 to 5.0	4
	± 5.1 to 5.5	7
	± 5.6 to 6.0	10
	Over ± 6.0	See Arts. 2.07c and d
No. 100	± 3.0	0
	± 3.1 to 3.3	3
	± 3.4 to 3.6	6
	± 3.7 to 3.8	10
	Over ± 3.8	See Arts. 2.07c and d

Where the aggregate is deficient in more than one sieve, the reductions in unit price for aggregate failure will be applied on the basis of the largest deduction only.

c. For in place density:

Percent of Laboratory | Percent Reduction

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Density Attained	in Unit Price
97 and over	0
96.0 to 96.9	3
95.0 to 95.9	6
94.0 to 94.9	9
93.0 to 93.9	12
92.0 to 92.9	15
Less than 92	See Art. 2.07e

d. The total percentage deduction in unit price for deficiencies will be determined by adding the percentage reduction due to deficiency in asphalt content, if any, to the highest percentage reduction due to deficiencies in aggregate grading in any of the sieve sizes, and to the percentage reduction due to density deficiencies. However, the total percentage deduction to be applied for these three combined causes shall not exceed 25%. Such reduction will be in addition to any reduction in payment for excess tonnage in pavement thickness provided under Article 401-3.14.

401-5.03 Payment will be made under:

Pay Item	Pay Unit
Hot Plant-Mix Bituminous Pavement Mix S-1 (50 or 75)*....	Ton
Hot Plant-Mix Bituminous Pavement Mix S-2 (50 or 75)*....	Ton
Hot Plant-Mix Bituminous Pavement Mix L-1 (50 or 75)*....	Ton
Hot Plant-Mix Bituminous Pavement Mix L-2 (50 or 75)*....	Ton
Hot Plant-Mix Bituminous Pavement Mix B-1 (50 or 75)*....	Ton
Hot Plant-Mix Bituminous Pavement Mix B-2 (50 or 75)*....	Ton

* Indicate the number of applicable hammer blows (AASHTO T 245).

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 301-001
Description =====> Subbase Course (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
000030	Avenida Zafiro Caguas	16-Mar-92 Ismael Gonzalez Construction	2,760.000	$6.00
000035	Interseccion Avenida Zafiro Caguas	04-Dec-97 Hato Tejas Construction	5,500.000	$12.00
000063	Mejoras a la Avenida Dunsco Mayaguez	01-Jul-96 Jusor Corporation	12,600.000	$10.00
000067	Nuevo Acceso y Fac de Est d Mayaguez	16-Sep-96 Constructora Santiago	10,000.000	$15.00
000109	Mejoras a Calle Serrania, d Guaynabo	20-Nov-01 Constructora Fortis, Inc.	132.000	$20.00
000136	Mejoras Geometricas y Ensan Cayey	28-Dec-00 Rivero Construction	15,000.000	$10.80
000234	Ensanche Carretera PR-2 Aguadilla-Aguada	19-Jul-93 Constructora Santiago	40,151.000	$9.50 *
000248	Interseccion Carretera PR-2 Guaynabo	24-Jun-96 Caribbean Contractors, Inc	1,200.000	$22.00
000249	Rehabilitacion P/S PR-102, Sabana Grande	20-Sep-01 Mid North Engineering	100.000	$35.00
000273	Mejoras Geometricas a Int P Aguadilla	06-Oct-97 Jusor Corporation	13,900.000	$8.00
000515	Ensanche de la PR-5 Catano	22-Dec-97 Del Valle Group	5,649.000	$11.00
000520	Construccion PR-5 Ave. Rio Bayamon	02-Jan-96 Constructora Santiago	54,587.000	$9.55
000523	Construccion de Interseccio Bayamon	27-Mar-95 Del Valle Group	40,000.000	$7.50
000526	Avenida Rio Hondo,Fase II,d Bayamon	12-Oct-00 Rio Construction	40,228.000	$9.00

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 301-001
Description =====> Subbase Course (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
000527	Construccion de Avenida Rio Bayamon	17-Jan-97 Rexach Construction	21,650.000	$9.70
000528	Conector Rio Hondo Bayamon	20-Oct-97 LPC & D, Inc.	21,700.000	$14.50
000528	Conector Rio Hondo Bayamon	20-Oct-97 LPC & D, Inc.	2,188.000	$23.60 *
000529	Ensanche PR-5 Catano	16-Mar-98 Del Valle Group	5,379.000	$15.00
000532	Centro de Transferencia AMA Catano	25-Apr-97 Caribbean Contractors, Inc	1,505.000	$14.00
000536	Mejoras y Terminacion de la Bayamon	08-Jan-01 Rio Construction	2,350.000	$18.00
000901	Expreso Este Oeste, PR-9, P Ponce	19-Jun-95 Del Valle Group	86,757.000	$5.00
000905	Construccion de PR-9 desde Ponce	13-Nov-98 Del Valle Group	100,714.000	$5.00
000908	PR-9 desde La est 0+96.56 (Ponce	22-Apr-99 Del Valle Group	62,347.000	$2.25
000909	Interseccion de PR-9 con PR Ponce	21-Jun-00 Constructora Jose Carro	26,000.000	$15.00
001069	Construccion Adjuntas-Ponce Adjuntas-Ponce	31-Jul-95 Constructora Jose Carro	52,850.000	$4.00
001070	Adjuntas-Ponce Ponce	13-Sep-96 Rexach Construction	37,269.000	$3.60
001091	Arecibo-Utuado Arecibo	01-Aug-94 Constructora Jose Carro	26,400.000	$2.00
001471	Avenida Malecon Ponce	03-Feb-92 Redondo Construction	10,080.000	$2.80

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AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 301-001
Description =====> Subbase Course (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
001492	P/S Calle Comercio Ponce	19-Jun-95 Constructora Santiago	6,735.000	$7.80
001725	Paso Elevado para Peatones San Juan	19-Aug-94 R.B.R. Construction, S.E.	50.000	$12.00
001727	Rampa Acceso Avenida Jesus San Juan	11-Aug-95 R.B.R. Construction, S.E.	350.000	$15.00
001732	Mejoras Ave Jesus T. Piñero San Juan	06-Dec-96 Rio Construction	3,600.000	$20.00
001835	Reemplazo del Puente Num 95 San Juan	18-Feb-02 Constructora Santiago	2,000.000	$15.00
002027	Avenida Periferal La Muda Guaynabo	02-Nov-95 Las Piedras Construction	51,300.000	$2.28
002035	Expreso Martinez Nadal San Juan-Guaynabo	27-Dec-94 Rio Construction	36,910.000	$7.00
002043	Construccion de Marginal La Guaynabo	16-Mar-98 Guirimar Construction, Inc	3,416.000	$1.00
002045	Mejoras a la Interseccion d Guaynabo	27-Jun-97 LPC & D, Inc.	1,750.000	$18.00
002050	Plaza de Peaje expreso Mart Guaynabo	25-Oct-99 CC Construction, Corp.	18,340.000	$26.00
002053	Mejoras a Interseccion Expr Guaynabo	23-Mar-99 LPC & D, Inc.	14,500.000	$14.00
002056	Ensanche PR-20 desde PR-199 Guaynabo	05-Jul-99 Guirimar Construction, Inc	4,805.000	$12.00
002127	Mejoras Geometricas Villa E Bayamon	29-Sep-95 Del Valle Group	5,350.000	$10.00
002132	Rehabilitacion y Ensanche, San Juan	10-Dec-01 CC Construction Corp.	6,800.000	$13.00

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M H I S T O R Y

Specific Code ===> 301-001
Description =====> Subbase Course (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
002316	Centro de Transferencias de San Juan	09-Nov-95 Caribbean Contractors	365.000	$22.00
002618	Baldorioty de Castro Expres Carolina	18-May-95 Las Piedras Construction	23,898.000	$3.00
002637	Mejoras al Area de Los Ange Carolina	19-Sep-94 Mejia Construction	9,234.000	$9.00
002651	Rehabilitacion Pavimento PR Carolina	04-Oct-93 R.B.R. Construction, S.E.	7,480.000	$10.00
002653	Mejoras PR-26 Int. PR-187 Carolina	03-Feb-94 Rio Construction	12,800.000	$8.00
002658	Conversion a Expreso Avenid Carolina	11-Mar-96 Constructora Santiago	1,250.000	$100.00
002661	Mejoras PR-26, Lazo San Jua Carolina	06-Dec-93 Caribbean Contractors, Inc	1,110.000	$9.50
002665	Rampa de Acceso de hacia Sa Carolina	22-May-95 Las Piedras Construction	4,020.000	$5.00
002688	Mejoras al drenaje y Rehab Carolina	10-Jul-00 DMI Construction	1,400.000	$18.50 *
003038	Humacao-Yabucoa Humacao	22-Apr-91 Constructora Santiago	61,740.000	$1.00
003040	Ensanche Nuevo Acceso Parqu Las Piedras	11-Mar-96 Las Piedras Construction	23,332.000	$0.30
003052	Mejoras Desvio Sur Humacao Humacao	30-May-95 Del Valle Group	6,800.000	$6.80
003062	Ensanche a 6 carriles PR-30 Caguas-Gurabo	31-Jul-00 Constructora I. Melendez	34,370.000	$12.00
003064	Ensanche de los Puentes Num Caguas	10-Nov-99 Kaiser Construction	2,042.000	$14.00

