May 1, 2007

Sra. Edith Calzadilla, Architecture Department Manager
CSA Group
Mercantil Plaza
2 Avenida Juan Ponce de León
San Juan, Puerto Rico 00918

Dear Sra. Calzadilla,

Please find enclosed our report entitled Energy Efficiency in Water Infrastructure. This report was written at CSA Group during the project's duration from March 13 through May 2, 2007. We completed preliminary work for the project while in Worcester, Massachusetts prior to our arrival in Puerto Rico. Copies of this report are being submitted simultaneously to our advisors, Professor Susan Vernon-Gerstenfeld and Professor Arthur Gerstenfeld. Upon faculty review, the original will be catalogued in the Gordon Library of Worcester Polytechnic Institute. Your help, interest, and coordination on our project has been greatly appreciated. Thank you.

Sincerely,

Andrea Marinelli
Rachel Patenaude
Mary Kate Toomey

Report Submitted to:

Susan Vernon-Gerstenfeld and Arthur Gerstenfeld

Puerto Rico, Project Center

By

Andrea Marinelli ________________________________

Rachel Patenaude ________________________________

Mary Kate Toomey ________________________________

In Cooperation With

Edith Calzadilla, Architecture Department Manager

CSA Group A/E Firm

ENERGY EFFICIENCY IN WATER INFRASTRUCTURE

April 25, 2007

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

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

EXECUTIVE SUMMARY

Societies around the world depend on the resources the planet provides. Currently, more than 99 percent of electricity in Puerto Rico is produced using fossil fuels. As the supply of fossil fuels continues to deplete, alternative energy sources are becoming a necessity. Solar Energy International (2005) points out that renewable energy has the potential to produce at least 40 percent of the electricity needs of the United States by 2020 if implemented proactively. Additionally, Puerto Rico, the site of our research, is losing 43 percent of potable water to leaks in infrastructure, which is contributing not only to the reduction of this vital yet scarce resource, but also to an increase in energy use (Quinones, 2005). This increase in energy use is due to the need to pump more water. Because of these circumstances, our group focused our investigation on reducing energy use in water infrastructure, including pumping stations and treatment plants, with the use of renewable energy and pipeline maintenance techniques. Through working with CSA Group we accomplished our goal of determining energy-efficient methods for water infrastructure that could be promoted to clients.

In order to accomplish this goal we had three main objectives. ***The first was to research feasible sources of renewable energy systems, including hydro, solar, wind, and methane power, as well as energy-efficient pipeline maintenance procedures. Our second objective was to recommend the implementation of alternative energy systems in addition to predictive and preventive maintenance procedures for water facilities and pipelines based on a cost-benefit analysis. The third was to create an informational***

brochure about renewable energy, including solar, wind, and methane power, which could be distributed to clients.

Prior to our arrival in Puerto Rico, our group examined published material to gain a background on green technologies including renewable energy and pipeline maintenance. Through investigation of case studies, our group gained an understanding of which renewable energies and maintenance procedures have been successful around the world. In addition to this information, we analyzed technical data and feasibility maps to determine which renewable energies held potential to be implemented in Puerto Rico. From this background research we were able to determine that hydro, solar, wind, and methane power all had potential for successful implementation.

Upon arrival in Puerto Rico, our group then needed to become familiar with the current usage of renewable energy as well as the current maintenance procedures for the water pipelines on the Island. To gain this information, we conducted thirteen interviews with experts who have experience in the fields of renewable energy and water infrastructure. From these interviews, we discovered there were two main concerns regarding the implementation of renewable energy. The first concern, as the President of the Institute of Civil Engineers M. Torres Díaz noted, was due to a lack of knowledge among engineers about these technologies. The second concern was the financial feasibility of renewable energy systems in Puerto Rico.

The majority of professionals held similar perceptions about each of the four energy sources we were researching. We found that many experts we interviewed believed that hydro power was currently being used to its fullest potential on the Island. Solar power was believed to have the most potential because it currently has the widest implementation in Puerto Rico. Methane was perceived to be a feasible source of renewable energy because it is currently implemented successfully on the Island. We also found that although experts believed methane could be used to produce electricity, they were resistant towards implementation of anaerobic digesters due to the lack of knowledge about this technology. Finally, we found that experts believed wind turbines would require more space than Puerto Rico was able to dedicate to wind energy. Although there is no current implementation of wind power in Puerto Rico, we discovered that the electric company PREPA currently has contracts for the future implementation of two wind farms on the Island.

However, the main concern many professionals had was the financial viability of renewable energy systems in Puerto Rico. In order to address this concern, our group conducted a cost-benefit analysis for each type of renewable energy system at pumping stations, water treatment plants, and wastewater treatment plants. To conduct those analyses, we used the net present value formula, which takes into account the initial cost of the system, the prime interest rate on the money spent for the system, and the net cash flow of a system during its lifetime. The net present value allowed us to determine the payback period of the system and the future savings the system would incur over its lifetime.

As a result of those analyses, our group determined that wind power was the most financially beneficial system in pumping stations and in water treatment plants, potentially producing over 100 percent of the facility’s needed energy. However, at wastewater treatment plants, the implementation of anaerobic digesters held the greatest economic benefit.

Based on the integration of information gathered through our extensive literature review, interviews with experts, and cost-benefit analysis, our group made recommendations as to which renewable energy system would be the most financially beneficial to implement at each facility. We recommended that CSA Group promote the use of 20 kW wind turbines in pumping stations and 600 kW wind turbines in water treatment plants, which can have a future profit of $28,000 and $1.5 million during the expected lifetime of the wind turbines, respectively. Within wastewater treatment plants, our group recommended that CSA Group promote the use of anaerobic digesters, which can produce a future profit of $8 million and reduce methane emissions, a gas that is twenty-one times more harmful than carbon dioxide.

Since solar power was determined to be financially infeasible when implemented in 2010, the earliest date used in our analyses, on the large scale of treatment plants, we also conducted a cost-benefit analysis for hybrid wind and solar powered systems to take advantage of multiple sources of clean renewable energy. Because the cost of solar power will decrease by 50 percent over the next decade, which would make this technology fiscally feasible for Puerto Rico’s treatment plants, we recommended the implementation of a 600 kW wind turbine in 2010 followed by the implementation of a solar energy system in 2020.

We concluded our results with information we gathered about the economic benefits of a predictive and preventive maintenance plan, which is not currently implemented. Therefore, our group recommended a predictive and preventive pipeline maintenance plan that uses computer detection technologies as well as low-friction pipe liners, which can reduce unnecessary maintenance cost by 90 percent after five years.

In order to supply CSA Group’s clients with information about these renewable technologies, we created a brochure. We intended that the brochure be distributed to clients, including the Puerto Rico Aqueduct and Sewer Authority, in order to make them aware of possible alternative energy sources and the benefits they provide. It contains information about the basics of solar, wind, and methane technologies, a comparison of renewable energy and current electricity costs, societal benefits, and sources of more information.

The cost-benefit analysis we conducted has proven that renewable energy is financially viable. However, the societal benefits that result from the implementation of renewable energy in water infrastructure reinforce the economic benefits.

The social implications of this project can affect the entire population of Puerto Rico. By reducing the amount of fossil fuel used to create electricity, the amount of CO_2 emissions will be reduced.

These environmental benefits of implementing energy-efficient methods lead to the improved health of citizens. Because the use of alternative energy sources would lead to a reduction of air pollution, the number of cases of respiratory illness in citizens of Puerto Rico would decrease. For example, a study done in Cataño, a neighborhood in the metropolitan area of San Juan, noted that there is an increase in asthma among children because of air pollution. This study also showed that residents living near a major emissions source, as they do, increased their risk of asthma by 108 percent.

Additionally, there are economic benefits that stem from the environmental and health implications. Our recommendations, having positive societal impacts, can lead to a healthier and less financially burdened populace.

ABSTRACT

The purpose of this project is to increase the energy efficiency of water infrastructure in Puerto Rico. This report contains technical and financial feasibility data regarding renewable energy systems and pipeline maintenance procedures. This data is followed by recommendations of cost-effective and environmentally-safe systems as well as maintenance procedures to be implemented. The report concludes with the social implications that will follow this implementation. The project team prepared this information for the Architecture and Engineering firm CSA Group, Inc., which will allow this company to promote energy-efficient practices to their clients through a brochure that the team provided at the conclusion of the project.

AUTHORSHIP PAGE

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And
Professor Arthur Gerstenfeld

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Edith Calzadilla, Architecture Department Manager

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CHAPTER ONE: INTRODUCTION

Societies around the world depend on the resources that the planet provides. Without those resources, a society will face a weakened economy, pollution induced health problems, and depletion of resources. While a complete solution is not yet available, there are current remedies aimed at alleviating the present situation. In order to prevent the aforementioned problems, nations will need to begin to incorporate green technologies into their design and construction processes.

When implemented, green technology (see Glossary) is able to protect against the negative effects that the mismanagement of world resources has on an economy. Reports regarding the link between improved water and sanitation and a higher growth in GDP made public in 2005 show that a 3.7 percent annual growth is possible in comparison to the 0.1 percent growth in countries without improved water purification and sanitation infrastructure (Halweil, Mastny, Assadourian, Starke & Worldwatch Institute, 2006). The implementation of green technology to create an improved water infrastructure system will allow for a more sustainable economic system.

Protecting the planet's resources will also eliminate some of the adverse effects, including air pollution, that current infrastructure has on the environment. According to the European Environmental Agency, in 2005, the European Union faced rising green house emissions because of an increase in the use of coal to generate energy (Halweil et al., 2006). Buildings are responsible for approximately 40 percent of the world's total annual energy consumption (Omer, 2006). This demonstrates the harmful environmental effects of using fossil fuels to create energy for infrastructure. Similar to the opinion found in the Science Blog from Virginia Tech in 2003, some people believe that in the future burning coal may become cleaner and cheaper than it is currently (Burning Coal, 2003).

However, renewable energy is currently able to produce power cleanly, unlike fossil fuels. Air pollution, an effect of fossil fuel produced energy, has proved harmful to the general population of the Caribbean (R. Suro-Maldonado, A. Gonzalez & A. Rivera-Rentas, 2006). In 2006, a report by R. Suro-Maldonado, A. Gonzalez and A. Rivera-Rentas showed that in the Caribbean air-pollution induced asthma is becoming a major health issue. Specifically in Puerto Rico, results showed that there was a significantly higher prevalence of asthma, at 19.6 percent over a lifetime, than the United States, showing an 11.6 percent prevalence.

The planet's resources are being not only contaminated, but also depleted. The total energy consumption from all resources increased globally by approximately 15 percent in the ten years between 1991 and 2001 (World Resources Institute et al., 2005). Noting this rise in consumption and considering that in 2001 79.5 percent of that consumption was of fossil fuel sources as opposed to renewable ones (World Resources Institute et al., 2005), it becomes clear that the overuse of resources in ways that harm the environment is a global issue preventing the formation of sustainable societies.

A report by Earth Trends (2003) shows that, between 1990 and 1998, Puerto Rico had a 49 percent increase in CO_2 emissions. Comparatively, there was a 27 percent increase in Central America and the Caribbean and an 8 percent increase in the world. Although not current, this data shows the steady rise in consumption of fossil fuels in Puerto Rico and its dependence on them for electricity production. More recently, in

2006, Puerto Rico was using fossil fuels to create 99.4 percent of its energy (see Figure 1), which shows a continued dependence on fossil fuels.

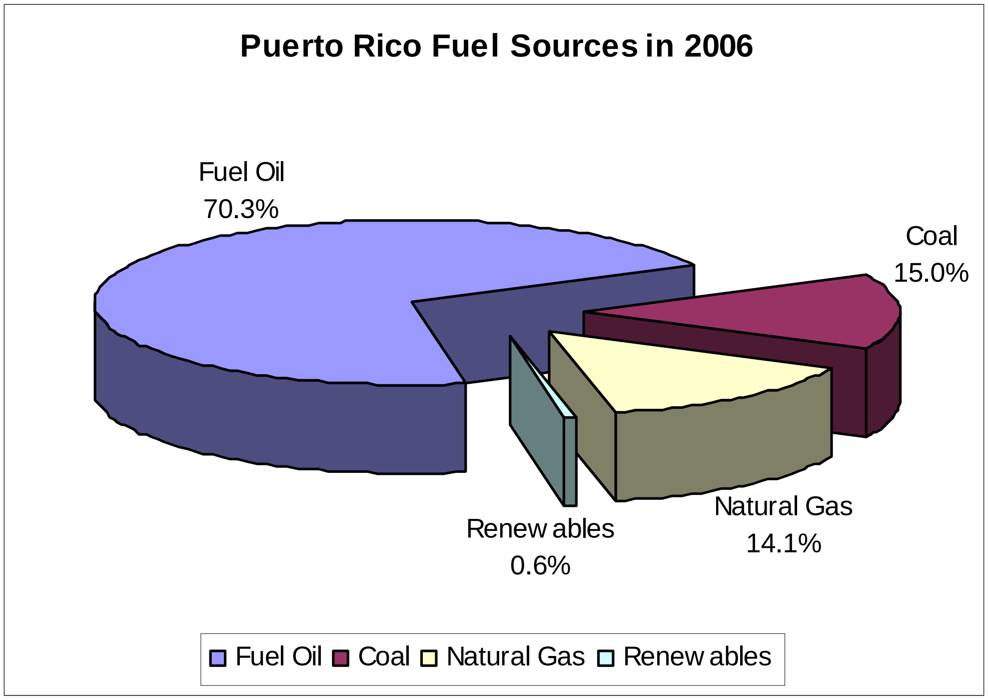

Figure 1. Puerto Rico's Fuel Sources for Net Energy Production in 2006
Data supplied by PREPA Department Head in the Planning Division M. Franco (personal communication, April 17, 2007)

As many developed and developing nations from around the world strive to improve the technology, infrastructure, and prosperity of their societies, there are often negative effects. Ideally, nations would work towards improving the quality of life of their citizens with a full awareness of and respect for the planet through environmentally-friendly practices and renewable resource use. However, abuse of planetary resources is made apparent by the worldwide 12.7 percent increase of CO_2 emissions from 1990 to 2005 (World Resources Institute, United Nations Environment Programme, United Nations Development Programme, & World Bank, 2005). This increase is not purely because of the growth in population, as the data also shows there was a 2.3 percent increase of the CO_2 emissions per capita between 1990 and 2005 (World Resources Institute et al., 2006). Countries need a means to make the necessary improvements in infrastructure while avoiding the adverse effects of the current methods used in construction and power generation.

Sustainability is becoming a more pressing issue for the conservation of the environment and the overall survival of the planet; therefore, the adoption of green technologies, starting on an industrial level, is essential. CSA Group (see Appendix A), an Architecture and Engineering (A/E) firm with an office in Puerto Rico, has shown an interest in incorporating green technologies into their current undertakings in energy efficiency of water infrastructure and has requested assistance from students studying at Worcester Polytechnic Institute to present data about green technology to CSA Group clients.

Puerto Rico is an island facing many environmental problems because its population is increasing while resources are scarce and decreasing. As discussed by Repetto (2004), Puerto Rico possesses potential for green technology implementation practices that have been found to work in other areas of the world. Although the island is managing to sustain its current population's basic needs, a strain on water resources and a dependence on imported fuel for all its electricity generation needs will pose a problem in the near future. Further, Repetto (2004) states that Puerto Rico could benefit greatly from additional research and the use of more advanced technologies that would provide sustainability to areas of infrastructure that are strained.

Currently, water leaks are commonplace; it is estimated that in Puerto Rico, anywhere between 40 and 50 percent of the water treated is lost to leaks before reaching consumers (Cimadevilla, 2004). Therefore, with renovations incorporating sustainable design, water infrastructure can last longer while running more efficiently (Quinones, 2004).

Degrading infrastructure is a problem found throughout the world. Doyle (2006) states that despite this problem, if the water resources could be managed properly, there would be enough water for the rising population. Quality water infrastructure is a significant problem for Puerto Rico. In his discussion about water resources, Quinones (2004) presents information regarding the quality of water infrastructure in Puerto Rico. This sector in Puerto Rico’s infrastructure is one that is degrading with time, which makes it difficult to supply adequate water to a rising number of consumers. Further, Quinones (2004) concludes that sustainable design will greatly reduce the number of leaks Puerto Rico currently experiences.

Additionally, the rising population and decreasing resources of Puerto Rico have created a strain on the energy infrastructure. As the dominant fuel in Puerto Rico’s energy mix, imported oil provides the majority of electrical energy needs (Altaii & Farrugia, 2003). Considering that, in Latin America and the Caribbean, the population is rising and the region's energy use will rise by 60 to 85 percent by 2025 (Haraksingh, 2001), the need to think about more sustainable methods of technology is evident.

Deering and Thornton (1999) present renewable energy as a viable and affordable solution for an island like Puerto Rico; it can be used in many applications to power and sustain infrastructure such as communications, water purification and pumping, and lighting. These observations were presented by Deering and Thornton in 1999, but since then, additional research has been conducted on alternative energy resources in Puerto

Rico. Many of these renewable energy technologies have decreased in cost over the past few years as well as advanced through technology allowing for smaller systems with higher and more efficient output (Haraksingh**,** 2001).

These renewable energy technology options have produced positive results in previous studies. Deering and Thornton (1999) discuss that when traditional energy sources are replaced with renewable solar systems, partial and even full operation to generate electricity and hot water can still be maintained. Additionally, wind studies show similar positive results. A study done on wind speeds in four parts of Puerto Rico provided results favorable to the possibility of wind use as a source of energy in Aguadilla and Ponce (Altaii & Farrugia, 2003). Further investigation of state of the art technologies for providing renewable energy based on previous studies of viability would greatly aid Puerto Rico in finding the sustainable technologies that may help with its particular environmental problems.

Many companies around the world, including firms like CSA Group, currently lack the data and knowledge to be able to persuade clients to accept integrating greener technologies into their work. Although studies of alternative energies, including wind and solar power, have taken place to ascertain the benefits of sustainable technologies, these tests have rarely been applied to running infrastructure systems efficiently and cleanly (Altaii & Farrugia, 2003; Sen, 2004; and Orer & Ozdamar, 2006).

CSA Group has expressed an interest in applying renewable energy sources as well as alternative design methods to water infrastructure projects in order to increase their energy efficiency, which is a concern due to high and increasing energy costs. Information gathered about the benefits of these potential methods of sustainable design in CSA Group's projects will be provided to their clients. This increased awareness about the benefits of greener technologies will start to transform the way water infrastructure projects are designed and executed.

In order to present useful information to CSA Group and its clients, our group examined renewable energy projects around the world that have been successful. Additionally, we investigated predictive and preventive maintenance plans implemented globally. This gave our group a better understanding of the energy-efficient methods that would be useful for CSA Group to promote to their clients.

Our group conducted further research, which included interviewing experts with experience in the fields of water infrastructure and renewable energy as well as representatives from Puerto Rico Electric and Power Authority (PREPA) and Puerto Rico Aqueduct and Sewer Authority (PRASA). In these interviews with professionals, we discussed the current situation and our ideas for future possibilities in Puerto Rico regarding renewable energy and pipeline maintenance. We then investigated what the most viable options for energy-efficient improvements are and the reasons they are not currently in effect in Puerto Rico. With this information, we completed a cost-benefit analysis to demonstrate the financial feasibility of alternative energy systems and maintenance procedures. Based on the cost-benefit analysis, we made recommendations of how to improve the energy efficiency of Puerto Rico's water infrastructure.

CHAPTER TWO: BACKGROUND

The goal of this project is to provide CSA Group with necessary information about energy efficiency, allowing them to promote stronger infrastructure with innovative methods to their clients in Puerto Rico. Information contained in the discussion of our background chapter focuses on the current infrastructure problem, the need for renewable energy, potential sources of renewable energy at each water facility, as well as maintenance techniques to reduce energy use. The background chapter concludes with a discussion of the social implications that this project could have.

CURRENT INFRASTRCUTURE PROBLEM

According to the Center of Strategic and International Studies (CSIS) (2005), the mismanagement of precious water resources combined with the steady rise in populations, increasing urbanization, and economic growth has created an imbalance of the water supply to the water demand in many areas across the globe. The CSIS (2005) also says that humans already use over half of all accessible freshwater resources, and the future consumption is expected to rise. If this consumption level continues to rise, by the year 2025, over half the world will live in water-scarce or water-stressed countries (CSIS, 2005).

These problems may be part of the reason why, in 2001, the Puerto Rico Aqueduct and Sewer Authority (PRASA) planned to invest $331.2 million on projects important to citizens, such as water infrastructure (Government of Puerto Rico, 2001). Currently, this agency is working towards renovating their water infrastructure, contracting multiple projects to solve current problems, and upgrading to more efficient systems. With increased efficiency within the water infrastructure system, PRASA will also reduce their energy consumption (Commonwealth of Puerto Rico, 2007).

The *Save Energy* report (2002) by Watergy, a company that works with developing countries to supply and treat water resources efficiently, explains that 3 percent of the total energy the world consumes is used to treat and pump water. Further, the report states that by using more energy-efficient methods within water infrastructure, the amount of energy consumed could be reduced by as much as 25 percent. By taking advantage of untapped energy and water efficiency opportunities in systems, energy use can be optimized, water wastage and water costs will be reduced, and ultimately water services will be improved (*Save Energy*, 2002).

THE NEED FOR RENEWABLE ENERGY

Because Puerto Rico is an island, it greatly depends on imported fuels to provide the Commonwealth with energy (Altaii and Farrugia, 2003). Altaii and Farrugia (2003) point out that because Puerto Rico does not have the necessary reserves of hydrocarbon fuels (see Glossary) internally, it cannot fulfill its energy needs autonomously. In addition, they discuss that because of this dependence on imported fuels, it is important for Puerto Rican companies and government organizations to investigate alternative energy sources.

McPhaul (2004) explains in an article in *Caribbean Business* that although Puerto Rico has plans for reducing their consumption of oil by 2012, it is through the use of other fossil fuels such as coal and natural gas, not renewable sources of energy (McPhaul, 2004). According to CSA Group VP Infrastructure, Program Manager Advisor F.

Fletcher (personal communication, March 23, 2007), Puerto Rico currently implements two different kinds of renewable energies, solar power and methane generation, on a small scale. However, Puerto Rico may have the resources to further employ these technologies as well as wind power on a wider scale.

POTENTIAL RENEWABLE ENERGY SOURCES

Sen (2004) explains that solar energy is one of the top prospects for sustainable energy systems around the world due to its abundance and because it is more evenly distributed in nature in comparison with other renewable sources of energy. As Strickland (2003) points out, it is also important to consider the limitations of solar power. He explains that the intermittent nature of sunlight, which is based on the weather, limits the amount of power solar panels can supply consistently. Although Sen (2004) says that some areas of the world do not have enough solar radiation or clear sunny days to make solar energy a feasible prospect, he also states that the potential is good for climate zones close to the equator, which receive plenty of solar radiation. Because of Puerto Rico's proximity to the equator, it has some potential to use solar energy. As seen in Figure 2, Puerto Rico has an annual solar radiation ranging from 5.0-6.0 kWh/m^3/day.

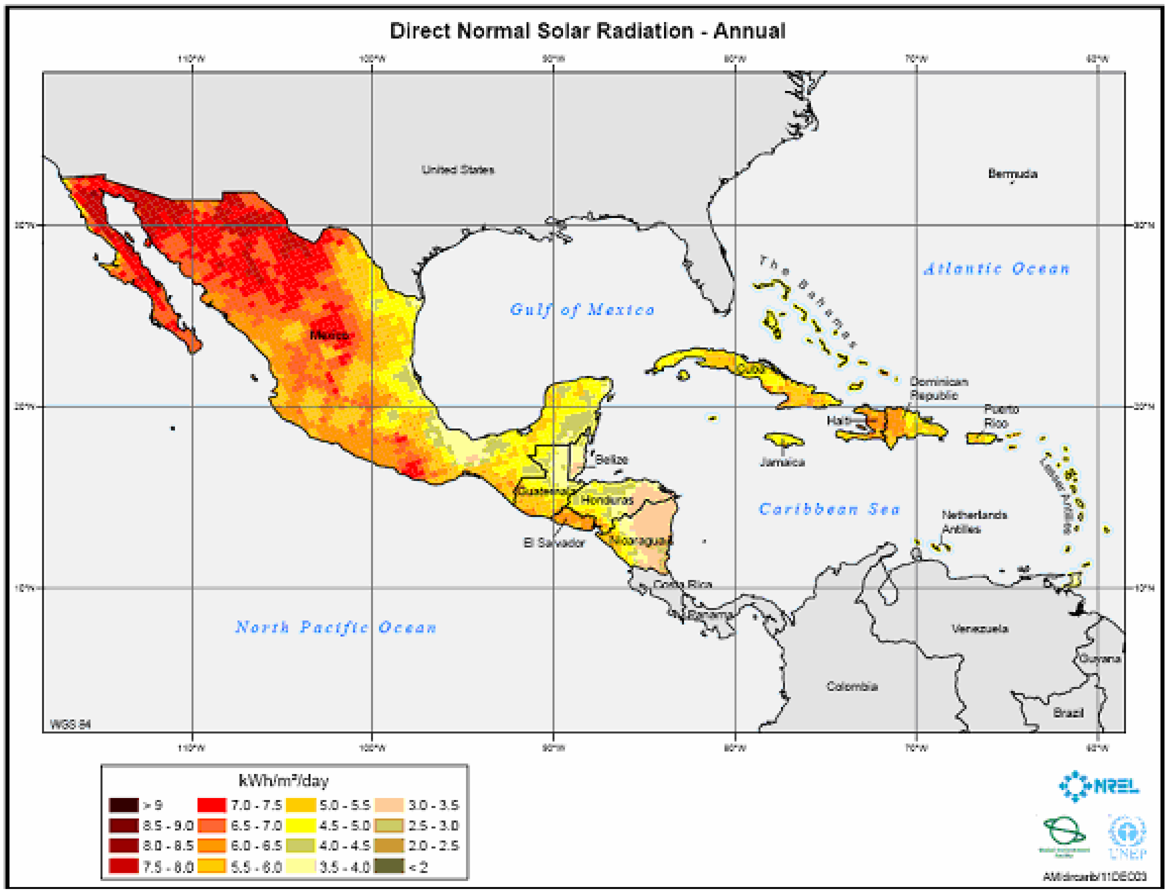

Figure 2. Annual Direct Solar Radiation (NREL, 2003)

Sen (2004) also addresses the factor of cost by drawing attention to the fact that, while energy produced by fossil fuels is currently less expensive than solar energy, there is room for research and developments in solar energy production processes that could decrease the cost. Conversely, he states that the technology required to produce energy from fossil fuels has been studied extensively, and it is unlikely that there will be any significant decline in price. Although Sen's (2004) studies found that fossil fuels were cheaper than alternative energy sources, these studies are not current. Also, he states that it is also important to consider the social and environmental hazards of fossil fuel use, such as pollution. There seem to be benefits in solar energy; however, significant amounts of data have not been collected to test the true feasibility of implementing solar energy systems in Puerto Rico as a main resource.

As with solar energy, methane as an alternative fuel has been implemented in few applications in Puerto Rico. The U.S. Department of Energy (2005) discusses the potential for energy production using methane emitted from a process called anaerobic digestion (see Glossary). Methane, a natural byproduct of this organic waste treatment process, can be easily captured and used as a substitute for natural gas either to heat the digester in cooler temperatures or to produce electricity for the treatment facility (Department of Energy, 2005). Talbert (2003) states that the many advantages of methane capture and use outweigh the few costs created by implementation of the technology. The recent technological advances that allow methane gas to be captured during wastewater treatment and used as a fuel for generators have the added environmental benefit of reduced greenhouse gas emissions since the emission of methane into the atmosphere is twenty-one times more potent than that of carbon dioxide (CO_2) in the warming effect (Talbert, 2003).

The U.S. Department of Energy (2005) states that methane can be employed as a substitute fuel in many applications, such as boilers, hot water heaters, turbines (see Glossary), and fuel cells (see Glossary). Currently, the most popular technology to convert the methane gas to energy uses an internal combustion engine to run a generator, which produces electricity. As the National Energy Policy (2007) discusses, an additional application that has been proven successful is the use of micro-turbines (see Glossary), which are small scale generators about the size of a refrigerator that are able to produce outputs of 25 to 500 kilowatts (kW) of electricity through the combustion of methane fuel

(National Energy Policy, 2007). Micro-turbines have many advantages compared to other small scale generators. These include optimal efficiency, reduced emissions, and lower energy costs (National Energy Policy, 2007).

Additional technologies are beginning to be used to produce electricity with methane gas, including fuel cells and Stirling engines (see Glossary). Fuel cells are a developing technology that uses hydrogen as a fuel with primarily water emissions. The hydrogen needed to operate a fuel cell can be derived from anaerobic digestion gas. When employed, fuel cells are able to potentially produce up to 2 megawatts (MW) of energy (National Energy Policy, 2007). The use of fuel cells has many advantages, when compared with gas turbines and diesel generators, including a reaction that takes place without combustion, moving parts, and negligible pollution emissions (California Energy Commission, 2001). However, the California Energy Commission (2001) points out that, as a developing technology with a limited market, the main deterrent for the implementation of fuel cells is cost. The equipment and installation costs for a 200 kW system could equate to around $5,000 per kW of power. Government incentives may be available to offset the current cost and increase future demand, which would make the use of fuel cells cost-effective in addition to being environmentally-friendly (California Energy Commission, 2001).

In 2004, the King County's Wastewater Treatment Division, FuelCell Energy Inc., and the Office of Wastewater Management of the U.S. Environmental Protection Agency developed a fuel cell demonstration project using anaerobic digester gas as fuel. The project aimed to test the technology and establish the benefits of fuel cells. Located in Renton, Washington the 1 MW fuel cell demonstration was to operate for two years. In order to produce 1 MW of electricity, enough to power 1,000 households, a wastewater treatment plant needs to be treating at least 30 million gallons per day (mgd) (King Country, 2006). More recent updates have shown the success of this fuel cell demonstration. Holt (2005) explains in an article in the Seattle Post that the fuel cell is creating enough energy to power 800 homes and the treatment plant at only 5.7 cents per kW hour. Also, the treatment plant is experiencing a savings of $450,000 a year in electricity costs. However, there are maintenance costs, which are expected to be around $1 million every three years (Holt, 2005).

Another developing technology is Stirling engines, which do not require the degree of maintenance that other methane technologies need (U.S. Department of Energy, 2005). Similar to the fuel cell technology, these small scale engines have fewer moving parts and are generally more efficient. Additionally, the engines operate with a wider range of fuels and solar power. The output of small scale Stirling engines ranges from 800 watts to 1200 watts (Godin, 2005). Godin (2005) discusses, in a Power Generation and Energy Efficiency forum, that the capital cost of Stirling engines equates to about $4,000 to $8,000 per kW of power with a payback period of ten years. Further acknowledged is the need for continued improvements in order to reduce the costs of this technology, including increased electrical efficiency, longer durability, and greater reliability (Godin, 2005).

Although not utilized currently within Puerto Rico, wind power is another potential solution to Puerto Rico’s dependency on imported oil. Globally, it is estimated that approximately 10 million MW of energy could be produced continuously from the earth’s wind (Herbert, Iniyan, Sreevalsan, and Rajapandian, 2005). According to

Strickland (2003), this would account for approximately 83.3 percent of the electricity used globally in 1995. Herbert and his colleagues (2005) believe that if wind energy can be used, it will offer a solution not only to the economic problem of dependence on importation, which many countries share, but also to the environmental problem of pollution by fossil fuel byproducts. However, the feasibility for wind power in particular areas is dependent on many factors. They say that, in order to determine the feasibility of using wind turbines to provide sustainable energy, research needs to be done to gain information about factors such as wind speed, local landscape, and wind supply.

Although it is not extensive, there is some documentation regarding the feasibility of wind power as a source of energy in Puerto Rico. According to Altaii and Farrugia (2003), who collected data at sites in Aguadilla, Ponce, San Juan, and Gurabo, there is potential for wind powered energy producing systems in Aguadilla and Ponce, as seen in Figure 3.