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 301-001
Description =====> Subbase Course (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
003068	Ensanche 6 Carriles, Expres Caguas-Gurabo	23-Mar-99 Constructora Santiago	5,201.000	$30.00
003068	Ensanche 6 Carriles, Expres Caguas-Gurabo	23-Mar-99 Caribbean Contractors, Inc	4,886.000	$32.00
003068	Ensanche 6 Carriles, Expres Caguas-Gurabo	23-Mar-99 LPC & D, Inc.	4,938.000	$14.00
003068	Ensanche 6 Carriles, Expres Caguas-Gurabo	23-Mar-99 Constructora Hartman, S.E.	5,425.000	$8.00
003070	Ensanche P/S Rio de Grande Caguas-Gurabo	22-Jan-99 LPC & D, Inc.	2,320.000	$14.00
003074	Mejoras Interseccion PR-30, Juncos-Las Piedras	02-Dec-99 DBA Construction	10,000.000	$11.00
003075	Mejoras Intersecciones PR-3 Caguas-Gurabo	18-Dec-00 DMI Construction	2,960.000	$10.00
003076	Mejoras a PR-30, Fase III, Humacao-Las Piedras	24-Jul-00 DBA Construction	350.000	$12.00
003133	Reemplazo P/S Quebrada Los Las Piedras	20-Sep-01 Constructora WF	2,850.000	$8.00
005302	Carretera PR-53 Ceiba	13-Apr-92 Las Piedras Construction	83,200.000	$9.48
005303	Construccion PR-53 desde PR Ceiba	08-Aug-94 Redondo Construction	138,200.000	$1.00
005304	Construccion Carretera Esta Naguabo-Ceiba	10-Mar-95 Redondo Construction	162,602.000	$3.50
005305	Expreso Fajardo-Guayama PR- Naguabo	10-Mar-95 Rexach Construction	164,256.000	$5.50
005306	Expreso Fajardo-Guayama PR- Naguabo-Humacao	03-Jul-95 Francisco Levy, Hijo	130,512.000	$5.00

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Description =====> Subbase Course (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price	
005307	Carretera PR-53 Humacao	13-Apr-92 Redondo Construction	52,500.000	$2.90	
005310	Carretera PR-53 Yabucoa	13-Apr-92 Rexach Construction	113,200.000	$2.55	*
005326	Extesion Calle Marginal, PR Fajardo	08-Aug-94 Redondo Construction	2,240.000	$5.00	
005402	Construccion de la PR-54 Guayama	28-Dec-98 Del Valle Group	31,250.000	$8.04	
010021	Ensanche de la Carretera PR Cabo Rojo-Hormiguero	24-Feb-97 Cabimar Construction, S. E.	25,440.000	$6.00	
010022	Ensanche PR-100 y P/S Rio G Hormigueros-Cabo Roj	03-Sep-01 Robles Asphalt Corp.	3,910.000	$14.00	
010523	Construccion de Muros de Co Maricao	11-Aug-00 Paisy Asphalt	15.000	$40.00	
010822	Reconstruccion Miradero-Rio May-Ana-L. Marias	22-Aug-94 Cabimar Construction, S. E.	130.000	$7.00	
011107	Desvio Norte de San Sebasti San Sebastian	10-Aug-92 Jusor Corporation	22,199.000	$7.50	
011107	Desvio Norte de San Sebasti San Sebastian	10-Aug-92 Jusor Corporation	22,199.000	$9.00	*
011182	Correccion Deslizamiento San Sebastian	12-May-93 Del Valle Group	2,000.000	$8.00	*
011184	Reemplazo Puente Num 236 Qu San Sebastian	13-Apr-00 JJMR Construction SE	900.000	$20.00	
011187	Ensanche y Mejoras Geometri Lares	25-Feb-02 Tamrio, Inc.	21,950.000	$8.00	
011193	Ensanche de PR-111, desde k Utuado	17-Jul-00 JJMR Construction SE	200.000	$35.00	

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Project	Project Name Municipality	Start Date Contractor	Quantity	Unit Price
011194	Ensanche de PR-111 Utuado	18-Feb-02 Robles Asphalt Corp	1,400.000	$20.00
011523	Reconstruccion de la PR-115 Rincon	10-Mar-97 PROTA Construction	23,635.000	$9.00
011526	Reconstruccion PR-115 Rincon	28-Dec-92 Jusor Corporation	3,241.000	$4.75
011625	Reemplazo P/S Rio Loco Num Yauco	10-Aug-98 Tamrio, Inc.	2,310.000	$12.00
011627	Ensanche PR-116 de Int con Guanica	06-Oct-97 Constructora I. Melendez	45,000.000	$7.50
011628	Ensanche de la PR-116 Guanica	05-Dec-00 Tamrio, Inc.	10,423.000	$8.00
012014	Muro de Contencion, Kilomet Maricao	19-Jul-01 Paisy Asphalt	70.000	$20.00
012310	Reemplazo del Puente Num 15 Adjuntas	25-Feb-02 Lasami Construction	1,000.000	$8.00
012709	Remplazo P/S Rio Guayanilla Guayanilla	27-Mar-95 Constructora W. F.	2,185.000	$6.00
012710	Reemplazo de P/S Rio Guayan Guayanilla	27-Mar-00 Constructora WF	405.000	$8.00
012832	Sistema de Semaforos Yauco	06-Nov-00 Bermundez & Longo, S.E.	1,240.000	$11.00
013701	Carretera 137, Desde PR-670 Vega Baja	20-Dec-96 Constructora Jose Carro	125,011.000	$1.00
013702	Franquez-Torrecilla Morovis	27-Mar-95 Equipos y Constructora, R.V.D.	68,500.000	$1.00
013803	Desvio Sur de Coamo Coamo	16-Mar-99 MAS Construction	60,472.000	$1.00

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
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OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 301-001
Description =====> Subbase Course (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price	
013804	Desvio Sur de Coamo Coamo	22-Jan-02 Carro y Carro Enterprises, Inc	2,000.000	$30.00	
014202	Nuevo Acceso a Corozal Corozal	22-Apr-96 Las Piedras Construction	32,550.000	$14.00	
014203	Construccion de la Carreter Toa Alta-Corozal	07-Jan-97 LPC & D, Inc.	3,426.000	$8.00	
014206	Acceso Corozal Corozal	24-May-99 Constructora Jose Carro	13,363.000	$1.00	
014207	Acceso a Corozal Conector P Dorado-Toa Alta	15-Jun-98 Constructora Jose Carro	38,046.000	$1.00	
014207	Acceso a Corozal Conector P Dorado-Toa Alta	15-Jun-98 Constructora Jose Carro	2,553.000	$9.00	*
014208	Nuevo Acceso a Corozal Dorado	16-Mar-99 Tamrio, Inc.	27,245.000	$8.00	
014209	Acceso a Corozal PR-142 y M Dorado	19-Dec-00 Constructora Fortis, Inc.	9,214.000	$10.00	
014211	Acceso a Corozal, PR-142, M Corozal	01-Oct-01 Constructora Fortis	2,609.000	$10.00	
014429	Muro de Contencion Jayuya	08-Jan-01 Constructora Del Rio Encantado	45.000	$30.00	
014705	Construccion de la PR-147 Naranjito	30-Jan-95 Rio Construction	7,000.000	$7.00	*
014806	Carretera PR-148, desde Car Naranjito-Bayamon	27-Sep-99 Constructora Jose Carro	93,085.000	$0.50	
014811	Ensanche de PR-167 Bayamon	28-Dec-00 Del Valle Group	5,600.000	$16.00	
014966	Ensanche de Carretera PR-14 Juana Diaz	18-Dec-00 Del Valle Group	33,252.000	$8.00	

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
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Description =====> Subbase Course (CuM)

Project	Project Name Municipality	Start Date Contractor	Quantity	Unit Price
015204	Desvio de Barranquitas, des Barranquitas	06-Nov-96 Constructora Jose Carro	16,412.000	$2.50
015614	Mejoras y Relocalizacion PR Caguas	16-Sep-96 Las Piedras Construction	22,500.000	$2.50
015652	Mejoras y Relocalizacion Aguas Buenas	11-Aug-95 Las Piedras Construction	14,300.000	$0.54
015679	Reconstruccion PR-156 Comerio	25-Mar-96 Up Construction	623.000	$18.00
015679	Reconstruccion PR-156 Comerio	25-Mar-96 Up Construction	500.000	$30.00 *
016101	Desvio Norte Santa Isabel P Santa Isabel	16-Jan-96 Constructora I. Melendez	22,952.000	$5.00
016549	Mejoras PR-165,PR-869 a P/S Catano-Toa Baja	10-Oct-94 Rio Construction	8,000.000	$8.00
016561	Reemplazo P/S Rio La Plata Dorado	30-May-95 Las Piedras Construction	2,600.000	$8.00
016575	Reemplazo del P/S Canales R Toa Baja	06-Nov-00 Miseners Marine	7,400.000	$8.00
016576	Ensanche de La PR-165 desde Toa Baja	20-Dec-96 Del Valle Group	27,800.000	$11.70
016700	Construccion PR-167, Ext. A Toa Baja	21-Nov-95 Del Valle Group	17,615.000	$8.50
016718	Mejoras desde Ave Sabana Se Catano	21-Jul-97 Del Valle Group	12,000.000	$15.00
016776	Ensanche PR-167 (Cana-Van S Bayamon	03-Feb-94 Kaiser Construction	1,600.000	$12.00
017118	Reemplazo P/S Río La Plata Cidra	12-Oct-98 Leafar Construction	900.000	$11.50