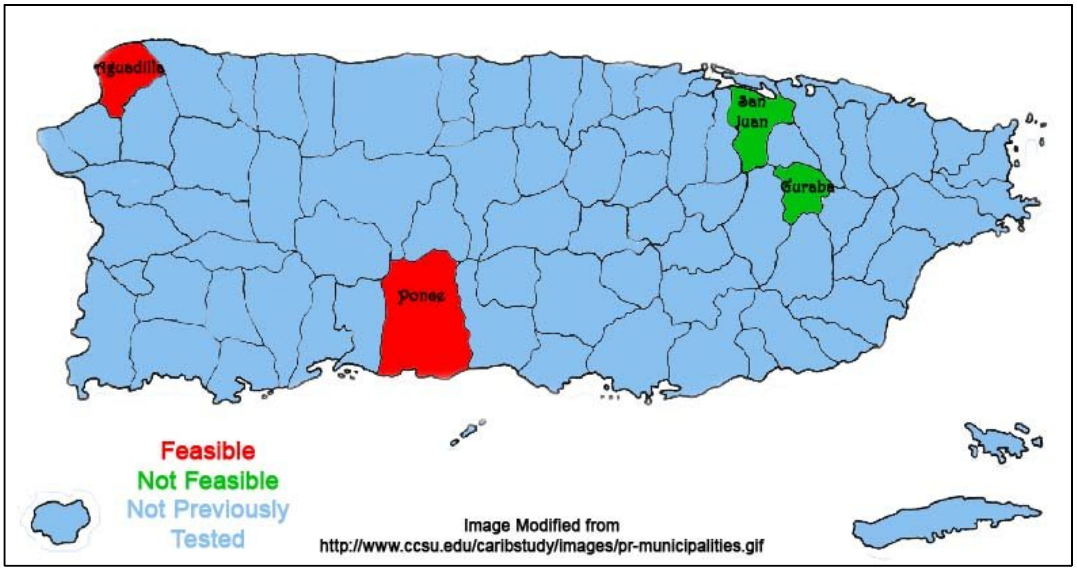

Image Modified from http://www.ccsu.edu/caribstudy/images/pr-municipalities.gif

Figure 3. Altaii and Farrugia (2003) wind study results

In order to add significant data to the current collection, Altaii and Farrugia (2003) believe it would be necessary to monitor wind data at higher altitudes and at more frequent height intervals. With this information, they think it would be possible to establish a more definite potential for instituting wind power. Altaii and Farrugia (2003) say it would be beneficial to continue to collect data at Aguadilla and Ponce as well as to begin to collect data at additional sites in Puerto Rico. The authors suggest that the additional sites should be chosen based on height relative to mean sea-level, site exposure, and geographical features of the potential sites. After collecting more detailed data from a larger range of sites, analysis of that data would clarify if and where wind power in Puerto Rico would be able to provide sustainable energy that would be a financially viable and publicly accepted investment.

Altaii and Farrugia (2003) also assert that it is important to consider how the people of Puerto Rico would accept the implementation of wind power. Wolsink (2005) explores some of the reasons for objections to wind power through studies performed in the Netherlands. These studies show that although most subjects claimed their opposition towards turbines was because of the noise production, in reality, the most common resistance towards the wind turbines was because of their visual impact. Although this study took place in the Netherlands, it explains some of the societal issues associated with implementing wind power.

IMPLEMENTATION OF RENEWABLE ENERGY INTO WATER FACILITIES

Based on previous studies of renewable energy potential done in Puerto Rico, solar and wind power are a feasible energy source for facilities on the island.

Investigating global application of these renewable energies in water treatment and wastewater treatment plants as well as pumping stations provides information regarding the benefits and costs of the integration of renewable energy in treatment facilities in Puerto Rico.

The benefit of solar energy applied to treatment plants has already been experienced. A wastewater treatment plant in Orville, California installed solar panels to produce 1.1 million kW hours per year for the 6.5 mgd plant, which services 15,000 families and industries. With a projected payback period of nine years, this operation was able to cut energy costs by 80 percent with the use of solar panels to produce energy (Vote Solar Initiative, 2002).

Also, in 2001, The Osaka Prefectural Government in Japan installed solar panels with a maximum output of 300 kW to a wastewater treatment plant, which made it the first sewage treatment plant in Japan to introduce full-scale solar energy generation. The energy consumption was cut by 1 percent, which is estimated to be the equivalent of the use of 400 drums of oil per year. The environmental benefits are far more extensive considering the reduction in carbon dioxide emissions amounted to about 50 tons per year (Kippo News, 2001).

Although generally creating a smaller energy output, wind power is also being implemented in treatment plants. In Browning, Montana, four 10 kW wind turbines were installed to provide supplemental energy to the town’s wastewater treatment plant. Ultimately, the turbines were able to provide one-quarter of the energy used by the plant (U.S. Department of Energy, 2001).

Additionally, cities throughout Massachusetts have been planning on saving money and energy through the implementation of wind technology. For example, the wastewater treatment plant in Lynn, Massachusetts is preparing to cut energy costs in half by supplementing with renewable wind energy (The Boston Globe, 2006).

Wastewater treatment plants hold additional renewable energy potential through methane power in addition to the solar and wind powered systems that could be implemented into treatment plants. Anaerobic digesters have been used in many wastewater treatment plants around the world successfully. Taking into consideration that the average American produces 100 gallons of wastewater per day, gaining a renewable source of energy from this waste will be beneficial (U.S. Department of Energy, 2005). In an article by the U.S Department of Energy (2005), the benefits of anaerobic digestion are discussed. About 22 percent of the wastewater treatment facilities in the United States employ anaerobic digestion technology, allowing them to create methane, which is mainly used to heat the digesters to the needed temperature. However, methane can also be used to produce electricity.

This technology has been implemented successfully in Puerto Rico. In 1984 the Bacardi Corporation utilized the anaerobic digestion process to treat distillery wastes. The methane produced by this process was used as boiler fuel (ASCE, 1984). According to the ASCE (1984), the use of methane was providing an annual estimated fuel savings of $1 million. With continued success, the Bacardi Corporation was acknowledged by the Environmental Protection Agency in 2004 for the use of methane produced in the company’s anaerobic digester. As of 2004, the generation of steam from methane has been used to power machinery. This process produced 75 percent of the Corporation's needed energy (U.S. EPA, 2004).

The progress being made in treatment plants through the implementation of renewable energy can also apply to pumping stations. Because the energy required to pump water through a pumping station is less than the amount needed for the operation of many other water infrastructure facilities, using solar and wind energy to create power for a pumping station is a very realistic option (PowerLight Corporation, 2006; Solar Depot, 2004; Badran, 2003; Omer, 2006). This is shown by the previous implementation and expected success of other pumping stations that have renewable energy systems.

Solar energy has been used to provide energy to pumping stations in various locations outside of Puerto Rico. According to a PowerLight Corporation press release (2006), in the city of Napa, California, solar power through photovoltaic panels has been implemented in order to reduce electricity costs at the Hennessey Pump Station. In the case of this 365 kW solar power system created by PowerLight Corporation, the expected savings in avoided electricity purchases is greater than $100,000 annually (PowerLight Corporation, 2006). In the case of Napa, the expected $3.2 million in electricity bill savings over the next twenty-five years shows the potential of the system (PowerLight Corporation, 2006). As well as the cost saving advantages, PowerLight Corporation (2006) points out that there are also environmental benefits. The city of Napa estimates that this solar powered pump station will reduce CO_2 emissions by 4,200 tons over the course of its expected thirty year lifetime. This would have the same effect as planting 1,170 acres of trees or driving 10.5 million fewer miles on the roads of California (PowerLight Corporation, 2006).

In San Rafael, California, the same concept of solar powered pumping stations is being applied on a smaller scale. The reclamation pump station (see Glossary) located in the Las Gallinas Valley Sanitary District, which treats 3.56 million gallons of wastewater per day, receives power from an 89 kW solar power system (Solar Depot, 2004). According to the Solar Depot Press Release (2004), Megan Clark, a 2004 board member of the Las Gallinas Valley Sanitary District, believes the 89 kW solar power system, which uses only solar energy as a power source, will pay for itself. Along with using renewable energy, the district upgraded the pumping station to obtain higher energy efficiency. According to an article on renewableenergyaccess.com (2006), EI Solutions, the company who installed the first system of solar panels, has completed phase two of the project. The article states that the 490 kW addition to the project will allow the system to create a total savings of $170,000 per year (renewableenergyaccess.com, 2006).

Wind energy provides another opportunity to produce clean renewable energy that powers pumping stations. In Jordan, there have been six mechanical wind pumping systems installed at different sites between the years of 1983 and 1993 (Badran, 2003). These facilities have pump outputs ranging from 4 to 30 cubic meters per hour (m^3/h) (Badran, 2003). According to Badran (2003), these pumping stations are an improvement from diesel pumping stations because they need less maintenance, automatically stop in emergencies, which creates a higher level of safety, and do not consume fuel or pollute the air.

There are also wind powered pumping stations operating in Sudan. These wind pumps, which were imported from the Netherlands, were installed by the Energy

Research Institute (Omer, 2006). While most of the wind pumps are still in place and functional, there are some definite problems with the systems. According to Omer (2006), the problem in the Sudan program that has the greatest impact is with the CWD 5000 model. The main problem with the CWD 500 model, locally manufactured machine, is that it is high in cost; however, it is the only model they have tested.

Although cost may or may not be a large problem in Puerto Rico, one of the concerns that may arise in the use of wind turbines is the spatial impact. According to CSA Group VP Infrastructure, Program Manager Advisor F. Fletcher (personal communication, March 23, 2007), because of the lack of available land area in Puerto Rico, the idea of installing large wind turbines may not be realistic. However, according to LaMonica (2006), some companies are starting to explore smaller turbines that would fit on rooftops of buildings. This could provide a possible solution to the problem of the comparatively large amount of space a more traditional wind turbine would occupy.

MAINTENANCE TECHNIQUES

In order to fulfill the water demand in Puerto Rico, the Commonwealth needs adequate water infrastructure. The U.S. Geological Survey states that this is becoming a more pressing issue as, between the years of 1995 and 2000 alone, water demand jumped almost 20 percent on the island of Puerto Rico (Cimadevilla, 2004). Additionally, Cimadevilla (2004) discusses that the inadequate water infrastructure, which includes leaking pipes and is a main concern of the island, compounds the need for an improved water distribution system.

In 2002, PRASA supplied 80 percent of the necessary water to the island of Puerto Rico, pumping 151 mgd to 3.8 million people (Quinones, 2005). However, from the amount of water PRASA supplies daily, only 85 mgd are consumed by the public. This shows an approximately 43 percent loss in production, which Quinones (2005) attributes to infrastructure problems. Considering Lahlou's (1998) statement that a 10 to 20 percent loss of water is accepted as normal, the amount of water lost in transport in Puerto Rico is cause for concern. In addition to water loss, the associated loss of energy is also problematic.

Acknowledging this problem with infrastructure in Puerto Rico, PRASA has recently finished a plan of action, the Master Infrastructure Plan, which among many things plans to address the issue of leaks (Quinones, 2005). The replacement of leaky pipes and fire hydrants is planned to reduce losses by 30 percent in five years, while maintaining pipes with further leak detection technologies (Quinones, 2005).

Mergelas, Atherton, and Kong (2002) present a four-dimensional case study between companies that do not utilize monitoring techniques and companies that frequently utilize monitoring techniques to identify current or likely problems in their piping. Those companies that made their decisions based on results from leak identification systems to determine frequency and location of distressed piping were able to defray costs and eliminate the potential for large problems to occur in the future. Additionally, the authors note that economic, political, and health and safety consequences can result from the breakage of water lines when preventive maintenance is not implemented.

Social Implications of Water Pipeline Maintenance

While new technology may provide PRASA with the information and leak prevention techniques to save money in future maintenance costs, the citizens of Puerto Rico will also experience societal benefits with the implementation of these energy efficiency techniques. Ruiz-Marrero (2001) reported the many water infrastructure problems that PRASA was experiencing and the effects they had on the surrounding communities. As far back as 1995, the inadequate water infrastructure and many EPA violations by PRASA were hindering the supply of clean drinking water, causing many communities on the eastern side of the island to go without water (Ruiz-Marrero, 2001; EPA, 2001).

Public Citizen (2005) references a report written by the Movimiento Agua Para Todos (MAPT) in 2001, a coalition of waterless communities in eastern Puerto Rico, which documented the effects of the water crisis on public health in these eastern communities. Resulting from the lack of adequate clean water, citizens experienced skin allergies, gastroenteritis, and conjunctivitis. In addition citizens experienced muscular spasms from the need to carry heavy water containers from water sources back to their homes. Further, Public Citizen (2005) notes the mental effects the water crisis had on community members, including irritability, anxiety, frustration, loss of self-esteem, and depression.

The water infrastructure problem experienced in Puerto Rico is not one that is contained on the island; it is a world issue. As Barlow (1999) notes in the *Blue Gold* report, global water consumption is doubling every twenty years, which is more than twice the growth rate of the human population. Therefore, the rehabilitation and advancements completed on the water infrastructure by PRASA could be an example of environmental progress that could benefit many communities around the world.

CHAPTER THREE: METHODOLOGY

This project aims to identify and evaluate renewable energy sources as well as methods of leak detection and prevention that will be useful to CSA Group of Puerto Rico. This information will then be promoted to PRASA in future CSA Group proposals. The focus of our background research involved analyzing what studies have been done in Puerto Rico concerning the application of renewable energy and pipeline maintenance. This helped us identify where there are gaps in research and what techniques CSA Group has used to promote more sustainable systems. Our group was able to develop a set of objectives for our project. These objectives included:

1. Identify feasible energy-efficient methods for water infrastructure.
2. Make recommendations for feasible renewable energy systems and maintenance procedures based on a cost-benefit analysis.
3. Create an informational brochure about renewable energy systems.

DATA COLLECTION

Because of the technical nature of our project focus, the main source of information available was secondary data. Since our group was unable to conduct feasibility studies of the potential implementation of wind, solar, and methane power under the conditions present on the Island, we analyzed problems with and successes of current projects being conducted around the world. Information collected in our previous research, discussed in Chapter Two, about international projects as well as data showing solar and wind potential in Puerto Rico allowed us to determine which energy-efficient technologies would be appropriate for similar projects applied in Puerto Rico in the future. Following this initial research, we gained information through interviews with CSA Group employees to help us establish the current uses and feasibility of different types of renewable energy sources in Puerto Rico's water infrastructure.

Additionally, in our interviews, our group explored the current maintenance practices used to detect and prevent leaks in water piping. We then researched better methods of leak detection and prevention that can be implemented to improve the efficiency of the pipeline system.

Interviews

To help us gather further information on the feasibility and costs of green technology implementation, we conducted eleven face-to-face interviews. Additionally, two e-mail interviews were conducted when the schedule and location of our intended interviewees did not permit a face-to-face meeting.

We interviewed professionals with experience in the fields of water infrastructure and renewable energy implementation. We used purposive sampling, with the help of our project liaison CSA Group Architecture Department Manager Edith Calzadilla, to begin our consultation process within CSA Group. To gain information about current and past attempts at the implementation of renewable energy in Puerto Rico, we interviewed three CSA Group Program Manager Advisors in the water infrastructure field including Engineers Arturo Galletti and Fred Fletcher. Additionally, we interviewed a former employee of CSA Group with almost fifty years of experience in the fields of water infrastructure and green design Dr. Antonio Santiago Vasquez. These interviews provided us with a background on the common reasons behind client resistance toward implementing green technology. In addition, these engineers were able to give us information regarding the current status of pipeline maintenance and its effect on energy efficiency.

Through the initial interviews as well as an interview with Planning Manager Dr. Hector D. Rivera, an employee of CSA Group involved with water infrastructure projects, we collected expert opinions as to which types of renewable energy would be the most feasible and accepted in water infrastructure in Puerto Rico.

After our initial interviews, we used snowball sampling. Many of our primary contacts identified more professionals within CSA Group. A referral from CSA Group Senior Program Manager Advisor Luis Pagán to the cost estimation department of CSA Group allowed us to gain more detailed data regarding the technical specifications of pumping stations and treatment plants from Cost Estimator Rafael Green.

Snowball sampling also helped us identify professionals from outside CSA Group involved with the specific renewable energy technologies our group determined to be most feasible. Because the referrals from CSA Group employees improved the likelihood of these professionals participating in an interview, we were able to interview five additional professionals. For instance, our interview regarding anaerobic digesters with CSA Group Environmental Scientist Isabel Szendrey supplied us with contact information for her father Dr. Michael Szendrey, who designed and implemented the active anaerobic digester at the Bacardi wastewater treatment plant in Puerto Rico. Additionally, Miguel Torres Díaz, the President of the Institute of Civil Engineers, who we interviewed, passed on a list of questions we created to experts on wind, solar, and methane power.

Additionally, we were referred to Javier Colignon from PRASA and Maribel Franco from PREPA, by our project liaison Architecture Department Manager Edith Calzadilla. Through these interviews, we were able to gather data on the companies' perception of renewable energies. Additionally, through the interview with Javier Colignon, we were able to gather information regarding PRASA's plan for improving Puerto Rico's water infrastructure maintenance procedures. Finally, Maribel Franco was able to provide information on PREPA's upcoming plans for integrating renewable energy into the Island's electricity production.

Cost-Benefit Analysis

The information we obtained through these interviews set up the basis for our cost-benefit analysis. Throughout the design and construction phases, clients are primarily focused on the financial and business aspects of the project. A cost-benefit analysis presents a tangible, quantitative figure that owners can use to evaluate a bid. The model our group used to conduct our cost-benefit analysis was Net Present Value (NPV).

NPV is an analysis of the initial cost of a system in comparison to the monetary output or savings over the lifetime of the system. This helps to compare the initial investment, the payback period, and the lifetime savings of one project to those of another. We used Equation 1 to compute these values. For each analysis, we used a discount rate equal to the current prime interest rate, which was approximately 8 percent.

Equation 1: Net Present Value

$$\text{NPV}= \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} - C_o$$

Where:

t - the time of the cash flow
n - the total time of the project
r - the discount rate
C_t - the net cash flow (the amount of cash) at time t.
C_0 - the capital outlay at the beginning of the investment time ($t = 0$)

Where system costs are expected to decrease in the future, we computed the NPV for implementation in 2010 and 2020 in order to compare current and future financial viability. With these numbers we completed an electricity savings comparison. The electricity savings comparison is a comparison of the NPV over the expected lifetime of each system. We applied the NPV data calculated from Equation 1 to the implementation of the system in 2010, 2020, and never. For the years when a system was not in use, the NPV remained constant at its previous value.

Once this analysis was completed for each of the renewable energy systems, we analyzed our results and made recommendations of which systems to implement at what facilities and when. We based our recommendations on which system had the smallest payback period and the highest net savings at the end of its lifetime. We also considered the initial investment of each system and made secondary recommendations of systems that would still be cost effective, yet require less of an initial investment.

We did not compute an NPV for maintenance plans because we were not able to obtain a current maintenance budget. However, we did provide economic feasibility data based on savings statistics and case studies. We used this information to make recommendations about which systems would be most likely to reduce energy and maintenance costs.

CHAPTER FOUR: RESULTS AND DISCUSSION

The information provided in this section investigates the technical and economic feasibility of implementing renewable energy in water infrastructure facilities and energy-efficient maintenance procedures into water delivery pipelines. In each of the following sections, we discuss the perceptions held by the professionals we interviewed as well as conduct a cost-benefit analysis where applicable.

GENERAL PERCEPTIONS ABOUT RENEWABLE ENERGY SYSTEMS

Through the interviews we conducted with three CSA Group Program Manager Advisors, one CSA Group Planning Manager, and eight other professionals, in addition to information we gathered through review of published articles, we were able to gather data on the current use as well as the perceptions held of renewable energy use in Puerto Rico. Many professionals held similar general perceptions of the renewable energies our group has investigated. CSA Group water infrastructure professionals expressed concern that the high fee of connecting to a backup source provided by PREPA and combined with the generally high initial cost of the system would make renewable energy systems less cost-effective than remaining with the current energy source. We accounted for this backup source in our cost-benefit because by assuming these systems would be implemented into current facilities already connected to the grid.

Additionally, many of the professionals we interviewed had concerns that alternative energy systems will not be cost-effective because they are unable to sell electricity back to PREPA. Without net metering, the systems would have to use batteries to store excess energy to be used at times when the system is not producing an adequate amount of energy. This is a concern because batteries are costly and, according to the data collected in our interviews, need to be replaced every two to three years on average. Professionals are skeptical about the financial viability of a system requiring batteries due to the high cost of battery replacement.

However, in our interview with PREPA Department Head in the Planning Division M. Franco (personal communication, April 17,2007), we learned that there is a federal mandate that applies to Puerto Rico that requires net metering to be in place in 2008. Through further research, we found that this mandate is the Energy Policy Act of 2005. Therefore, with systems that do not need to be self-sufficient, batteries will not be required. When net metering is implemented, it will bring the maintenance cost of a system down making it more financially feasible.

Because the opinions we collected in our interviews all suggest that financial viability is the main issue preventing the adoption of alternative energies here in Puerto Rico, the cost-benefit analysis is particularly important. The background information about the water facilities we used to compute this analysis can be found in Appendix B.

HYDRO POWER FEASIBILITY

One form of renewable energy being used is hydro power. Although we heard positive comments about the current use of hydro power, our group was told in our interviews with ASV Engineering Group, PSC President Dr. A. Vasquez (personal communication, March 30 , 2007) and VP Infrastructure, Program Manager Advisor F. Fletcher (personal communication, March 23, 2007) that hydro power is already being used where it is possible. PREPA currently uses a hydro plant to produce some power.

Other attempts have been made to produce electricity using hydro power, such as a dam to power a filtration plant. However, these attempts failed because of a lack of sufficient surface water supplies. Supporting our background research, this information showed that hydro power is a thoroughly explored technology that is being used in most places where it is possible. For this reason, we did not complete a cost-benefit analysis for this technology.

SOLAR POWER FEASIBILITY

Through our interviews, we learned that on the Island, solar power has the widest current implementation of any renewable energy. It is currently being used as a form of electricity in Federal Post Office buildings and in hot water heating systems. Solar power is also currently being tested on the island of Culebra, located off the east coast of Puerto Rico. In an interview, CSA Group VP Infrastructure, Program Manager Advisor F. Fletcher (personal communication, March 23, 2007) stated that plans for small pumping stations as well as a school being designed on Culebra include solar energy.

While solar power is not yet implemented on a large scale, multiple professionals we interviewed used the implementation of solar power in Culebra and U.S. Post Offices in Puerto Rico to support the opinion that solar power is the most feasible prospective renewable energy source on the island. These examples show that there is a positive response, at least in the engineering field, to this type of alternative energy. However, a positive social response is not enough evidence to prove the feasibility of solar power alone. Therefore, we completed a cost-benefit analysis to compute the economic feasibility of these systems.

Solar Power Cost-Benefit Analysis

The average current characteristics for a photovoltaic (PV) solar panel (see Glossary) are listed in Table 1.

Table 1. Solar Panel Characteristics*

System	1 kW Panel in 2008	1 kW Panel in 2010	1 kW Panel in 2020
Panel Area (sq. ft)	90	90	90
Efficiency (%)	15	-	-
Average Output (kWh/yr)	1700	2010	2010
System Cost ($)	9,000	6,030	3,015
Life Expectancy (yrs)	25	25	25
Maintenance and Operation Costs ($/yr)	32.40	21.71	10.854
Cost of Solar Produced Electricity ($/kWh)	0.12	0.06	0.03

*(sources in Appendix C)

Tables 2, 3, and 4 show the percentage of energy consumed at each facility that could be produced by a PV system in pumping stations, water treatment plants, and wastewater treatment plants, respectively. We calculated the number of panels for the PV system (see Tables 2, 3, and 4) based on the rooftop area available at each facility (see Appendix B). If the available area allowed for the production of more energy than the facility consumes, we also calculated a PV system to accommodate 100 percent of the energy.

Table 2. PV System for Pumping Stations

Pumping Stations	Number of Panels	Percentage of Energy (%)
Low Energy Station	6	2.2
Med Energy Station	37	170.8
Med Energy Station (100%)	22	100
High Energy Station	20	16.4

Table 3. PV System for Water Treatment Facilities

Wastewater Treatment Plant	Number of Panels	Percentage of Energy (%)
Barranquitas	71	36.3
Humacao	71	9.4
Canóvanas	71	4.4

Table 4. PV System for Wastewater Treatment Facilities

Wastewater Treatment Plant	Number of Panels	Percentage of Energy (%)
San Lorenzo	71	21.8
Yabucoa	71	18.9
Fajardo	71	12.8

Pumping Stations.

The Net Present Value (NPV) (see Chapter Three) of each PV system at each Pumping Station, shown in Table 2, are shown in Figures 4, 5, 6, and 7. The NPV was calculated at the pricing of the systems in 2010 (see Table 1).

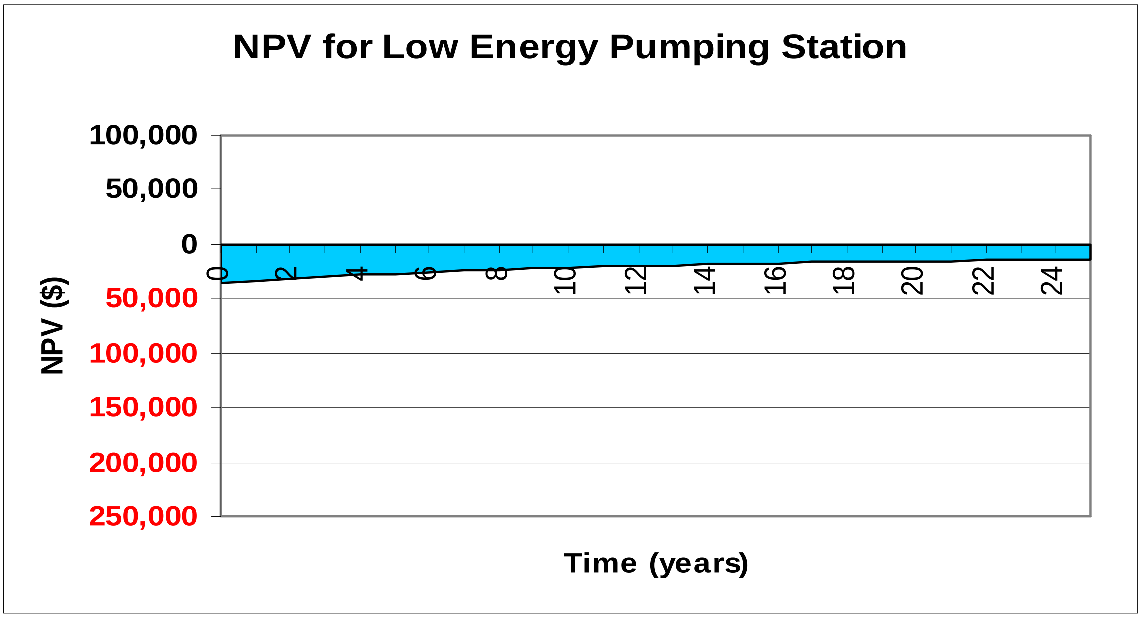

Figure 4. NPV for Low Energy Pumping Station at an 8% Prime Rate Over 25 Year System Lifespan

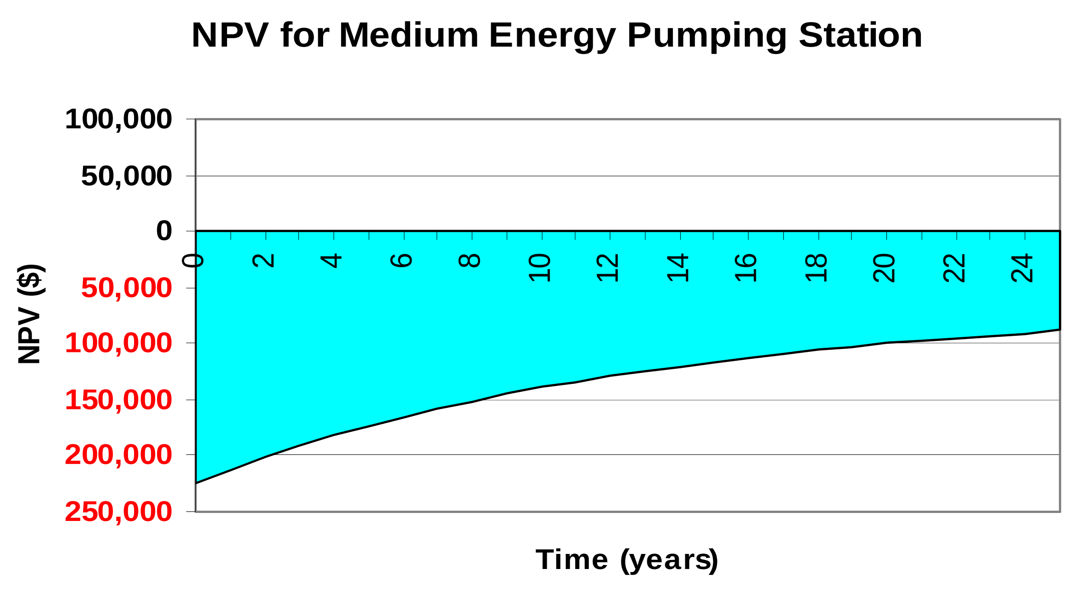

Figure 5. NPV for Medium Energy Pumping Station at an 8% Prime Rate Over 25 Year System Lifespan

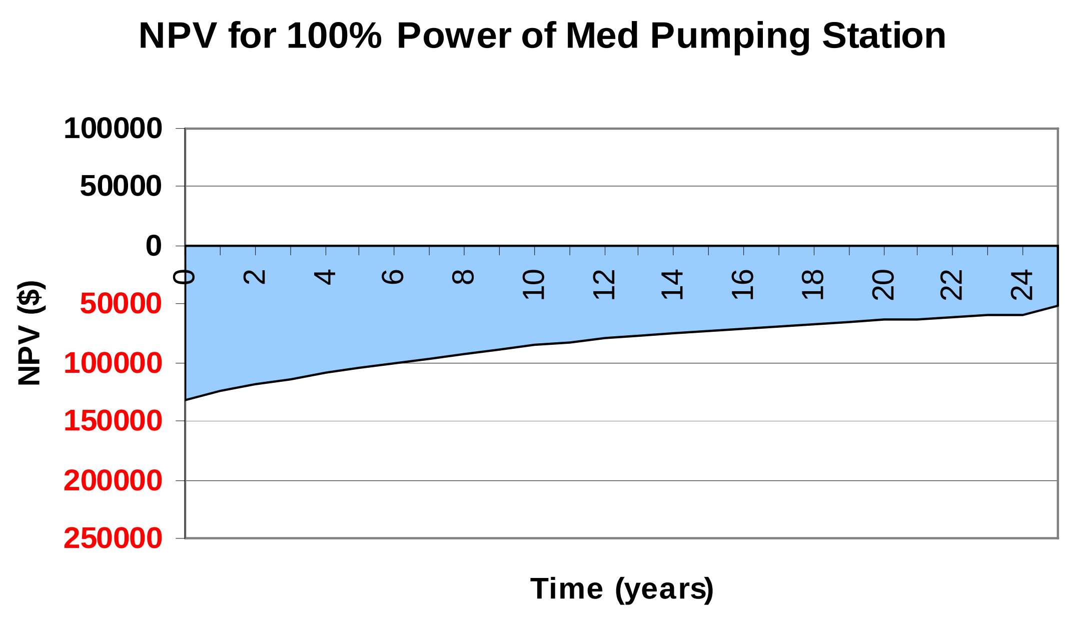

Figure 6. NPV for 100 Percent Power of Medium Energy Pumping Station at an 8% Prime Rate Over 25 Year System Lifespan

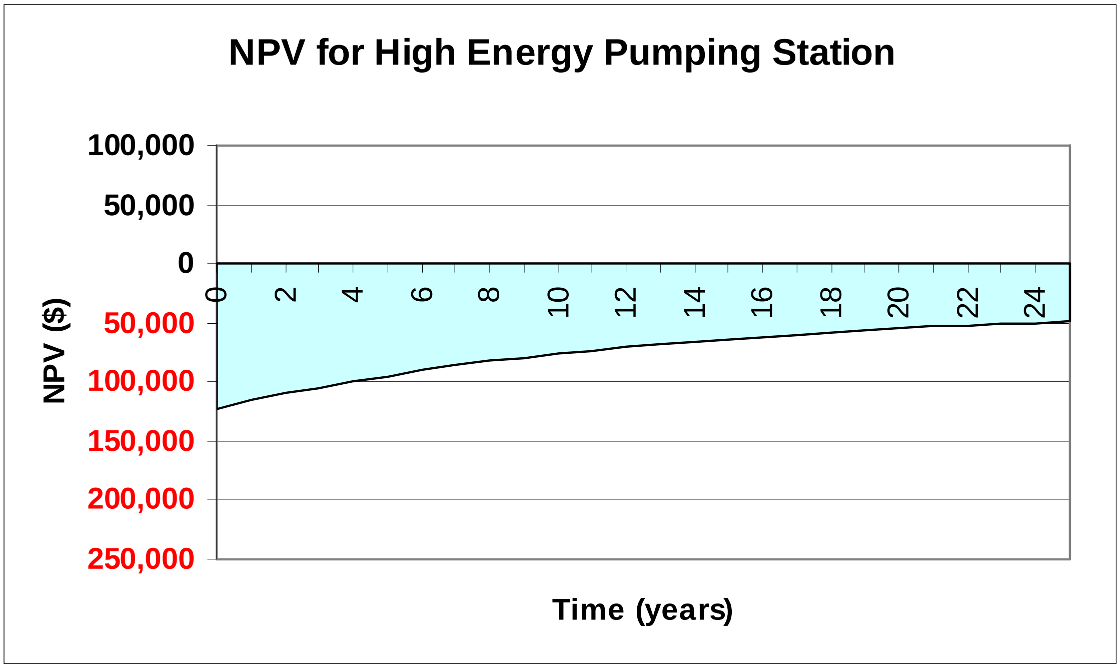

Figure 7. NPV for High Energy Pumping Station at an 8% Prime Rate Over 25 Year System Lifespan

Figure 4 illustrates that the PV system of six panels for the Low Energy Pumping Station requires an initial investment of about $35,000 and does not reach a payback period within the expected twenty-five year lifespan of the system. Figure 5 illustrates that the PV system of thirty-seven panels for the Medium Energy Pumping Station requires an initial investment of $224,000 and also does not reach a payback period within the expected twenty-five year lifespan of the system. Additionally, the PV system with twenty-two panels to produced 100 percent of the power needed by the Medium Energy Pumping Station, as shown in Figure 6, has a lower initial investment of $131,000, but it still does not reach its payback period within the lifetime of the system. Following a similar trend, the PV system with twenty panels for the High Energy Pumping Station, as shown in Figure 7, has an initial investment of $122,000 and no observed payback period.