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

ITEM HISTORY

Specific Code ===> 301-001
Description =====> Subbase Course (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
017228	Relocalizacion Acceso al Pa Cidra	19-Aug-94 Constructora W. F.	3,200.000	$9.00
017235	Trabajos Term Acceso Parque Cidra	06-Nov-96 Constructora W. F.	2,000.000	$15.00
017329	P/S Rio La Plata Aibonito-Cidra	06-Oct-97 Lasami Construction, Inc.	480.000	$15.00
017618	Relocalizacion Avenida Cupe San Juan	22-May-95 Rio Construction	9,215.000	$7.00
017723	Mejoras Int. PR-52 Y La PR- San Juan	08-May-95 Best Work Construction	672.000	$25.00
018172	Reemplazo P/S Rio Grande de Patillas	31-Jul-00 Constructora WF	5,200.000	$8.00
018213	Reemplazo de P/S Rio Guayan Yabucoa	10-Jan-02 Best Work S.E.	5,450.000	$7.50
018808	Atarjea Km 4.3 Canovanas	09-Mar-98 Del Valle Group	120.000	$18.00
018925	Mejoras Geometricas, (Unida Gurabo	23-Oct-96 Guirimar Construction, Inc	2,600.000	$10.00
019129	Rehabilitacion derrumbes Km Rio Grande	19-Jan-98 Rio Construction	55.000	$100.00
019908	Avenida Las Cumbres, (PR-20 Guaynabo	28-Dec-92 Rio Construction	38,080.000	$4.30
019912	Ensanche PR-846 y PR-850 Trujillo Alto	25-Jun-92 Caribbean Contractors	8,142.000	$6.00
019913	Ensanche PR-850 Trujillo Alto	01-Apr-96 DBA Construction	12,070.000	$8.50
019916	Avenida Las Cumbres San Juan-Trujillo Al	15-Jun-98 Redondo Construction	39,776.000	$10.30

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
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OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 301-001
Description =====> Subbase Course (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
019918	Construccion de La Carreter Guaynabo	27-Mar-95 R.B.R. Construction, S.E.	8,500.000	$8.00
019920	Mejoras Avenida Las Cumbres Bayamon	16-Jul-98 Rexach Construction	19,500.000	$9.49
019920	Mejoras Avenida Las Cumbres Bayamon	16-Jul-98 Rexach Construction	1,308.000	$10.00 *
019921	Avenida Las Cumbres (Etapa Guaynabo	29-Jul-96 Rio Construction	15,060.000	$8.00
019922	Ensanche de la Carretera PR San Juan	24-Feb-95 Constructora Hartman, S.E.	880.000	$18.00
019948	Mejoras Avenida Las Cumbres San Juan	08-Jan-01 Guirimar Construction	8,050.000	$6.00
019950	Avenida Las Cumbres San Juan	26-Oct-00 LPC & D, Inc.	58,800.000	$2.00
019953	Reconstruccion Sist de Sema San Juan	07-Nov-97 Unique Builders	1,280.000	$10.65
020303	P/S Rio Grande de Loiza San Lorenzo	22-Apr-96 Redondo Construction	27,760.000	$1.20
020304	Construccion de Calle Margi San Lorenzo	21-Feb-02 Morales Construction	1,500.000	$6.00
030108	Carretera PR-301, Conector Cabo Rojo	23-Nov-00 Constructora Jose Carro	14,000.000	$6.00
031903	Reemplazo P/S Rio Rosario N Hormigueros	24-Jul-00 Equipos y Constructora RVD	2,000.000	$9.00
034507	Extension de Atarjea Sobre Hormigueros	03-Jul-00 Tamrio, Inc	30.000	$30.00
035106	Muro de Contencion Mayaguez	19-Jul-01 Gill Enginnering Group	200.000	$30.00

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
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Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
037502	Jacanas-Yauco Yauco	16-May-94 King's Construction, Inc.	870.000	$4.50
042306	Reemplazo P/S Rio Culebrina San Sebastian	23-Apr-98 Constructora W. F.	405.000	$9.00
043003	P/S Rio Grande de Añasco Anasco	16-Jun-97 Constructora Santiago	2,777.000	$15.00
046609	Bajuras Isabela	19-Oct-98 Empresas Codel	20,000.000	$13.50 *
051108	Reemplazo P/S Rio Inabon Nu Ponce	10-Dec-01 Ragon Construction	124.000	$3.00
051501	Relocalizacion de PR-515 Adjuntas	16-Mar-99 Redondo Construction	4,200.000	$4.96 *
053603	Relocalizacion PR-536, desd Santa Isabel	18-Oct-01 Construcciones Jose Carro	82,000.000	$14.00
056708	Reconstruccion PR-567 Orocovis-Morovis	16-May-94 Robles Asphalt, Corp.	140.000	$15.00
064605	Reemplazo P/S Qda Hicotea N Vega Baja	11-Sep-00 Equipos y Constructora RVD	650.000	$11.00
067004	Ensanche de la Carretera 67 Vega Baja-Manati	20-Jul-98 Constructora Fortis	4,350.000	$10.00
068807	Reemplazo P/S Rio Cibuco Nu Vega Baja	03-Sep-01 Constructora Fortis	3,300.000	$10.00
069007	Construccion PR-690 Int. PR Vega Alta	04-Mar-96 MAS Construction	550.000	$10.00
069313	Construccion PR-6693, Desvi Dorado	01-May-95 MAS Construction	13,500.000	$8.86 *
069318	Reconstruccion PR-693 desde Dorado-Vega Alta	13-Jul-98 Betteroads Asphalt	1,350.000	$13.80

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Project	Project Name Municipality	Start Date Contractor	Quantity	Unit Price
069319	Mejoras Interseccion PR-22 Dorado	13-Jul-98 Del Valle Group	1,850.000	$22.00
069901	Construccion de la Carreter Dorado	01-Jun-98 Constructora Fortis	700.000	$10.00
073502	P/S Quebrada Beatriz Cayey	27-Dec-94 Empresas Inabon	3,855.000	$7.50
073502	P/S Quebrada Beatriz Cayey	10-Mar-98 Morales Construction	3,855.000	$8.00
075403	Relocalizacion P/S Rio Pat Patillas	18-Mar-96 Lasami Construction, Inc.	3,770.000	$7.00
077507	P/S Rio La Plata Comerio	29-Sep-95 Equipos y Constructora, R.V.D.	65.000	$40.00
077906	Reconstruccion PR-779, PALO Comerio	19-Aug-94 Best Work Construction	170.000	$25.00
081407	Construccion de Muro de Con Naranjito	11-Sep-00 Constructora Fortis, Inc.	100.000	$20.00
082710	P/S La Quebrada Piña Toa Alta	18-Nov-96 Del Valle Group	2,300.000	$12.00
084205	Mejoras a PR-842, Caimito San Juan	03-Feb-94 DBA Construction	90.000	$10.00
085709	Reemplazo P/S Quebrada Laja Carolina	07-Feb-00 Lasami Construction	300.000	$15.00
086112	Reemplazo del Puente Num 56 Toa Alta	25-Feb-02 Jorli, Inc.	2,985.000	$10.00
086603	Ensanche PR-866 Toa Baja	04-Oct-93 Kaiser Construction	4,400.000	$10.00
087416	Centro de Transferencia de Carolina	07-Oct-96 Constructora Hartman, S.E.	1,200.000	$18.00 *

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Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
090120	Mejoras a PR-901, Yabucoa-M Yabucoa	08-Jan-01 Constructora I. Melendez	755.000	$18.00
090121	Reemplazo P/S Quebrada Las Maunabo	15-Nov-99 Best Work	1,300.000	$11.75
091606	Reemplazo del P/S Quebrada San Lorenzo	30-Jul-01 Best Wok, S.E.	3,430.000	$7.00
092509	Construcción de Calle Margi Humacao	19-Oct-00 Morales Construction	4,188.000	$5.00
093107	Mejoras Geometricas, (Unida Gurabo	23-Oct-96 Guirimar Construction, Inc	50.000	$10.00
094107	Reemplazo del P/S Rio Gurab Gurabo	06-Oct-97 Constructora Santiago	2,140.000	$11.00
096604	Reconstruccion de PR-966 Rio Grande	22-May-98 Burdocaf Inc.	3,000.000	$25.00
096611	Reconstruccion de la PR-966 Rio Grande	05-Dec-00 DBA Construction	1,000.000	$20.00
098002	Reemplazo Puente #436 P/S R San Lorenzo	16-May-94 Equipos y Constructora, R.V.D.	1,890.000	$7.00
098709	Reemplazo P/S Qda Sardinera Fajardo	21-Jun-99 Best Work Construction	1,900.000	$11.00
099707	Mejoras a Carretera PR-997 Vieques	05-Oct-02 Aluma Construction	160.000	$22.00
100013	Arecibo-Utuado, PR-10 Utuado	07-Nov-94 Las Piedras Construction	35,260.000	$1.00
100017	Arecibo-Utuado, PR-10 Arecibo	10-Oct-94 Redondo Construction	24,300.000	$6.25
100024	Construccion PR-10 Ponce-Ad Ponce	10-Jul-95 Jusor Corporation	31,400.000	$2.00