These calculations will change over the next decade because the cost of solar energy systems is expected to decline by 50 percent by the year 2020 (Navigant Consulting, Inc, 2006). This decline will decrease the initial cost of a system and should allow for a profit to be made from solar energy systems. This cost decrease can be seen in Table 1. The NPV of the PV systems calculated using the cost of a system in 2020 is shown in Figures 8, 9, 10, and 11.

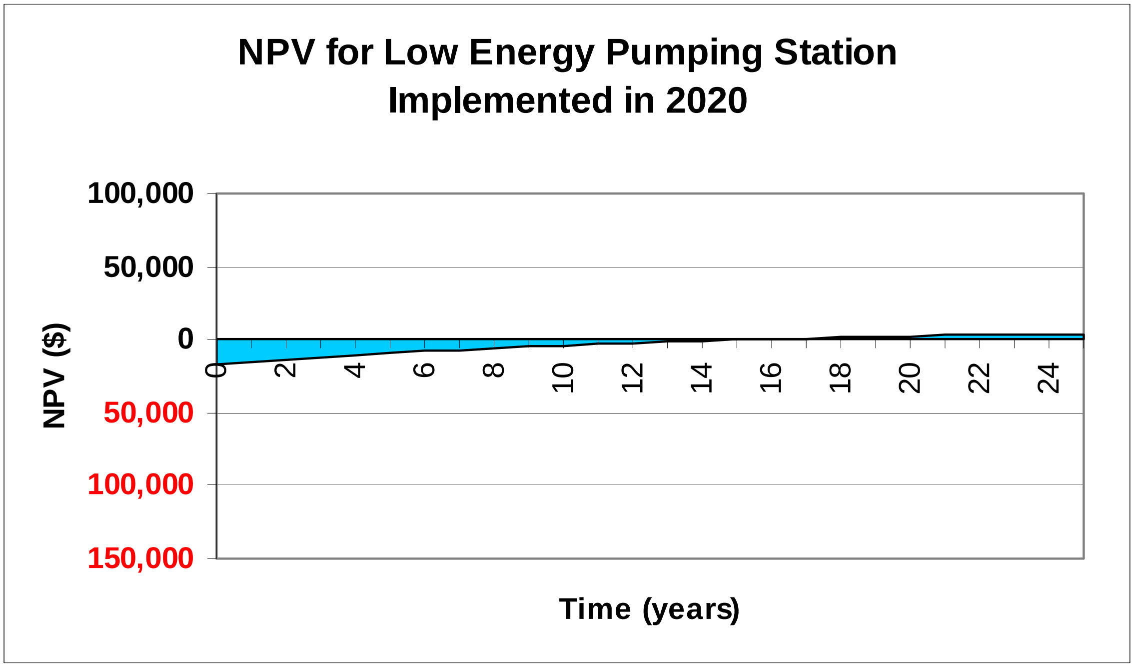

Figure 8. NPV for Low Energy Pumping Station in 2020 at an 8% Interest Rate Over a 25 Year System Lifespan

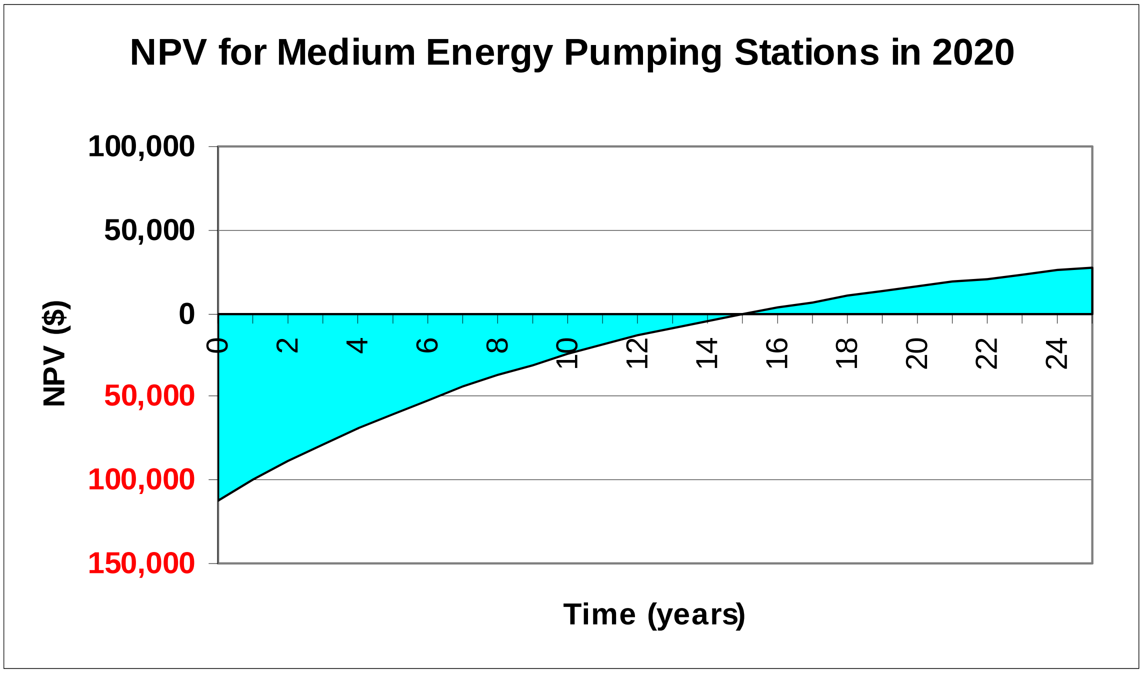

Figure 9. NPV for Medium Energy Pumping Station in 2020 at an 8% Interest Rate Over a 25 Year System Lifespan

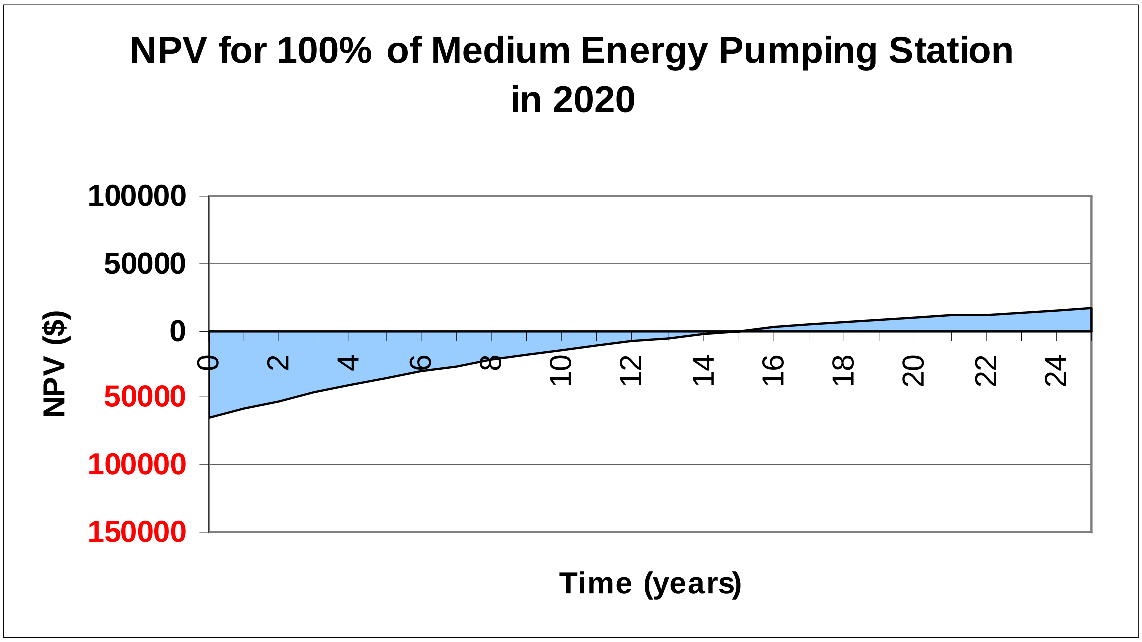

Figure 10. NPV for 100% Power of Medium Energy Pumping Station in 2020 at 8% Interest Rate Over 25 Year System Lifespan

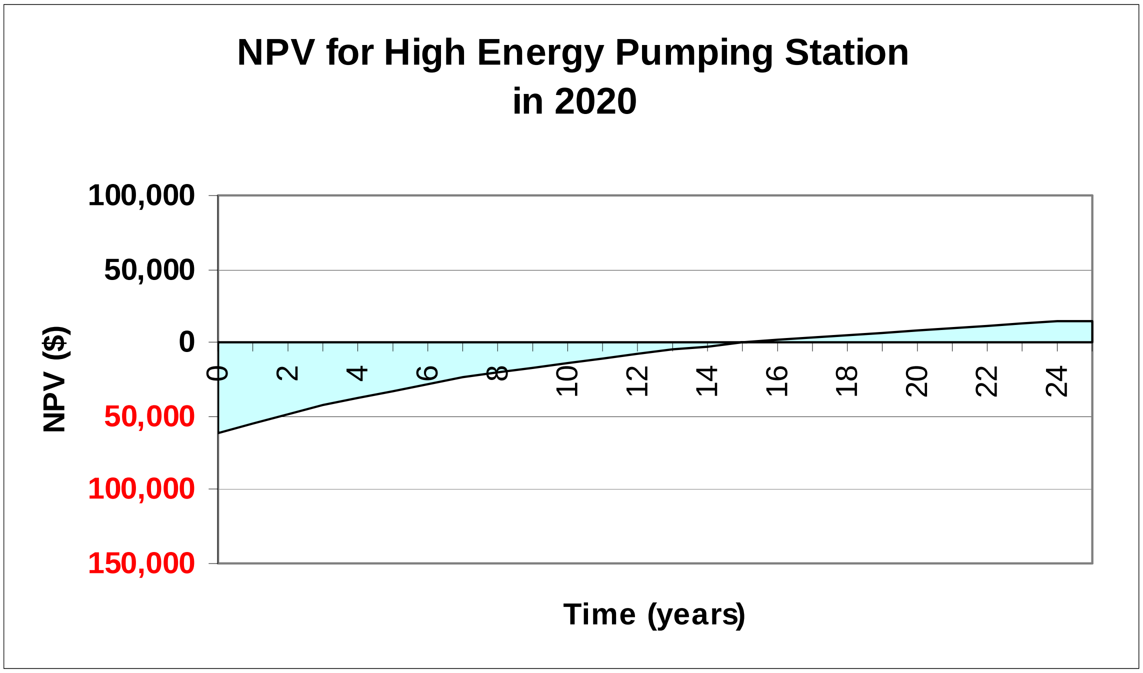

Figure 11. NPV for High Energy Pumping Station in 2020 at 8% Interest Rate Over 25 Year System Lifespan

The preceding Figures 8, 9, 10, and 11 show that each system has had a decrease in the initial cost, as well as a potential profit after a fifteen year payback period. Table 5 shows the differences in initial cost as well as the profits of each pumping station system implemented in 2020.

Table 5. Pumping Station Initial Cost Comparison

Pumping Station	Initial Cost in 2010 ($)	Initial Cost in 2020 ($)	Profit from system implemented in 2020 ($)
Low Energy	35,000	17,000	4,000
Med Energy	224,000	112,000	27,000
Med Energy (100%)	131,000	65,700	16,000
High Energy	122,000	61,000	15,000

An energy comparison, as seen in Figures 12, 13, 14, and 15, shows the electricity savings gained if each solar system were implemented in 2010, implemented in 2020, or never implemented.

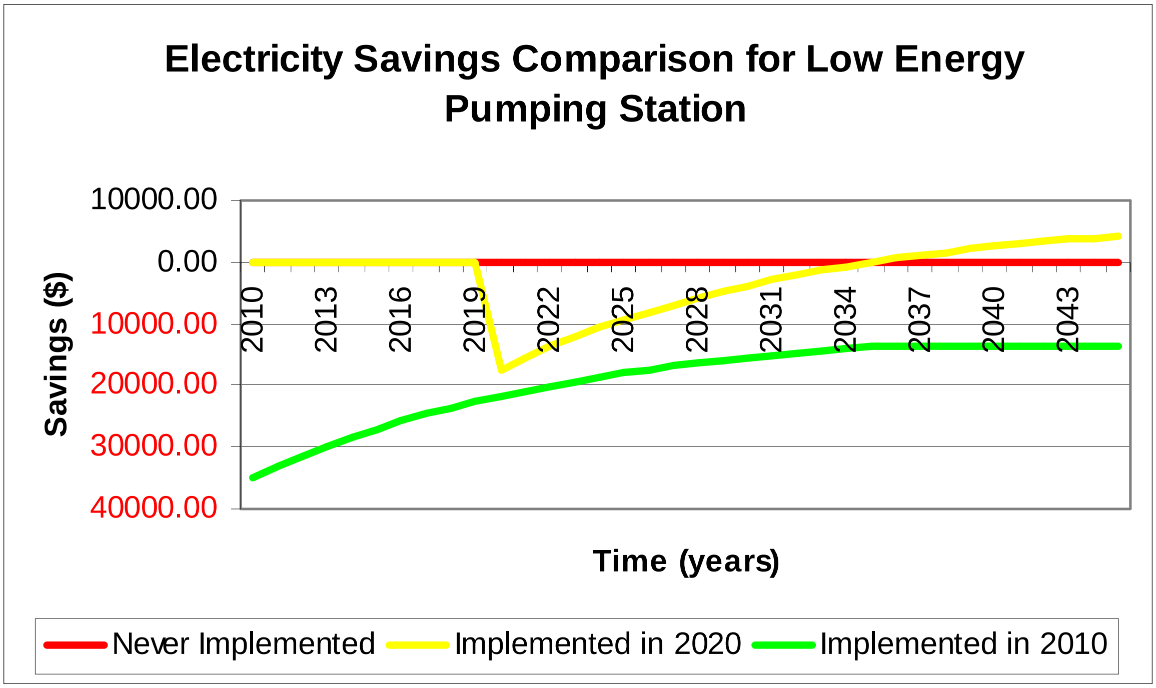

Figure 12. Electricity Savings Comparison for Low Energy Pumping Station

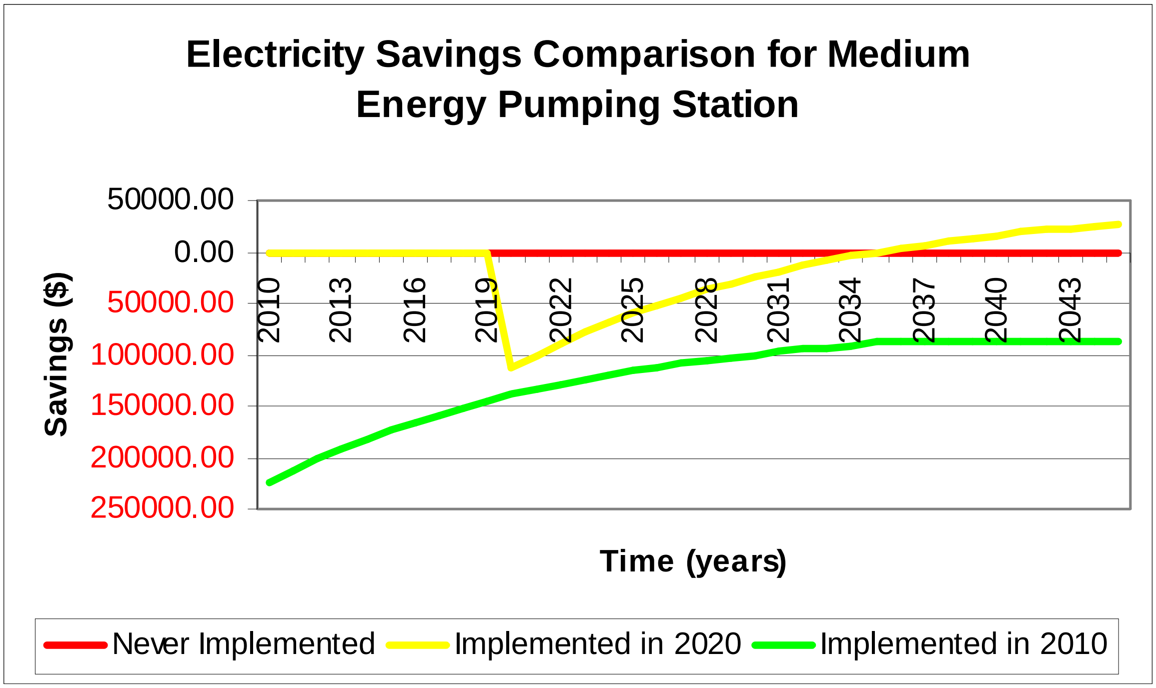

Figure 13. Electricity Savings Comparison for Medium Energy Pumping Station

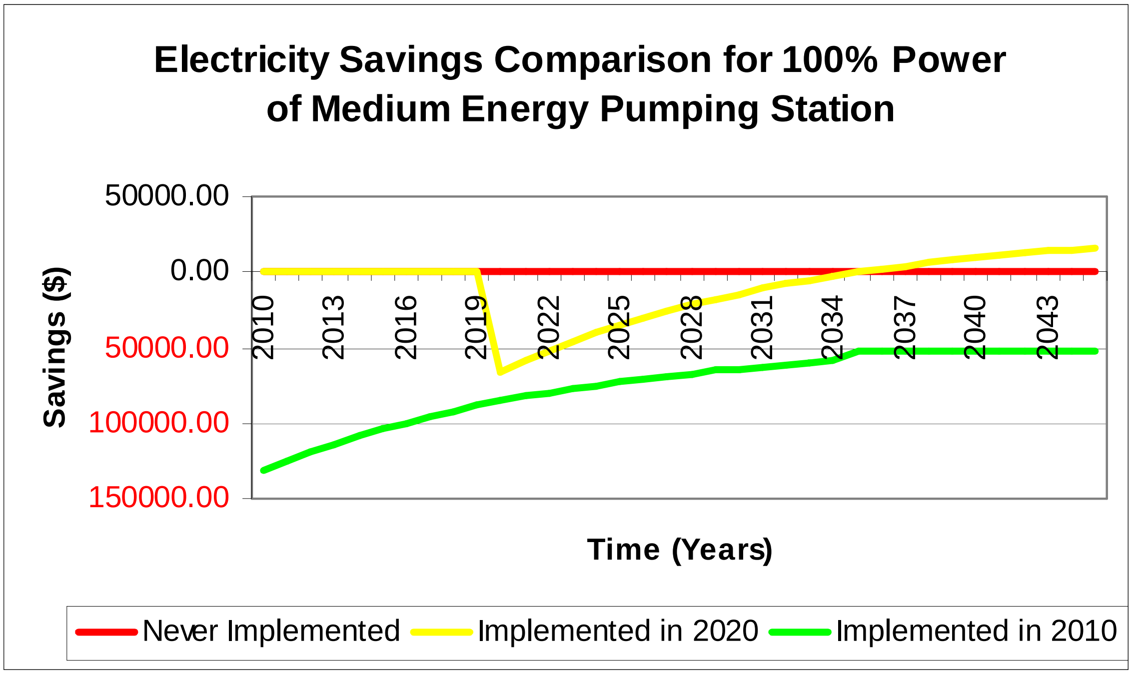

Figure 14. Electricity Savings Comparison for 100% Power of Med Energy Pumping Station

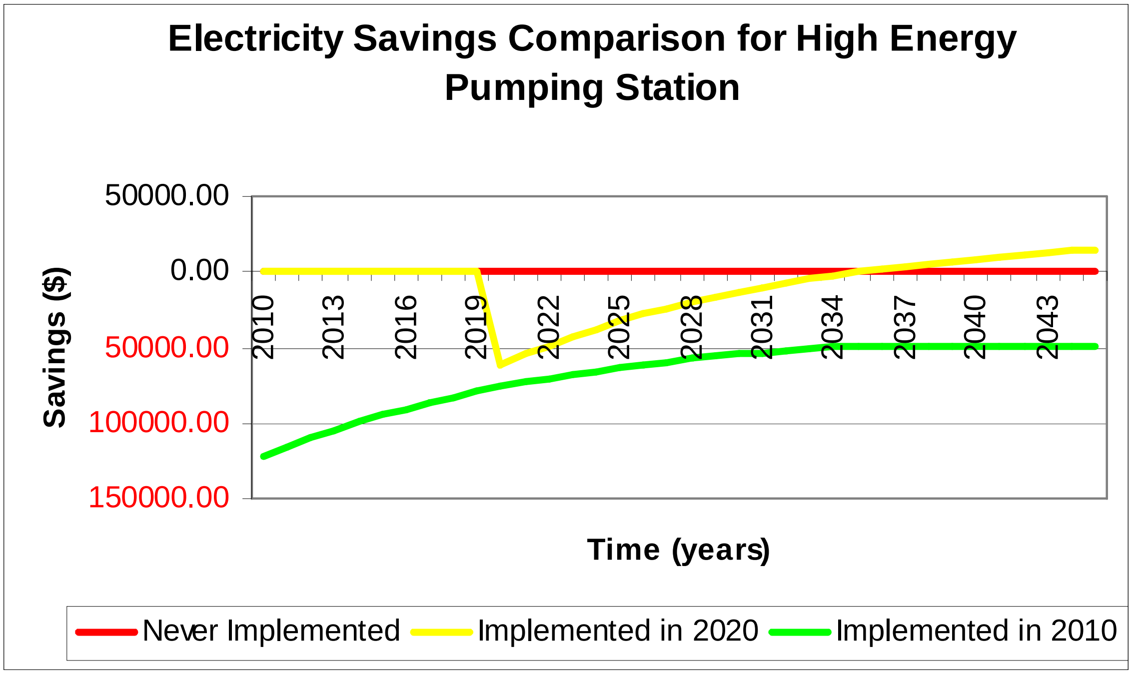

Figure 15. Electricity Savings Comparison for High Energy Pumping Station

Shown in these electricity savings graphs are the net electricity savings over the combined lifetime of both systems. The implementation of the solar panels causes a decline in savings equal to the amount of the initial cost of the system in 2020, the time of implementation.

Water Treatment and Wastewater Treatment Plants.

Since our group used the same available rooftop space area for both water treatment and wastewater treatment facilities, seen in Appendix B, the size of the solar systems for each plant will be the same, as shown in Tables 3 and 4. Therefore, the NPV for each PV system at each water treatment and wastewater treatment facility will be the same. This NPV is shown below in Figure 16.

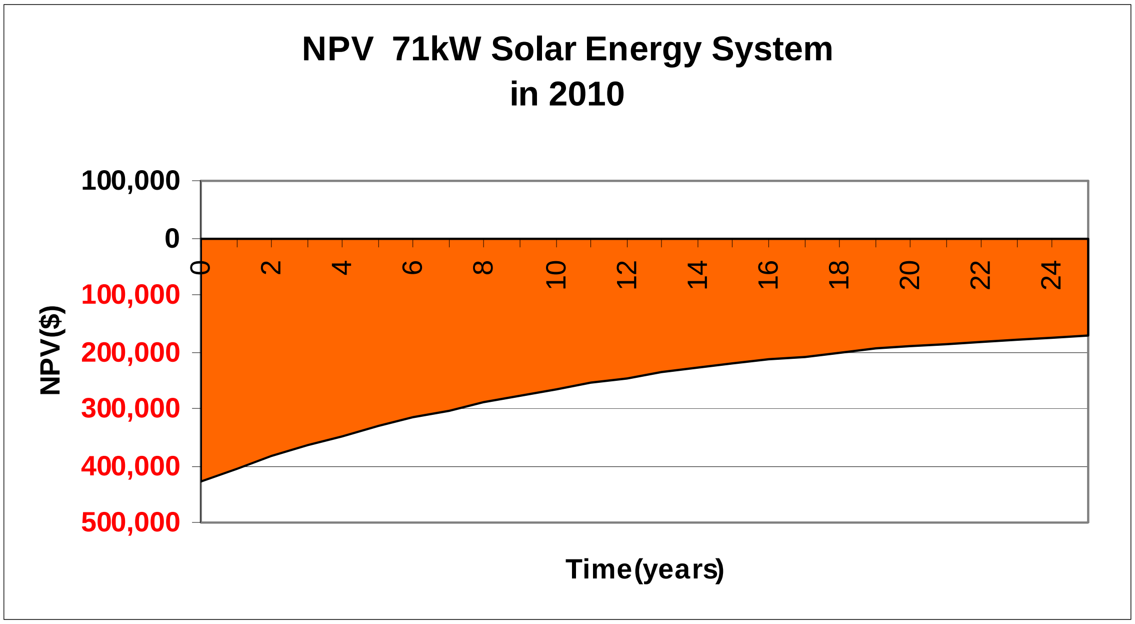

Figure 16. NPV 71 kW System at an 8% Interest Rate Over 25 Year System Lifetime

Figure 16 illustrates that the PV system of seventy-one panels for the treatment facilities requires an initial investment of $430,000 and does not reach a payback period within the expected twenty-five year lifespan of the system.

As seen with the pricing of solar systems in pumping stations, the 71 kW systems for treatment plants will have a decreased initial cost by 2020, which is shown in Figure 17.

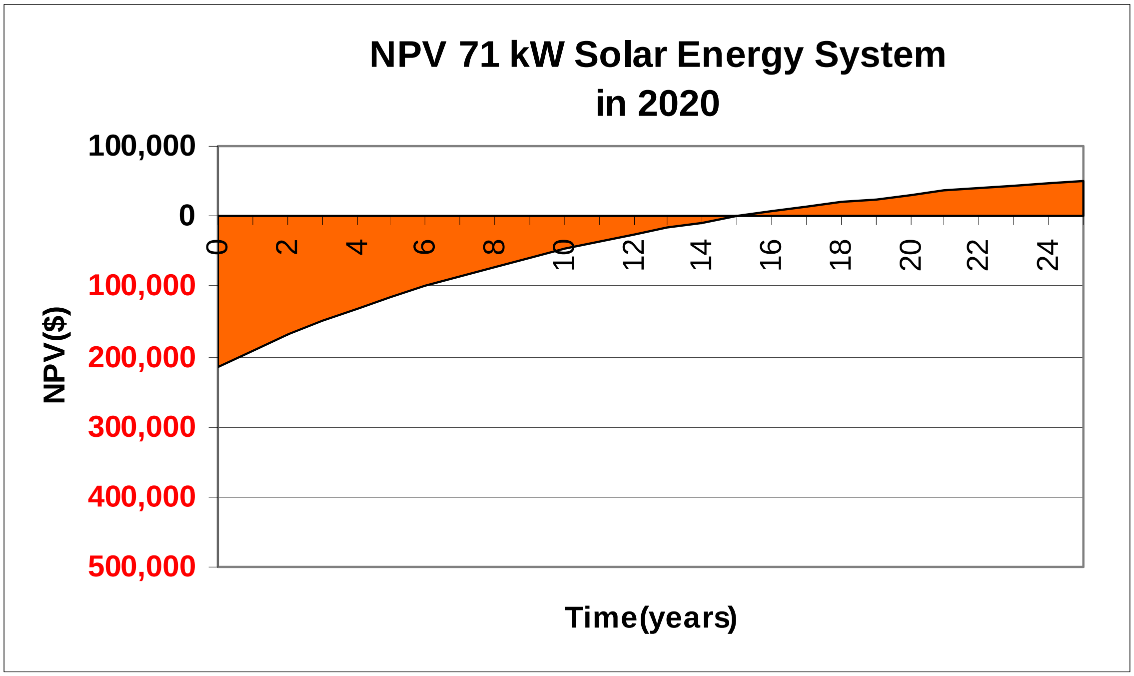

Figure 17. NPV for 71kW System in 2020 at 8% Interest Rate Over 25 Year System Lifespan

Figure 17 shows the decreased initial investment of $210,000 and a payback period of fifteen years. Additionally, when implemented in 2020, this system will make a future profit of $52,000.

In addition, a comparison of the electricity savings for the 71 kW system implemented in a treatment plant is shown below in Figure 18.

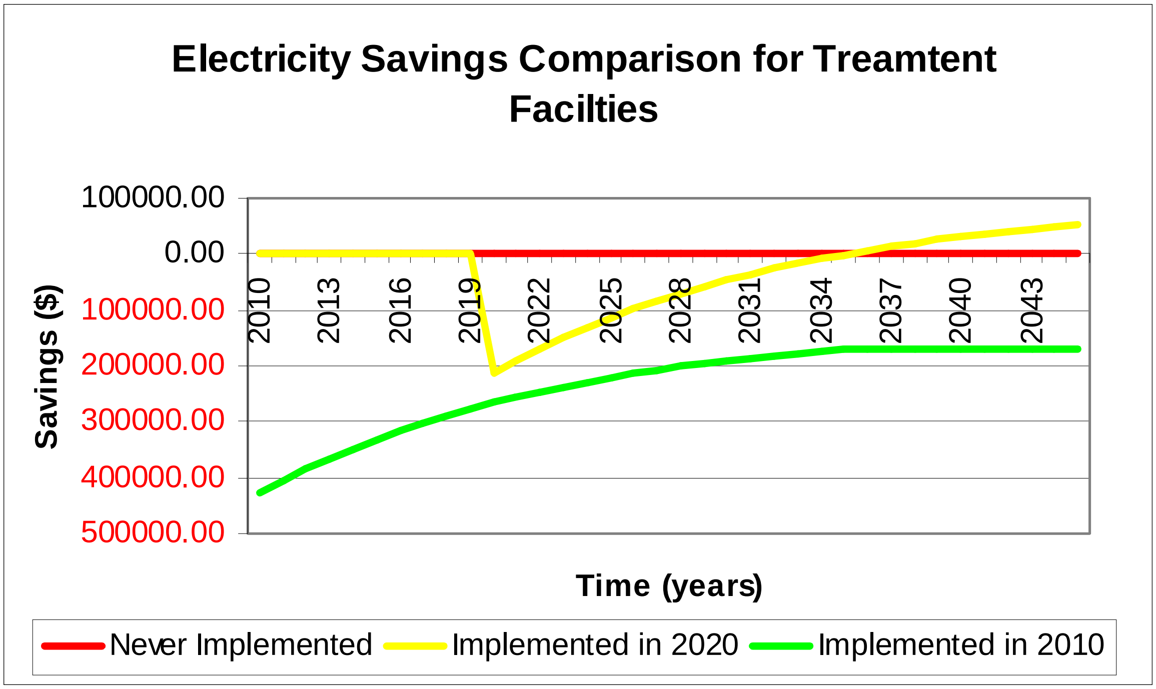

Figure 18. Electricity Savings Comparison for Treatment Facilities

Analysis of Solar Energy Systems

The NPV graphs displayed within the photovoltaic system cost-benefit analysis section show that implementation of solar energy systems should be delayed until 2020 in all water infrastructure facilities. Because the system costs will decrease between 2010 and 2020, the future solar energy systems will have a payback period as well as a future profit, shown in Figures 8, 9, 10, 11, and 17.

The electricity savings comparison graphs (see Figures 12, 13, 14, 15 and 18) further show that if solar energy is implemented in 2010, a negative net savings is incurred as opposed to the never implemented line which shows neither profits nor additional costs. However, if the implementation starts in 2020, there is an eventual profit shown.

Additionally, these graphs dispute the perceptions we found most professionals we interviewed to have about solar energy. Although there are current applications of solar energy in Puerto Rico as discussed in our interviews with professionals, these are on a small scale. As our results show, large scale applications of solar energy, such as those that would meet the energy needs of treatment plants, are not yet feasible within Puerto Rico. In addition to our cost-benefit analysis results for solar energy systems, through published material review, we determined that solar power was feasible on a large scale where incentives were available. However, Puerto Rico does not currently offer significant incentives for renewable energy that would apply to water infrastructure.

WIND POWER FEASIBILITY

In our interviews, we received some negative feedback involving wind power, a renewable source of energy not currently implemented in Puerto Rico. The main concern regarding wind power is the belief that the wind turbines would take up more space than the small island of Puerto Rico can afford to use for energy production. However, these concerns were stated as personal opinions and not facts. We found that many of the engineers we interviewed and from whom we collected information referred to wind farms consisting of 1 and 2 MW wind turbines. However, there are many other types of wind turbines, and after hearing about the concerns of the professionals we interviewed, we completed a cost-benefit analysis on Small-Size Wind Turbines (see Glossary), Micro-Size Wind Turbines (see Glossary), and Mid-Size Wind Turbines (see Glossary).

The wind turbines we investigated operate optimally in areas with wind speeds of 7 m/s. Although we found that the annual average wind speeds in Puerto Rico can produce sufficient wind power (see Figure 19), the wind speeds at individual sites would have to be tested before implementation. This service is often provided by the wind turbine distributor.