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
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I T E M   H I S T O R Y

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Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
100029	Adjuntas-Ponce Ponce	18-Nov-96 Redondo Construction	53,252.000	$0.40
100037	Construccion seccion de car Utuado	30-Nov-98 Las Piedras Construction	6,300.000	$6.00
100049	Desvio Temporero PR-10 Adjuntas	06-Apr-00 Constructora Jose Carro	900.000	$20.00 *
100053	Construcción de Atarjea Adjuntas	10-Jan-02 Tamrio, Inc.	700.000	$8.00
100100	Reemplazo del P/S Rio Majad Salinas	23-Nov-00 Constructora Jose Carro	6,126.000	$10.00
100197	Mejoras Geometricas, (Unida Caguas	23-Oct-96 Guirimar Construction, Inc	1,342.000	$10.00
100197	Mejoras Geometricas, (Unida Caguas	23-Oct-96 Guirimar Construction, Inc	200.000	$40.00
100200	Mejoras Geometricas en Int Caguas	06-Oct-97 DBA Construction	1,400.000	$12.00
100201	Reconstruccion y Mejoras PR Caguas	22-Oct-01 Bermudez y Longo	690.000	$7.70
100203	Ensanche PR-1, desde PR-15 Cayey	21-Nov-00 Best Work, S.E.	7,800.000	$8.00
100204	Conversion a Expreso PR-1, Gurabo-San Juan-Gagu	21-Dec-00 Rio Construction	1,600.000	$20.00
100210	Conversion a Expreso PR-1, Caguas	21-Dec-00 Rio Construction	640.000	$20.00
140005	Avenida Malecon Ponce	06-May-96 Constructora Santiago	3,460.000	$10.00
140009	Mejoras a la Interseccion d Ponce	13-Nov-98 Del Valle Group	297.000	$6.00

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I T E M   H I S T O R Y

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Description =====> Subbase Course (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price	
140014	Mejoras Geometricas, Inter Ponce	15-Oct-01 Robles Asphalt	140.000	$18.00	
156003	Mejoras a PR-156 Barranquitas	08-Jan-01 Lasami Construction	235.000	$12.00	
167005	Mejoras a PR-167, desde El Bayamon-Toa Alta	22-Jun-00 Del Valle Group	322.000	$15.00	
181003	Reemplazo P/S El Rio Grande Gurabo	08-Nov-01 Equipos y Constructora RVD	2,700.000	$12.00	
200006	Reconstruccion PR-2 Aguada-Anasco	28-Aug-95 Betteroads Asphalt	33,000.000	$3.00	
200036	Nuevo Via Ducto de Mayaguez Mayaguez	10-Mar-97 Jusor Corporation	3,000.000	$10.00	
200038	Hormigueros-San German Hormigueros	08-Mar-93 Cabimar Construction, S. E.	15,074.000	$4.00	
200046	Reemplazo P/S Rio Yauco Num Yauco	08-May-00 Tamrio, Inc.	8,261.000	$10.00	
200049	Ensanche de la PR-2 Manati	10-Oct-94 Jusor Corporation	14,000.000	$7.00	
200058	Reconstruccion PR-2 San German-Sab. Gde.	22-Nov-93 Cabimar Construction, S. E.	49,600.000	$2.00	
200059	P/S Quebrada Merle Mayaguez	24-Feb-95 Jusor Corporation	5,900.000	$8.00	
200067	Reconstruccion Camino Los V Mayaguez	05-Aug-96 Roberto Morales, Inc.	4,000.000	$11.00	
200067	Reconstruccion Camino Los V Mayaguez	05-Aug-96 Roberto Morales, Inc.	850.000	$20.00	*
200074	Ensanche PR-2 Est. 10+00 a Aguada	06-Oct-95 Betteroads Asphalt	34,600.000	$3.00	

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M H I S T O R Y

Specific Code ===> 301-001
Description =====> Subbase Course (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
200077	Relocalizacion Calle Post, Mayaguez	26-Jun-95 Jusor Corporation	2,880.000	$10.00
200078	Mejoras a la PR-2, Sec Maya May-Horm-Cabo Rojo	27-Mar-95 Empresas Inabon	190.000	$24.00
200079	Mejoras a la calle Post PR- Mayaguez	19-Aug-96 Jusor Corporation	2,700.000	$10.00
200081	Conversion a Expreso Avenid San Juan	19-Dec-97 ICA Miramar Corporation	24,908.000	$11.20
200082	Construccion de Conector en Barceloneta	25-Apr-97 Denton Construction	851.000	$10.00
200087	Conversion a Expreso Avenid San Juan	28-Dec-95 Unitech Engineering	6,300.000	$10.00
200099	Sistema de Semaforo y Mejor Hormigueros-San Germ	22-Jun-98 Tamrio, Inc.	1,000.000	$5.00
200105	Construccion de Carretera M Anasco	18-Jul-97 Jusor Corporation	7,580.000	$9.00
200109	Reconstruccion PR-2 y const Dorado-Vega Alta	11-Dec-97 MAS Construction	1,150.000	$20.00
200110	Mejoras a Interseccion Capa Guaynabo	21-Sep-98 Constructora Santiago	4,536.000	$12.00
200114	Mejoras a PR-2 Int. PR-343 Hormigueros	27-Jun-97 Cabimar Construction, S. E.	600.000	$9.00
200115	Conversion a Expreso Avenid San Juan	21-Sep-98 Constructora Santiago	125.000	$12.00
200117	Mejoras Geometricas y Siste Bayamon	18-Mar-99 Unique Builders	4,600.000	$10.65
200123	Rehabilitacion Pav PR-2, Pa Aguadilla	28-Dec-98 Constructora Santiago	10,000.000	$8.60

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 301-001
Description =====> Subbase Course (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price	
200125	Nueva Carretera Local y Mej Aguadilla	07-Feb-00 Tamrio, Inc.	1,600.000	$10.00	
200131	Conversion a Expreso Avenid San Juan	13-Mar-00 Guirimar Construction	1,534.000	$8.00	
200131	Conversion a Expreso Avenid San Juan	13-Mar-00 Guirimar Construction	1,800.000	$12.00	*
200133	Calle Marginal Norte, Secto Bayamon	28-Dec-00 Unique Builders	3,050.000	$13.45	
200158	Mejoras Calle Post (Etapa I Mayaguez	08-Jan-01 Cabimar, SE	150.000	$40.00	
200162	Mejoras Geometricas PR-2 in Aguadilla	03-May-01 Leafar Construction	1,750.000	$15.00	
200179	Rehabilitacion de Pavimento Anasco-Mayaguez	12-Mar-01 Cabimar S.E.	160.000	$20.00	
200272	Ensanche Carretera PR-2 Arecibo	01-Apr-96 Denton Construction	49,500.000	$9.50	
200278	P/S La Quebrada Berrinchin Yauco	16-May-96 Constructora W. F.	1,600.000	$6.00	*
220021	Expreso de Diego Vega Baja	01-Apr-91 Las Piedras Construction	68,000.000	$0.45	
220046	Expreso de Diego, PR-22 Manati	19-Sep-94 Redondo Construction	3,000.000	$6.80	
220050	Desarrollo las Acerolas Exp Vega Baja	08-Jul-94 MAS Construction	230.000	$10.00	
220051	Desarrollo Cordova-Davila P Manati	08-Jul-94 Del Valle Group	1,014.000	$2.20	
220057	Mejoras a la Interseccion d Toa Baja	16-Aug-96 Del Valle Group	2,000.000	$10.00	

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 301-001
Description =====> Subbase Course (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
220071	Construccion Carretera 2 Ex Manati	19-Feb-96 Francisco Levy, Hijo	1,425.000	$16.00
220091	Modificacion de Plaza de Pe Toa Baja	10-May-99 Tamrio, Inc.	22,000.000	$10.00
220095	Mejoras a Int Caparra, Fase San Juan	17-Nov-97 Redondo Construction	15,311.000	$11.00
220096	Modificacion Plaza Peaje y Hatillo	19-Jan-98 Constructora Fortis	17,978.000	$10.00
220103	Construccion de Rampa, Auto Vega Alta	01-Feb-99 Constructora Fortis	1,362.000	$12.00
220105	Mejoras a Plaza de Peaje Ve Vega Alta	10-Dec-01 Del Valle Group	8,700.000	$10.00
220112	Mejoras Geometricas Autopoi Bayamon	10-Jan-02 Del Valle Group	12,380.000	$12.00
220114	Ensanche y Mejoras Autopist Guaynabo	10-Jan-02 LPC & D, Inc.	12,635.000	$12.50
220116	Mejoras Interseccion Autopi Guaynabo	01-Mar-99 Constructora Santiago	1,700.000	$18.00
220129	Mejoras a Plaza de Peaje Bu Guaynabo	24-Jul-00 Constructora Hartman, SE	1,200.000	$42.00
220130	Mejoras Plaza Peaje Buchana Guaynabo	08-Jan-01 LPC & D, Inc.	21,200.000	$2.00
220132	Mejoras a Interseccion Auto Guaynabo	11-Aug-00 Guirimar Construction	2,000.000	$20.00
220150	Rampa de Acceso a Sector Be San Juan	25-Feb-02 Guirimar Construction	8,080.000	$4.00
300042	P/S Quebrada Lajas Rio Grande	05-Aug-96 Caribbean Contractors, Inc	200.000	$22.00