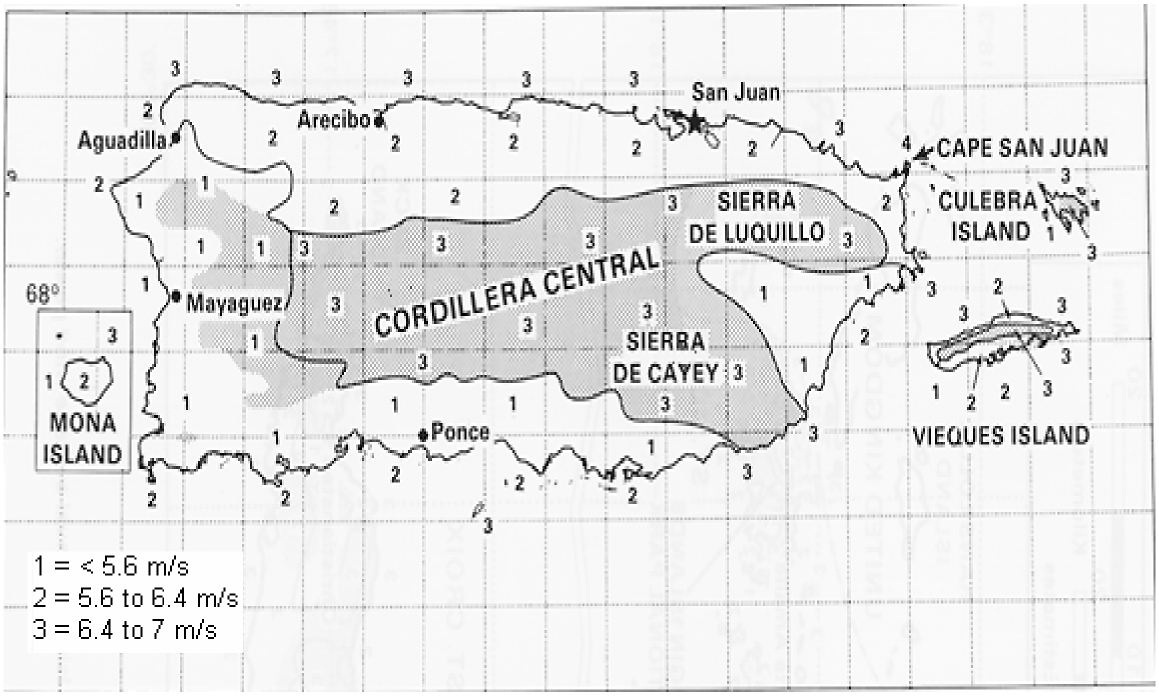

Figure 19: Annual Average Wind Speed (Modified from: http://rredc.nrel.gov/wind/pubs/atlas/maps/chap3/gifs/map3-71.gif)

Small- and Micro-Wind Turbine Cost-Benefit Analysis

The characteristics of a range of small- and micro-size wind turbines are listed in Table 6.

Table 6. Generalized Small- and Micro-Size Turbine Breakdown

System	**12 kW**	**20 kW**
Blade Diameter Size (m)	1.25	10
Height of Tower (m)	1.85	31
Efficiency (%)	30	30
Average Output (kWh/yr)	31,500	20,000 to 73,000
System and Installation Cost ($)	74,000	45,500
Life Expectancy (yrs)	20*	20
Maintenance and Operation Costs ($)	1,480	910
	* based on typical small wind turbine	

Tables 7, 8, and 9 show the percentage of energy consumed that could be produced by each of the represented small- and micro-size wind turbine systems in pumping stations, water treatment plants, and wastewater treatment plants, respectively.

Table 7. Small- and Micro-Wind Feasibility in Pumping Stations

Pumping Stations	% Energy Consumed at Low Station	% Energy Consumed at Medium Station	% Energy Consumed at High Station
Energy Produced by one 12 kW System	5	3	0
Energy Produced by two 12 kW Systems	10	2	0
Energy Produced by one 20 kW System	3 to 11	1 to 4	0

Table 8. Small- and Micro-Wind Feasibility in Water Treatment Plants

Water Treatment Plant	% Energy Consumed at Barranquitas	% Energy Consumed at Humacao	% Energy Consumed at Canóvanas
Energy Produced by two 12 kW Systems	16	4	2
Energy Produced by six 20 kW Systems	31 to 111	8 to 29	4 to 14
Energy Produced by eight 20 kW Systems	41 to 149	11 to 39	5 to 18

Table 9. Small- and Micro-Wind Feasibility in Wastewater Treatment Plants

Wastewater Treatment Plant	% Energy Consumed at San Lorenzo	% Energy Consumed at Yabucoa	% Energy Consumed at Fajardo
Energy Produced by two 12 kW Systems	10	8	5
Energy Produced by six 20 kW Systems	18 to 67	16 to 58	11 to 39
Energy Produced by eight 20 kW Systems	24 to 89	21 to 78	14 to 53

There is a basic guideline for determining the amount of space a turbine needs. Based on recommendations from manufacturer's representatives (see Appendix B), the turbines should have at least the height of the tower, ideally two to three times the height, as the distance to the next tower or other tall objects surrounding the tower. Additionally, the bottom of the blade should be at least 30 feet above the next tallest point on the site so the wind flow is not obstructed. If a greater distance can be provided, the turbine will supply more electricity. Based on this information, our group calculated the number of turbines that could fit at each facility and then performed a cost-benefit analysis for each system.

Pumping Stations.

Given the available space data provided to us for pumping stations (see Appendix B), our group determined pumping stations are not a feasible location for micro-size wind turbines because they do not have adequate roof space and require much more power to be produced than the output of the micro turbine (see Table 7). Because of this, we did not conduct a cost-benefit analysis of the 12 kW system implemented in pumping stations.

However, Table 7 shows that there is a potential to produce an adequate amount of energy at the low and medium energy pumping stations with one 20 kW wind turbine system. The space information provided to us did not allow for the implementation of a 20 kW wind turbine, as seen in Table 10, which shows the difference in space available and space needed for a small turbine at one pumping station's site. However, our group assessed this system because without access to further information, it cannot be assumed that there are not pumping stations with larger sites areas or in mountainous and remote areas that could accommodate a 20 kW turbine.

Table 10. Pumping Station Land Availability and Turbine Land Needs

	Actual Area (m^2)
Pumping Station Site Area Available	600
20 kW Area Needed Per Unit	983
Area Remaining Required by Turbine	383

We calculated the NPV for one 20 kW turbine, which can be seen in Figure 20.

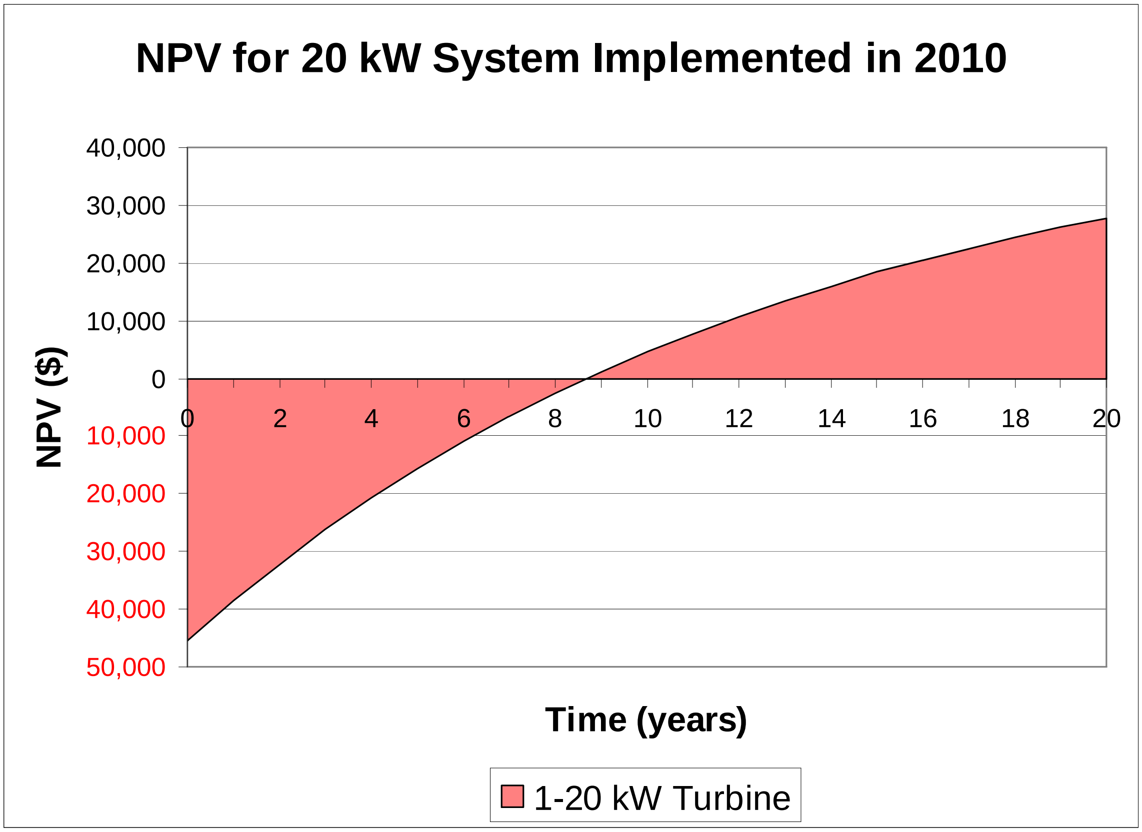

Figure 20. NPV of 20 kW System at Pumping Stations at an 8 Percent Prime Rate Over the 25 Year System Lifetime Implemented in 2010

Figure 20 shows that the initial cost of the 20 kW turbine is $45,500, has a payback period of 8.75 years, and a future profit in 2030 of $27,750.

Over the next decade the system cost will decrease by 20 percent (European Wind Energy Association, 2007), both decreasing the initial cost and increasing the future profit of the system, as seen in Figure 21.

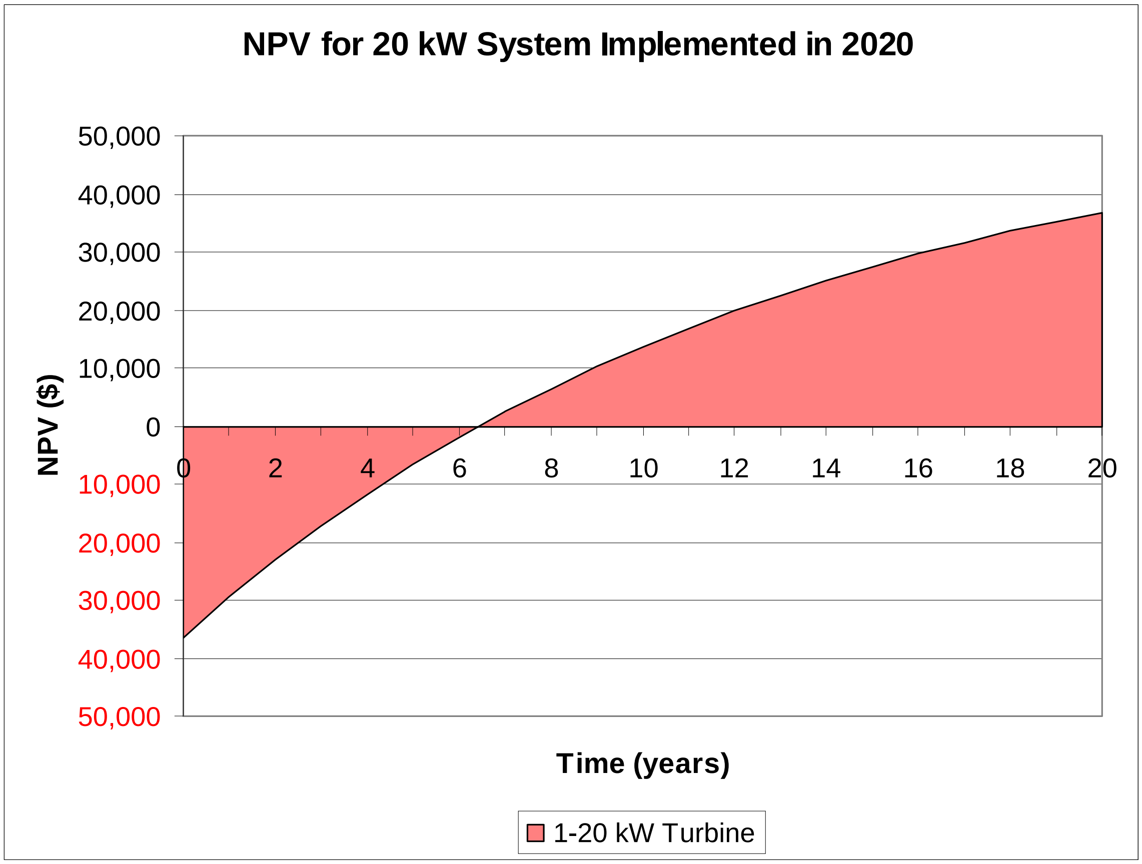

Figure 21. NPV of 20 kW Systems at Pumping Stations at an 8 percent Prime Rate Over the 25 Year System Lifetime Implemented in 2020

Figure 21 shows that the initial cost has decreased to $36,400, the payback period will be about seven years, and the future profit will increase to approximately $33,800.

However, the economic benefits of implementing a system sooner versus later are shown in Figure 22 for a 20 kW system.

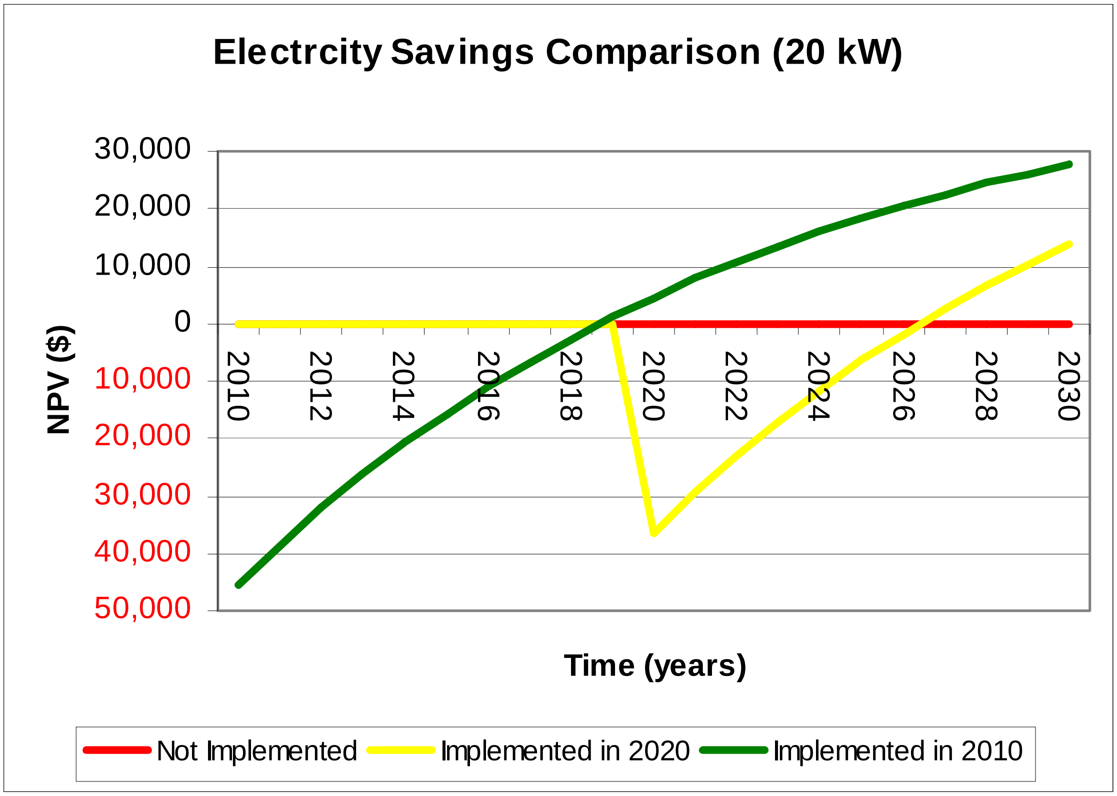

Figure 22. Electricity Savings Comparison of NPV for 20 kW System Through 2030 with an 8 Percent Prime Rate

Water and Wastewater Treatment Plants.