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 301-001
Description =====> Subbase Course (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
300048	Mejoras a Intersecciones Yabucoa	08-Jul-94 Caribbean Contractors	4,100.000	$8.00
300050	Mejoras Geometricas Desde P Carolina	07-Dec-95 RUTSA Construction	1,300.000	$13.00
300053	Interseccion PR-181 con PR- San Juan	28-Jan-02 LPC & D, Inc.	9,400.000	$5.00
300056	Mejoras PR-3 A Int. PR-3 a Patillas	21-Aug-95 DMI Construction	1,550.000	$5.00
300058	Mejoras Carreteras PR-3, de Guayama-Arroyo	18-Dec-00 Constructora I. Melendez	18,600.000	$9.00
300060	Mejoras PR-3 Km. 13.10 a 47 Carolina-Fajardo	18-Mar-96 Caribbean Contractors, Inc	2,400.000	$14.00
300063	Ensanche de PR-3 Arroyo	09-Feb-99 Constructora I. Melendez	1,750.000	$12.00
300064	Mejoras PR-3 Arroyo	26-Nov-99 MAS Construction	29,370.000	$10.00
300069	Mejoras a la PR-3, desde St Rio Grande	13-Oct-00 Rio Construction	4,000.000	$20.00
300073	Mejoras a PR-3 (Quebrada Co Guayama-Arroyo	07-Feb-02 L. Reyes Construction	6,800.000	$9.00
300076	Mejoras a PR-3, Desvio Sur Arroyo	12-Mar-01 Morales Construction	8,800.000	$7.00
300101	Mejoras Geometricas Gaguas-Gurabo	08-Jan-01 San Rental Equipment	808.000	$10.00
313201	Desvio Sur de Penuelas Penuelas	07-Feb-02 Cabimar S.E.	16,600.000	$7.00
330069	Mejoras Geometricas Canovanas-Rio Grande	08-Jan-01 Tamrio, Inc.	1,400.000	$12.00

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 301-001
Description =====> Subbase Course (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price	
331101	Reconstruccion de Carretera Cabo Rojo	11-Sep-00 Cabimar, SE	2,440.000	$15.00	
500044	Mejoras Corredor De Metrobu San Juan-Rio Piedras	18-Dec-95 Frank Rullan & Associates	50.000	$58.95	
520016	Rampa de Acceso Avenida Mon San Juan	03-Aug-98 Del Valle Group	4,000.000	$10.00	
520029	Rehabilitacion de Pavimento Santa Isabel	08-Jun-98 Cabimar Construction, S. E.	375.000	$18.00	*
520039	Mejoras a Autopista Luis A. San Juan	03-Sep-01 Guirimar Construction	19,600.000	$6.00	
520044	Repavimentacion de Autopist Cayey	24-Jul-00 Leafar Construction	50.000	$100.00	
520232	Estacion de Pesaje de Camio Salinas	17-Jul-00 Caribbean Quarry	24,900.000	$3.75	
525240	Pavimentos y Estructuras PR Ponce	03-Feb-94 Del Valle Group	13,500.000	$2.10	
525240	Pavimentos y Estructuras PR Ponce	03-Feb-94 Del Valle Group	60,947.000	$1.30	*
525241	Desvio Sur de Ponce Ponce	02-Jan-91 Redondo Construction	13,585.000	$4.50	
525246	Rehabilitacion Pavimento y Juana Diaz-Ponce	30-Oct-97 Del Valle Group	2,500.000	$10.00	*
525254	Mejoras a Plaza de Peaje y Salinas	18-Jul-94 Del Valle Group	3,000.000	$1.65	
525269	Construccion PR-52 Int PR-5 Ponce	27-Dec-94 Constructora Santiago	50,100.000	$3.90	
525277	Rampa en Interseccion con P San Juan	18-Sep-95 Constructora Hartman, S.E.	5,700.000	$2.00	

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 301-001
Description =====> Subbase Course (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
664201	Desvio Este de Florida Florida	16-May-94 Equipos y Constructora, R.V.D.	39,400.000	$1.50
700222	Construccion de Muro de Con Maricao	08-Jan-01 Paisy Asphalt	60.000	$27.00
773301	Desvio de Cidra Cidra	05-Sep-96 Ismael Gonzalez Construction	6,100.000	$8.00
885501	Calle Periferal Norte Fase Bayamon	18-Sep-96 Del Valle Group	30,189.000	$8.40
886005	Reconstruccion PR-8860 desd Carolina	11-Dec-97 Constructora Seguinot	3,780.000	$7.50
886006	Reconstruccion desde Zona I Trujillo Alto	22-May-98 Guirimar Construction, Inc.	15,500.000	$1.00
886101	Desvio Sur de Toa Alta Toa Alta	13-Jun-94 DMI Construction	600.000	$15.00 *
918901	Mejoras Geometricas, (Unida Gurabo	23-Oct-96 Guirimar Construction, Inc	2,000.000	$10.00
991301	Desvio Sur de Juncos Juncos	28-May-96 Best Work Construction	1,350.000	$8.50
991946	Construccion Desvio Norte d Juncos	11-Dec-97 LPC & D, Inc.	23,000.000	$0.69
992127	Avenida Rafael Cordero Caguas	18-May-92 Ismael Gonzalez Construction	6,935.000	$10.00 *
993605	P/S Rio Gurabo Las Piedras	08-Sep-97 R. O. Construction, Inc.	840.000	$9.25
993605	P/S Rio Gurabo Las Piedras	21-Oct-94 Empresas Inabon	840.000	$9.00
994402	Desvio Norte de Gurabo Gurabo	01-Feb-99 Morales Construction	2,256.000	$9.00

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 301-001
Description =====> Subbase Course (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price

308 Projects
Total Quantity ====> 4,413,058.000
Total Amount ======> $26,155,231.35
Weighed Mean ======> $5.93
Arithmetic Mean ===> $12.06
* Item by EWO

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AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 301-002
Description =====> Subbase Course (A-2-4 Only) (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
011195	Sistema de Semaforos PR-111 San Sebastian	11-Sep-00 Toledo Electrical Contractor	25.000	$8.13
014705	Construccion de la PR-147 Naranjito	30-Jan-95 Rio Construction	15,488.000	$6.00 *
111095	Sistema de Semaforos, PR-11 San Sebastian	11-Sep-00 Toledo Electrical Contractors	75.000	$7.19
515501	Desvio de Orocovis Orocovis	07-Jun-99 Caribbean Quarry	2,800.000	$15.00
700206	Correccion de Deslizamiento Adjuntas	11-Sep-00 Burdocaf Inc.	100.000	$25.00
700206	Construccion de Muros de Ga Coamo-Villalba	17-Apr-01 Constructora Fortis, Inc.	235.000	$20.00

6 Projects

Total Quantity ====> 18,723.000
Total Amount ======> $142,870.50
Weighed Mean ======> $7.63
Arithmetic Mean ===> $13.55
* Item by EWO

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M H I S T O R Y

Specific Code ===> 402-003
Description =====> Replacement Subbase Material (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
000063	Mejoras a la Avenida Dunsco Mayaguez	01-Jul-96 Jusor Corporation	90.000	$25.00
000273	Mejoras Geometricas a Int P Aguadilla	06-Oct-97 Jusor Corporation	135.000	$100.00
001848	Rehabilitacion de Pavimento San Juan	08-Jun-98 Jusor Corporation	8,316.000	$4.00
002312	Instalacion Sistema Semafor San Juan	29-Jul-96 Bermudez & Longo, Inc.	245.000	$53.55
002637	Mejoras al Area de Los Ange Carolina	19-Sep-94 Mejia Construction	60.000	$30.00
002651	Rehabilitacion Pavimento PR Carolina	04-Oct-93 R.B.R. Construction, S.E.	1,440.000	$10.00
002722	Mejoras Geometricas y al Si San Juan	22-Aug-97 Bermudez & Longo, Inc.	300.000	$46.60
002903	Mejoras Geom, Sistema de Se Bayamon	14-Sep-98 Bermudez & Longo, Inc.	3,000.000	$29.00
003131	Reconstruccion de PR-31 Humacao	28-Nov-94 Alco Corporation	180.000	$15.00
010517	Reconstruccion Maricao-Buca Maricao	22-Aug-94 Cabimar Construction, S. E.	250.000	$8.00
010822	Reconstruccion Miradero-Rio May-Ana-L. Marias	22-Aug-94 Cabimar Construction, S. E.	850.000	$8.00
010919	Reconstruccion PR-109 San Sebastian-Anasco	08-May-95 Alco Corporation	700.000	$11.00
011949	Reconstruccion PR-119 San Sebastian-Camuy	08-May-95 Alco Corporation	850.000	$11.00
012508	Calle Emerito Estrada River San Sebastian-Moca	08-May-95 Alco Corporation	36.000	$11.00

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 402-003
Description =====> Replacement Subbase Material (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
014962	PR-1 to PR-52 Juana Diaz	14-Mar-94 Empresas Tito Castro	1,400.000	$6.00 *
015114	Villalba to PR-143 Villalba	14-Mar-94 Empresas Tito Castro	150.000	$6.00
015559	Reconstruccion PR-155 Vega Baja	16-May-94 Robles Asphalt, Corp.	300.000	$15.00
015561	Reconstruccion de PR-155 Morovis	12-Sep-94 Constructora Fortis	1,400.000	$15.00
016777	Avenida Sabana Seca, PR-199 Bayamon	19-Sep-94 Betteroads Asphalt	4,190.000	$19.00
017330	Rabanal Cidra	24-Feb-95 Constructora Fortis	68.000	$35.00
018191	Trujillo Alto-San Lorenzo Gurabo-San Lorenzo	28-Nov-94 Alco Corporation	150.000	$15.00
018212	Guayabotas Yabucoa	14-Mar-94 Betteroads Asphalt	35.000	$22.00
018336	San Lorenzo-Las Piedras S.Lorenzo-Junco-L.Pi	28-Nov-94 Alco Corporation	225.000	$15.00
018925	Mejoras Geometricas, (Unida Gurabo	23-Oct-96 Guirimar Construction, Inc	2,650.000	$15.00
019920	Mejoras Avenida Las Cumbres Bayamon	16-Jul-98 Rexach Construction	500.000	$33.81
019953	Reconstruccion Sist de Sema San Juan	07-Nov-97 Unique Builders	250.000	$44.80
041113	Aguada-Bo. Atalaya Aguada	13-Jun-94 United Asphalt	200.000	$4.00
041607	Reconstruccion PR-416 Calle Aguada	11-Aug-95 Cabimar Construction, S. E.	80.000	$6.00

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 402-003
Description =====> Replacement Subbase Material (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
041709	Reconstruccion PR-417, Unid Aguada	11-Aug-95 Cabimar Construction, S. E.	200.000	$6.00
041907	Reconstruccion PR-419 Aguada	27-Mar-95 Cabimar Construction, S. E.	15.000	$5.00
042011	Reconstruccion de la PR-420 Moca	30-Jan-95 Betteroads Asphalt	30.000	$8.00
056207	Apeadero Dona Juana Villalba	14-Mar-94 Empresas Tito Castro	19.000	$6.00 *
056708	Reconstruccion PR-567 Orocovis-Morovis	16-May-94 Robles Asphalt, Corp.	100.000	$10.00
063206	Poniente Ciales	24-Feb-95 Constructora Fortis	50.000	$40.00
063207	Hato Viejo Manati	24-Feb-95 Constructora Fortis	90.000	$35.00
077510	Reconstruccion PR-775 Comerio	16-May-94 Empresas Inabon	80.000	$20.00
077906	Reconstruccion PR-779, PALO Comerio	19-Aug-94 Best Work Construction	30.000	$38.00
080204	Reconstruccion Carr. Palmar Corozal & Naranjito	13-Jun-94 Constructora Fortis	90.000	$30.00
081405	Reconstruccion de la PR-814 Naranjito	27-Dec-94 Alco Corporation	11.000	$25.00
085311	Reconstruccion PR-853, Call Canovanas	10-Oct-94 Betteroads Asphalt	135.000	$21.00
086603	Ensanche PR-866 Toa Baja	04-Oct-93 Kaiser Construction	165.000	$10.00
091706	Montones 1 Las Piedras	31-May-94 DBA Construction	84.000	$10.00

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 402-003
Description =====> Replacement Subbase Material (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
091707	Montones 2 Las Piedras	31-May-94 DBA Construction	50.000	$10.00
092709	Reconstruccion de PR-927 Humacao	28-Nov-94 Alco Corporation	100.000	$15.00
093106	Navarro Gurabo-San Lorenzo	28-Nov-94 Alco Corporation	25.000	$15.00
093506	Ceiba Norte Juncos	31-May-94 DBA Construction	225.000	$10.00
096204	Reconstruccion PR-962, Camb Canovanas	10-Oct-94 Betteroads Asphalt	25.000	$19.00
099204	Mameyes Luquillo	14-Mar-94 Betteroads Asphalt	90.000	$30.00
100035	Reconstruccion PR-10 de PR- Arecibo	02-May-97 Betteroads Asphalt	900.000	$20.00
200006	Reconstruccion PR-2 Aguada-Anasco	28-Aug-95 Betteroads Asphalt	4,800.000	$5.00
200061	Rehabilitacion de la PR-2 V. Alta-Baja, Manati	08-Jul-94 Redondo Construction	2,200.000	$8.50
200070	Mejoras Carril Reversible Bayamon-Guaynabo	27-Mar-95 Bermudez & Longo, Inc.	700.000	$49.50
200074	Ensanche PR-2 Est. 10+00 a Aguada	06-Oct-95 Betteroads Asphalt	2,866.000	$4.25
200076	Mejoras PR-2 desde Km 14 ha Bayamon-Toa Baja	24-Feb-95 Betteroads Asphalt	460.000	$20.00
200078	Mejoras a la PR-2, Sec Maya May-Horm-Cabo Rojo	27-Mar-95 Empresas Inabon	90.000	$24.00
200107	Rehabilitacion de Pavimento Ponce	03-Jul-97 Del Valle Group	450.000	$15.00

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 402-003
Description =====> Replacement Subbase Material (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
200109	Reconstruccion PR-2 y const Dorado-Vega Alta	11-Dec-97 MAS Construction	1,764.000	$30.00
200112	Reconstruccion PR-2 de PR-1 Isabela-Quebradillas	06-Oct-97 Betteroads Asphalt	22,700.000	$23.00
200116	Rehabilitacion de Pavimento Camuy-Hatillo	06-Oct-97 Del Valle Group	6,200.000	$20.00
200123	Rehabilitacion Pav PR-2, Pa Aguadilla	28-Dec-98 Constructora Santiago	200.000	$10.00
200277	Ensanche PR-2 Mayaguez-Añasco	13-Oct-92 Constructora Santiago	338.720	$8.18 *
220047	Repavimentacion PR-22 Hatillo	09-Dec-93 United Asphalt	565.000	$10.00
220066	Reparacion Carretera PR-22 Arecibo-Hatillo	02-Nov-95 Alco Corporation	1,659.000	$18.00
220091	Modificacion de Plaza de Pe Toa Baja	10-May-99 Tamrio, Inc.	1,500.000	$20.00
220114	Ensanche y Mejoras Autopist Guaynabo	10-Jan-02 LPC & D, Inc.	400.000	$30.00
300050	Mejoras Geometricas Desde P Carolina	07-Dec-95 RUTSA Construction	10,750.000	$12.00
525251	Reparacion Pavimento Cayey-Salinas	29-Jul-98 Insurance Company of North Ame	38.240	$10.00
525251	Reparacion Pavimento Cayey-Salinas	03-Feb-94 Empresas Inabon	45.000	$10.00
525287	Rehabilitacion y Mantenimie Salinas-Juana Diaz	08-Jul-96 Caribbean Contractors, Inc	1,500.000	$15.00
886005	Reconstruccion PR-8860 desd Carolina	11-Dec-97 Constructora Seguinot	7,625.000	$10.00

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 402-003
Description =====> Replacement Subbase Material (CuM)

Project	Project Name Municipality	Start Date Contractor	Quantity	Unit Price
886101	Desvio Sur de Toa Alta Toa Alta	13-Jun-94 DMI Construction	25.000	$20.00
918901	Mejoras Geometricas, (Unida Gurabo	23-Oct-96 Guirimar Construction, Inc	150.000	$15.00

72 Projects
Total Quantity ====> 97,589.960
Total Amount ======> $1,565,474.38
Weighed Mean ======> $16.04
Arithmetic Mean ===> $19.22
* Item by EWO

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 503-002
Description =====> Replacement Subbase Material (CuM)

Project	Project Name Municipality	Start Date Contractor	Quantity	Unit Price	
000273	Mejoras Geometricas a Int P Aguadilla	06-Oct-97 Jusor Corporation	518.000	$40.00	
001848	Rehabilitacion de Pavimento San Juan	08-Jun-98 Jusor Corporation	1,077.000	$34.00	
002651	Rehabilitacion Pavimento PR Carolina	04-Oct-93 R.B.R. Construction, S.E.	3,680.000	$5.00	
003049	Desvio Sur de Humacao Humacao	10-Aug-92 Del Valle Group	157.000	$16.00	
003050	Reparacion de Pavimento PR- Gurabo-Las Piedras	03-Feb-94 Redondo Construction	5,000.000	$7.00	
003052	Mejoras Desvio Sur Humacao Humacao	30-May-95 Del Valle Group	513.000	$12.00	
003053	Las Piedras Humacao, PR-30 Las Piedras-Humacao	21-Oct-94 Betteroads Asphalt	220.000	$8.20	
011523	Reconstruccion de la PR-115 Rincon	10-Mar-97 PROTA Construction	3,200.000	$30.00	*
019920	Mejoras Avenida Las Cumbres Bayamon	16-Jul-98 Rexach Construction	750.000	$33.81	
019953	Reconstruccion Sist de Sema San Juan	07-Nov-97 Unique Builders	438.000	$44.80	
101848	Expreso Las Americas, PR-18 San Juan	08-Jan-01 Rio Construction	500.000	$40.00	
181001	Rehabilitacion de Pavimento San Juan-Trujillo Al	12-Oct-98 Guirimar Construction, Inc	5,950.000	$12.00	
181001	Rehabilitacion de Pavimento San Juan-Trujillo Al	12-Oct-98 Guirimar Construction, Inc	130.000	$48.00	*
181001	Rehabilitacion de Pavimento San Juan-Trujillo Al	12-Oct-98 Guirimar Construction, Inc	160.000	$48.00	*

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M   H I S T O R Y

Specific Code ===> 503-002
Description =====> Replacement Subbase Material (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
181001	Rehabilitacion de Pavimento San Juan-Trujillo Al	12-Oct-98 Guirimar Construction, Inc	3,700.000	$26.90 *
200012	Mejoras al Pavimento Mayaguez-Hormigueros	16-Feb-96 Cabimar Construction, S. E.	27.000	$40.00
200038	Hormigueros-San German Hormigueros	08-Mar-93 Cabimar Construction, S. E.	2,903.000	$10.00
200039	Reparacion de Pavimento PR- Sabana Grande-Yauco	04-Oct-93 Empresas Inabon	4,500.000	$6.50
200058	Reconstruccion PR-2 San German-Sab. Gde.	22-Nov-93 Cabimar Construction, S. E.	6,321.000	$4.00
200123	Rehabilitacion Pav PR-2, Pa Aguadilla	28-Dec-98 Constructora Santiago	1,800.000	$13.00
200134	Rehabilitacion del Paviment Sabana Grande-Guanic	05-Dec-00 Constructora I. Melendez	1,200.000	$25.00
220041	Reparacion de Pavimento Arecibo-Hatillo	01-Dec-92 Del Valle Group	190.000	$11.00
220092	Ensanche hacia Isleta Centr Bayamon	15-May-00 LPC & D, Inc.	220.000	$60.00
220096	Modificacion Plaza Peaje y Hatillo	19-Jan-98 Constructora Fortis	44.000	$59.00
220100	Rehabilitacion de Pavimento Arecibo-Hatillo	23-Mar-98 Unitech Engineering	539.000	$20.00
220101	Rehabilitacion Pav PR-22 Km San Juan	14-May-98 Francisco Levy, Hijo	519.000	$6.00
220113	Ensanche hacia Isleta Centr Bayamon-Guaynabo	15-May-00 JJMR Construction, SE	220.000	$40.00
520014	Rehabilitacion Pav Aut Luis San Juan-Caguas	17-Nov-97 PROTA Construction	569.000	$26.00

AUTORIDAD DE CARRETERAS Y TRANSPORTACION
AREA DE CONSTRUCCION
OFICINA CONTROL DE PROYECTOS

I T E M H I S T O R Y

Specific Code ===> 503-002
Description =====> Replacement Subbase Material (CuM)

Project	Project Name / Municipality	Start Date / Contractor	Quantity	Unit Price
520018	Rehabilitacion Pavimento Au San Juan	14-May-98 Francisco Levy, Hijo	1,468.000	$6.00
520025	Reconstruccion de pavimento Salinas	30-Nov-98 Jusor Corporation	1,071.000	$29.00
520027	Rehabilitacion Pav Autopist Ponce	18-May-98 Del Valle Group	283.000	$12.00
520029	Rehabilitacion de Pavimento Santa Isabel	08-Jun-98 Cabimar Construction, S. E.	66.000	$30.00
525246	Rehabilitacion Pavimento y Juana Diaz-Ponce	30-Oct-97 Del Valle Group	6,100.000	$12.00
525246	Rehabilitacion Pavimento y Juana Diaz-Ponce	01-Mar-96 Empresas Inabon	6,100.000	$11.30
525251	Reparacion Pavimento Cayey-Salinas	29-Jul-98 Insurance Company of North Ame	2,249.990	$3.00
525251	Reparacion Pavimento Cayey-Salinas	03-Feb-94 Empresas Inabon	3,379.000	$3.00
525253	Reconstruccion de Pavimento Salinas	08-Aug-94 Redondo Construction	670.000	$12.00
525254	Mejoras a Plaza de Peaje y Salinas	18-Jul-94 Del Valle Group	3,200.000	$11.00
525287	Rehabilitacion y Mantenimie Salinas-Juana Diaz	08-Jul-96 Caribbean Contractors, Inc	2,370.000	$15.00

39 Projects
Total Quantity ====> 72,001.990
Total Amount ======> $943,507.87
Weighed Mean ======> $13.10
Arithmetic Mean ===> $22.32
* Item by EWO

H. Municipal Solid Waste Facts from the SWMA

ANALISIS GENERACION Y RECICLAJE POR MUNICIPIOS AÑO 1999

Municipio	LBS. REC.	TONS.	%RECI.	POBL. EST.(1999)	TGPD	TGPA	LBS/PERS/DIA
1 Adjuntas	299,440	150	3.51	19,644	16.40	4,265	1.67
2 Aguada	0	0	0.00	40,010	52.81	13,731	2.64
3 Aguadilla	354,753	177	0.70	67,050	96.89	25,191	2.89
4 Aguas Buenas	186,000	93	0.95	31,841	37.73	9,810	2.37
5 Aibonito	0	0	0.00	27,993	27.01	7,023	1.93
6 Añasco	1,099,309	550	4.11	28,556	51.40	13,364	3.60
7 Arecibo	573,070	287	0.49	102,294	226.07	58,778	4.42
8 Arroyo	115,468	58	1.49	20,153	14.91	3,877	1.48
9 Barceloneta	80,890	40	0.13	27,524	121.52	31,595	8.83
10 Barranquitas	147,636	74	1.26	29,031	22.50	5,850	1.55
11 Bayamón	668,000	334	0.26	236,688	491.13	127,693	4.15
12 Cabo Rojo	432,782	216	1.05	49,368	79.48	20,665	3.22
13 Caguas	10,464,823	5,232	5.04	145,193	399.28	103,813	5.50
14 Camuy	333,639	167	1.58	33,235	40.71	10,585	2.45
15 Canóvanas	128,000	64	0.28	51,925	89.05	23,153	3.43
16 Carolina	494,000	247	0.14	192,088	671.35	174,550	6.99
17 Cataño	68,240	34	0.03	32,365	455.21	118,356	28.13
18 Cayey	0	0	0.00	51,117	72.59	18,872	2.84
19 Ceiba	25,192	13	0.42	18,946	11.46	2,980	1.21
20 Ciales	414,505	207	1.69	20,997	47.24	12,283	4.50
21 Cidra	2,070,247	1,035	5.12	50,019	77.78	20,223	3.11
22 Coamo	106,821	53	0.41	37,330	50.21	13,054	2.69
23 Comerío	115,226	58	4.58	20,583	4.84	1,258	0.47
24 Corozal	382,000	191	3.95	36,804	18.59	4,832	1.01
25 Culebra	0	0	0.00	1,771	11.89	3,092	13.43
26 Dorado	1,077,789	539	2.20	35,104	94.08	24,460	5.36
27 Fajardo	1,274,067	637	1.46	38,605	167.93	43,662	3.70
28 Florida	43,060	22	0.42	9,107	19.53	5,079	4.29
29 Guánica	188,402	94	0.71	21,630	50.94	13,244	4.71
30 Guayama	1,106,023	553	4.09	44,066	52.00	13,519	2.36
31 Guayanilla	154,931	77	0.31	28,538	95.74	24,894	6.71
32 Guaynabo	1,143,000	572	0.69	104,936	319.01	82,941	6.08
33 Gurabo	494,189	247	3.16	34,006	30.10	7,825	1.77
34 Hatillo	105,211	53	0.29	40,897	70.96	18,449	3.47
35 Hormigueros	177,024	89	1.17	17,070	29.02	7,545	3.40
36 Humacao	293,526	147	0.36	60,036	155.49	40,428	5.18
37 Isabela	107,078	54	0.26	43,118	78.04	20,291	3.62
38 Jayuya	505,440	253	4.28	16,891	22.72	5,907	2.69
39 Juana Díaz	260,005	130	0.65	52,461	76.59	19,914	2.92
40 Juncos	5,361,759	2,681	26.14	43,591	39.45	10,257	1.81
41 Lajas	310,499	155	1.37	27,797	43.50	11,311	3.13
42 Lares	141,745	71	0.43	33,016	63.23	16,439	3.33
43 Las Marías	48,109	24	0.98	9,887	9.44	2,455	1.91
44 Las Piedras	498,020	249	3.31	32,137	28.92	7,520	1.80
45 Loíza	96,148	48	0.37	28,070	49.40	12,845	3.52
46 Luquillo	34,899	17	0.15	18,877	43.32	11,264	4.59
47 Manatí	224,000	112	0.31	42,079	140.12	36,432	6.66
48 Maricao	69,785	35	1.40	6,130	9.59	2,494	3.13
49 Maunabo	26,220	13	0.27	13,874	18.80	4,888	2.71
50 Mayaguez	501,605	251	0.36	100,463	267.73	69,611	5.33
51 Moca	89,066	45	0.31	38,424	56.10	14,586	2.92
52 Morovis	67,650	34	0.54	34,014	24.15	6,279	1.42
53 Naguabo	296,832	148	2.18	25,382	26.14	6,797	2.06
54 Naranjito	21,500	11	0.12	29,272	34.39	8,943	2.35
55 Orocovis	435,285	218	3.20	25,155	26.16	6,802	2.08
56 Patillas	114,200	57	2.09	21,904	10.51	2,734	0.96

57	**Peñuelas**	126,542	63	***0.39***		27,199	61.88	**16,088**	*4.55*
58	**Ponce**	8,303,591	4,152	***1.97***		193,640	812.32	**211,203**	*8.39*
59	**Quebradillas**	1,244,555	622	***5.64***		26,093	42.40	**11,024**	*3.25*
60	**Rincón**	317,451	159	***1.70***		14,317	35.94	**9,343**	*5.02*
61	**Río Grande**	122,609	61	***0.43***		51,267	55.11	**14,329**	*2.15*
62	**Sabana Grande**	353,059	177	***1.64***		24,917	41.49	**10,787**	*3.33*
63	**Salinas**	0	0	***0.00***		30,597	36.10	**9,387**	*2.36*
64	**San Germán**	436,719	218	***1.42***		38,814	59.00	**15,339**	*3.04*
65	**San Juan**	97,661,520	48,831	***18.18***		439,604	1,033.07	**268,598**	*4.70*
66	**San Lorenzo**	70,716	35	***0.30***		38,444	44.79	**11,645**	*2.33*
67	**San Sebastián**	148,662	74	***0.35***		43,854	80.69	**20,980**	*3.68*
68	**Santa Isabel**	0	0	***0.00***		20,155	50.29	**13,075**	*4.99*
69	**Toa Alta**	0	0	***0.00***		61,579	40.64	**10,567**	*1.32*
70	**Toa Baja**	292,140	146	***0.10***		94,837	550.53	**143,137**	*11.61*
71	**Trujillo Alto**	0	0	***0.00***		78,442	61.18	**15,908**	*1.56*
72	**Utuado**	721,736	361	***6.86***		35,475	20.22	**5,257**	*1.14*
73	**Vega Alta**	324,000	162	***1.28***		37,553	48.63	**12,644**	*2.59*
74	**Vega Baja**	54,000	27	***0.06***		62,329	162.06	**42,134**	*5.20*
75	**Vieques**	24,209	12	***0.40***		9,584	11.55	**3,003**	*2.41*
76	**Villalba**	14,960	7	***0.06***		24,713	49.92	**12,979**	*4.04*
77	**Yabucoa**	269,170	135	***2.02***		41,743	25.67	**6,675**	*1.23*
78	**Yauco**	1,288,502	644	***1.37***		45,289	180.25	**46,865**	*7.96*

tgpa - toneladas generadas por año según estudio de composición de los desperdicios sólidos en P.R. por Eco Future en 1993

tgpd - toneladas generadas por día según estudio de composición de los desperdicios sólidos en P.R. por Eco Future en 1993

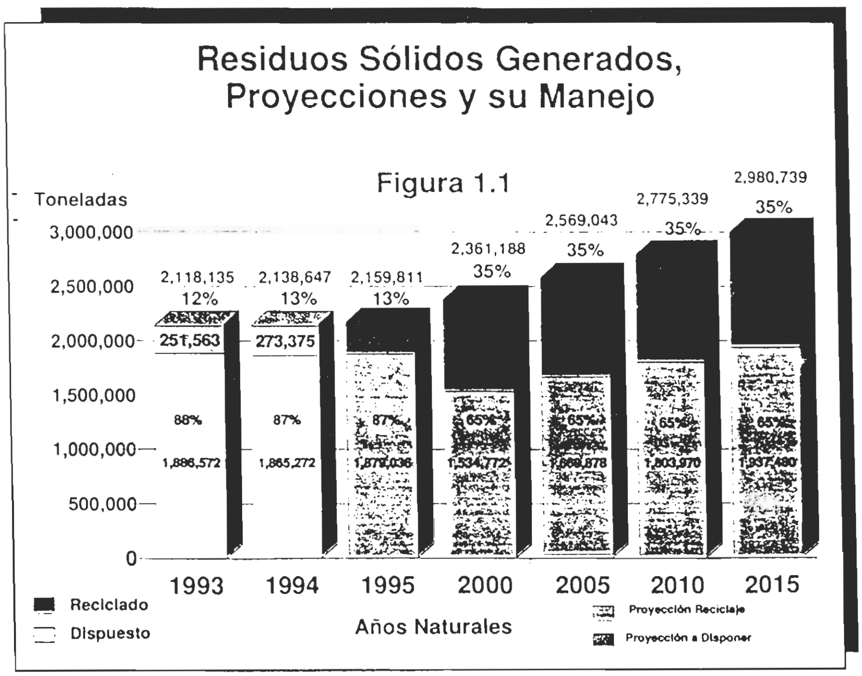
lbs. recuperadas según informes sometidos a ADS por los municipios

Desperdicios sólidos generados y proyecciones de generación

Año	Población [1]	Tasa per lbs/días [2]	Tons/ Residuos Sólidos Generados	Tasa Reciclaje Anual [3]	Toneladas Residuos Sólidos Recuperados	Toneladas Residuos Sólidos Dispuestos
1993	3,620,743	4.5	2,118,135	12	251,563	1,866,572
1994	3,655,807	4.5	2,138,647	13	273,375	1,865,272
1995	3,691,985	4.5	2,159,811	13	280,775	1,879,036
2000	3839,954	4.730	2,361,188	35	826,416	1,534,772
2005	3,975,431	4.971	2,569,043	35	899,165	1,669,878
2010	4,086,669	5.224	2,775,339	35	971,369	1,803,970
2015	4,175,699	5.491	2,980,739	35	1,043,259	1,937,480

Fuente:
1. Junta de Planificación, Oficina del Censo.
2. Estudio de Caracterización de los Residuos Sólidos del Año 1993-94, realizado por la Compañía Eco-Futures, Inc.
3. Ley 70 del 18 de septiembre de 1992, según enmendada.

Para el período del 2001 al 2015 consideramos para nuestras proyecciones una tasa de reciclaje constante de 35% para propósitos de análisis.



I. Information about Landfill Liners from BFI

BFI Waste Systems
BROWNING-FERRIS INDUSTRIES

Recycled paper

BFI of Ponce, Inc.

April 22, 2002

Mr. O'Malley Barton, Carlos Perez & Vinayak Rao

Re: Landfill Liners Currently in use in Puerto Rico
O'Malley Barton, Carlos Pérez, Vinayak Rao

Dear O'Malley Barton, Carlos Pérez, Vinayak Rao:

1. What material is being used as a landfill liner?

   The liners used at our landfill are:

   - Grosynthetic clay liner (bentonite) with a hydraulic permeability of 5×10^{-9}
   - HDPE (60 mi/mm) Geomembrane
   - Geocomposite (Geonet component & Grotextile)

2. Which landfills are using them?

   We are using them at Salinas Municipal Landfill and at Ponce Municipal Landfill.

3. Are they being capped daily?

   Yes, we cap daily all waste received during a working day.

4. How much it costs to cap and line the landfills?

   The daily cost to compact and cover the waste is approximately $5.00/cu.yd.

5. What are the important factors in using a landfill liner?

   To comply with Federal Law (RCRA) and to protect the environment.

6. What is the cost to landfill a ton of trash?

   The cost to landfill a ton is approximately $20.00

7. What is the cost of transporting trash on the island?

   Transportation cost is $17.00/cu.yd

Cordially,

BFI OF PONCE, INC.

Juan Rodríguez
Operations

JR/js

BARAMAYA AVENUE BO. LA COTORRA (00731) • P. O. BOX 7104 • PONCE, PUERTO RICO 00732
(787) 841-7775 • FAX: (787) 841-7772 • LANDFILL OPERATIONS DIVISION / (787) 841-1078 • SPECIAL WASTE DIVISION
QC/LAB 259-2707

J. Information from the EQB

REGLA 541 CRITERIOS DE DISEÑO

A. Todo SRS nuevo y expansiones laterales de SRS existentes deberán, al construirse, satisfacer una de las siguientes especificaciones:

1. ser diseñadas de conformidad con un plano certificado como correcto por un ingeniero licenciado para practicar la profesión en Puerto Rico. En el diseño se proveerá para asegurar que la concentración de las sustancias anotadas en la Tabla I de este Capítulo no serán excedidas en el punto de muestreo del acuífero superior. Para lograrlo, se usará un sistema de monitoría de aguas subterráneas aprobado por la Junta de Calidad Ambiental;

2. contar con una capa inicial de un revestimiento compuesto o material geosintético (liner) de una conductividad hidraúlica no mayor de 1 x 10^{-5} cm/sec y un sistema de recolección de lixiviados diseñado para que los jugos de lixiviación corran sobre el revestimiento.

B. Para que un diseño pueda recibir aprobación de la Junta de Calidad Ambiental deberá considerar y discutir adecuadamente:

1. las características hidrogeológicas indicadas en un estudio hidrogeológico de la unidad y el suelo circundante;
2. los factores climatológicos del área; y
3. el volumen, características físicas y químicas esperadas del lixiviado.

C. El punto de muestreo de aguas subterráneas especificado por la Junta de Calidad Ambiental no estará a más de ciento cincuenta (150) metros de los predios de la unidad. Estará ubicado en los terrenos pertenecientes al dueño de la unidad. Para determinar el punto de muestreo se analizarán:

1. las características hidrogeológicas incluidas en un estudio hidrogeológico de la unidad y el suelo circundante;
2. el volumen y las características físicas y químicas esperadas del lixiviado;
3. la cantidad, calidad y dirección del flujo del agua subterránea;
4. la proximidad y la tasa de extracción de las aguas subterráneas por los usuarios;
5. la calidad actual del agua subterránea, lo cual incluirá otras fuentes de contaminación y su impacto acumulativo sobre ésta, y si se utiliza o es razonable esperar se utilice como fuente de agua potable;
6. los efectos sobre la salud humana, la seguridad pública y el ambiente.