Through speaking with CSA Group Cost Estimator R. Green (personal communication, April 13, 2007), our group discovered that the average land area of a water treatment plant is generally between 4,000 m^2 and 8,000 m^2. Since our group was not able to obtain the land area for a wastewater treatment plant and CSA Group Cost Estimator R. Green (personal communication, April 13, 2007) stated that wastewater treatment plants are generally bigger in size than water treatment plants, we used the same available land area for all treatment plants.

Table 11 shows the number of systems able to be implemented at each treatment facility based on space. This number was determined by the maximum area of a treatment facility divided by the area required for one turbine. Since all treatment plants in our analysis are considered to have the same area, a maximum number of two 12 kW can be used given the spatial constraints. However, a maximum number of eight 20 kW turbines can be implemented.

Table 11. Minimum Units Needed to Supply up to 100% Plant Power Based on Space Feasibility

	12 kW	**20 kW**
Wastewater Treatment Plants		
San Lorenzo	2	8
Yabucoa	2	8
Fajardo	2	8
Water Treatment Plants		
Barranquitas	2	6
Humacao	2	8
Canóvanas	2	8

At the Barranquitas facility as seen in Table 11, six turbines can produce 100 percent of the energy consumed. Therefore, we completed a cost-benefit analysis for 20 kW systems using six and eight turbines.

Using cost data for 2010, seen in Tables 8 and 9, the NPV for the two 12 kW systems, as well as the six 20 kW and eight 20 kW systems are shown in Figures 23 and 24, respectively.

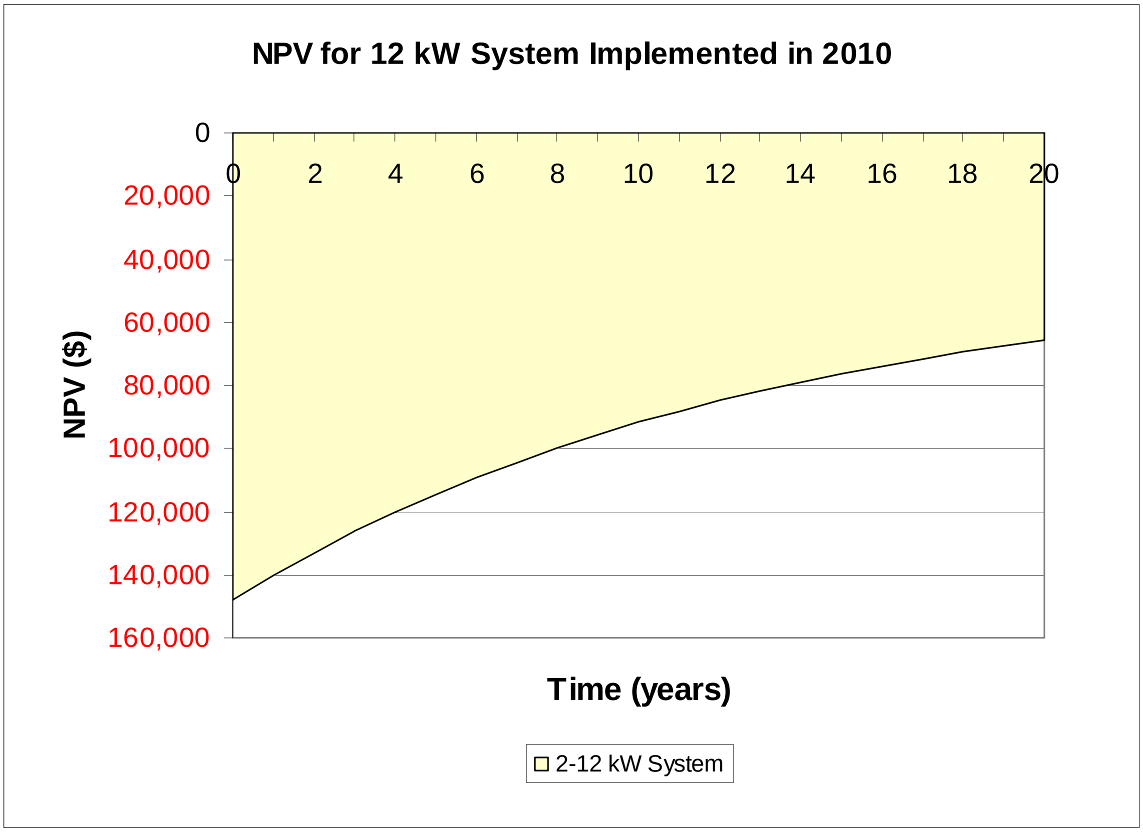

Figure 23. NPV 12 kW Systems at Wastewater and Water Treatment Plants at an 8 Percent Prime Rate Over the 20 Year System Lifetime Implemented in 2010

The payback period for the 12 kW system is independent of the number of turbines in the system and is shown in Table 12. Both Table 12 and Figure 23 show that the system does not payback during the expected lifetime of the system. It also shows the differences in initial cost and net savings.

Table 12. Payback Period, Initial Cost, and End Net Present Value of 12 kW Turbines at Treatment Plants Implemented in 2010

	Payback (years)	Initial Cost	End Net Present Value in 2030
Use of two 12 kW Turbines at Treatment Plants	>200	$148,000	- $65,700

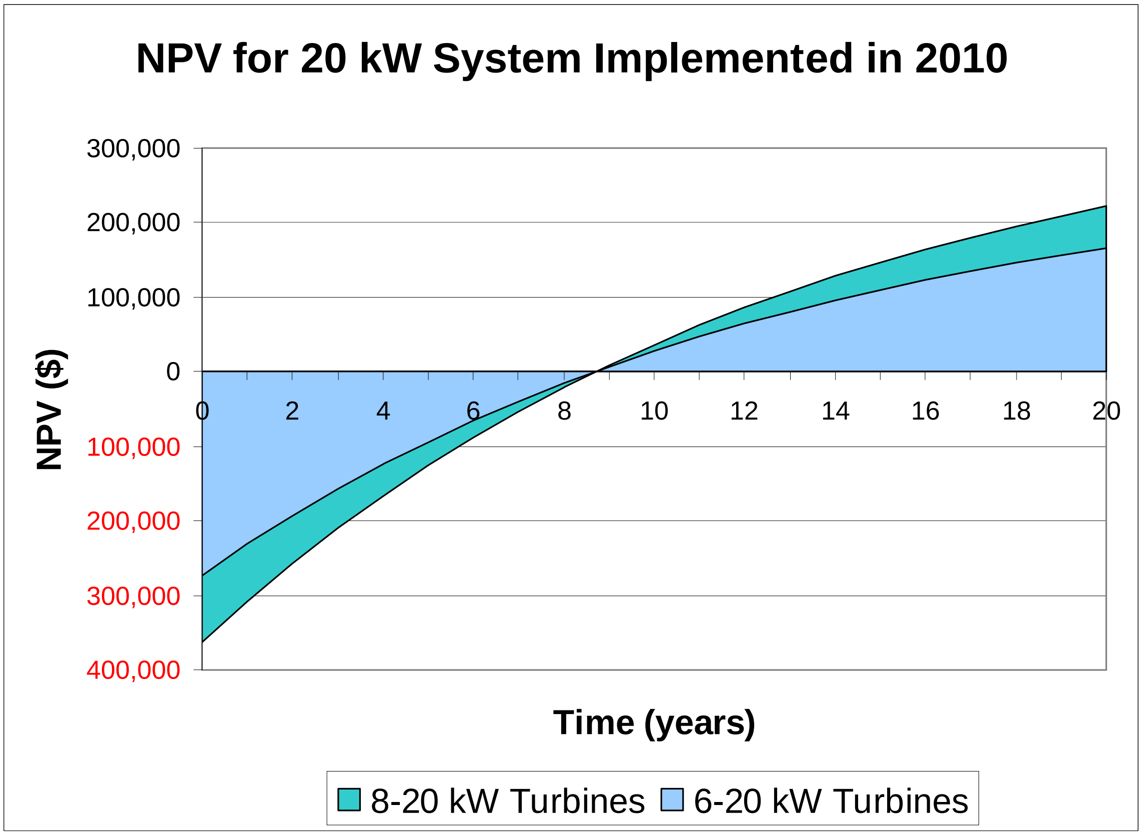

Figure 24. NPV of 20 kW Systems at Wastewater and Water Treatment Plants at an 8 percent Prime Rate Over the 20 Year System Lifetime Implemented in 2010

The payback period as well as the differences in initial cost and net savings of the system shown in Figure 24 are presented in Table 13.

Table 13. Payback Period, Initial Cost, and End Net Present Value of 20 kW Turbines Treatment Plants Implemented in 2010

	Payback (years)	**Initial Cost ($)**	**Future Profit in 2030 ($)**
Use of six 20 kW Turbine at Treatment Plants	8.75	273,000	166,500
Use of eight 20 kW Turbine at Treatment Plants	8.75	364,000	222,000

Similar to the wind turbine systems used in pumping stations, the NPV for the wind turbine systems will change as the system cost decreases. The NPV in 2020 for the two 12 kW systems, as well as the six 20 kW and eight 20 kW systems are shown in Figures 25 and 26, respectively.

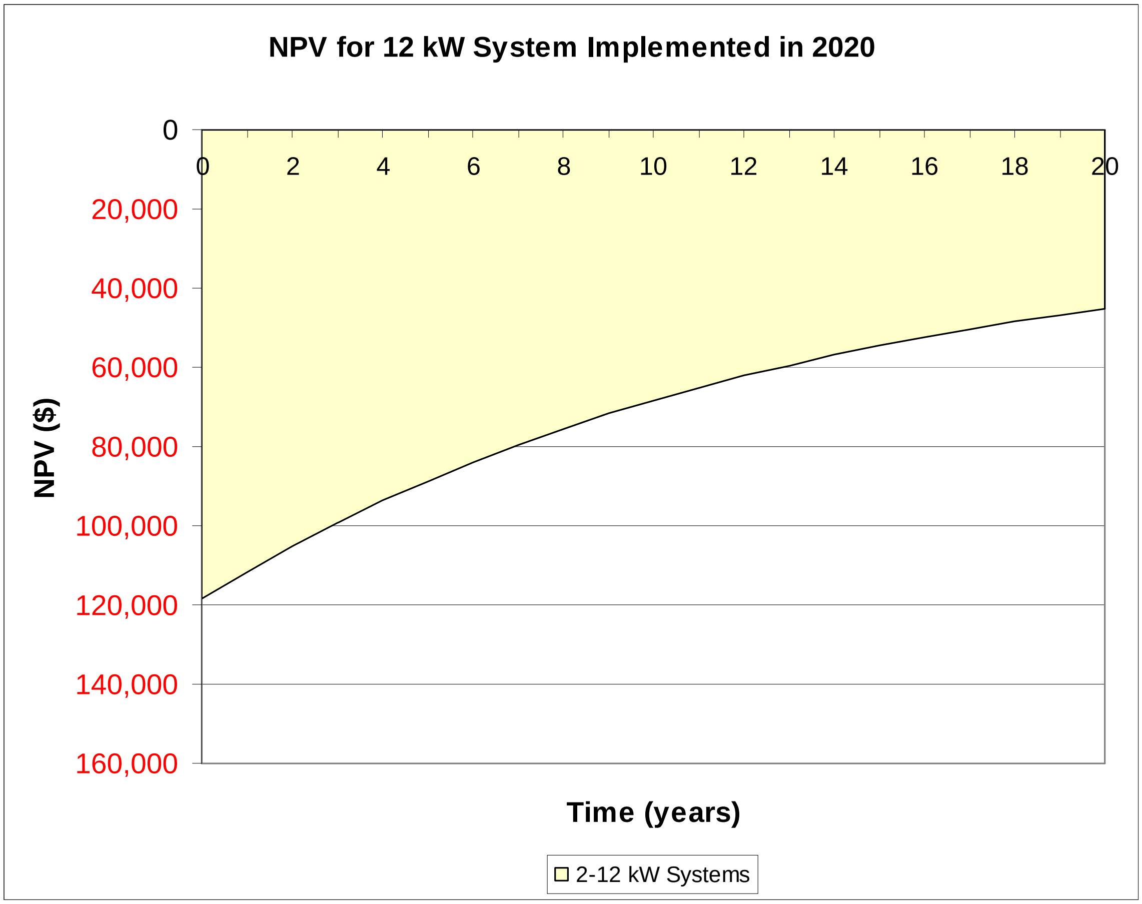

Figure 25. NPV of 12 kW Systems at Wastewater and Water Treatment Plants at an 8 Percent Prime Rate Over the 20 Year System Lifetime Implemented in 2020

Shown in Table 14 is the decreased initial cost of the two 12kW systems implemented in 2020 compared to the same system implemented in 2010.

Table 14. Payback Period, Initial Cost, and End Net Present Value of 12 kW Turbines Treatment Plants Implemented in 2020

	Payback (years)	**Initial Cost ($)**	**Future Profit in 2040 ($)**
Use of two 12 kW Turbines at Treatment Plants	>200	118,400	- 45,200

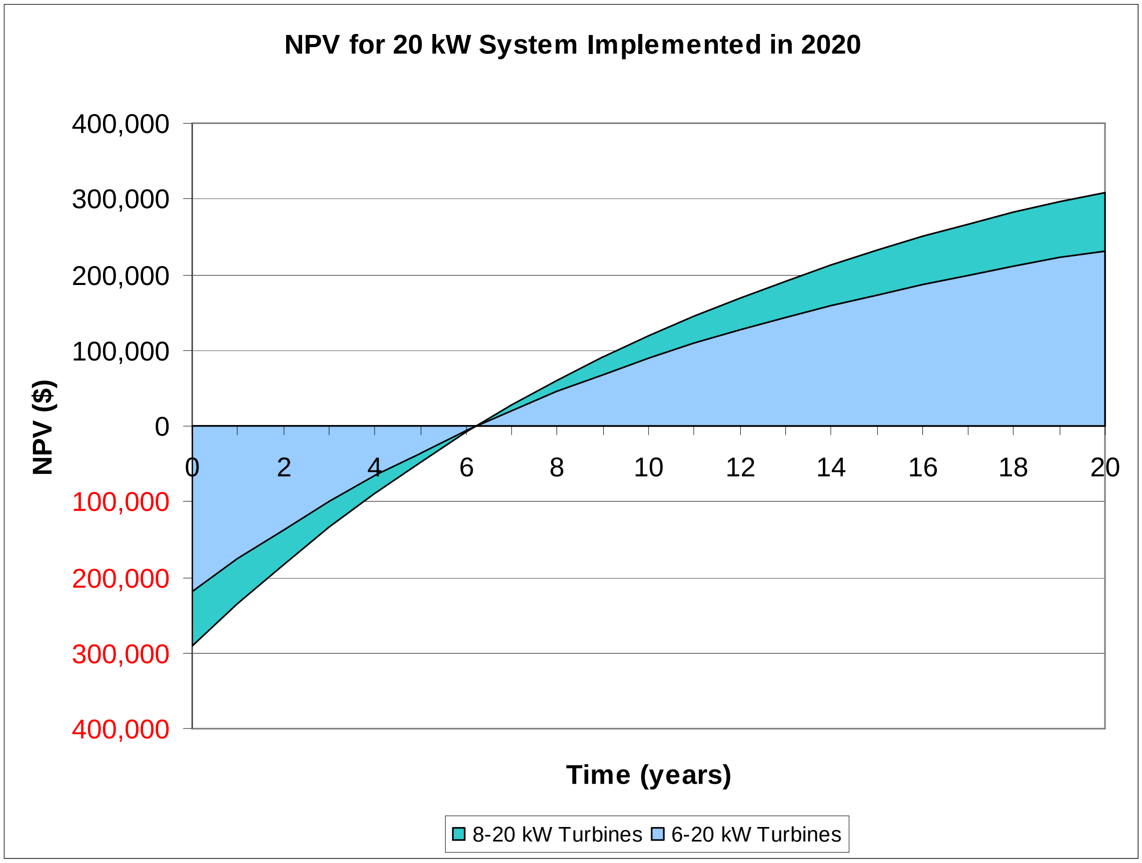

Figure 26. NPV of 20 kW Systems at Wastewater and Water Treatment Plants at an 8 percent Prime Rate Over the 20 Year System Lifetime Implemented in 2020

The payback periods of the six and eight 20 kW systems are shown in Table 15. Also shown are the differences in initial cost and net savings of the project in 2040, at the end of the systems lifetime.

Table 15. Payback Period, Initial Cost, and End Net Present Value of 20 kW Turbines at Treatment Plants Implemented in 2020

	Payback (years)	Initial Cost ($)	Future Profit in 2040 ($)
Use of six 20 kW Turbine at Treatment Plants	7	218,400	232,000
Use of eight 20 kW Turbine at Treatment Plants	7	291,200	309,000

Additionally, the economic benefits of implementing a system sooner versus later are shown in Figure 27 for the 12 kW system and in Figure 28 for 20 kW systems.

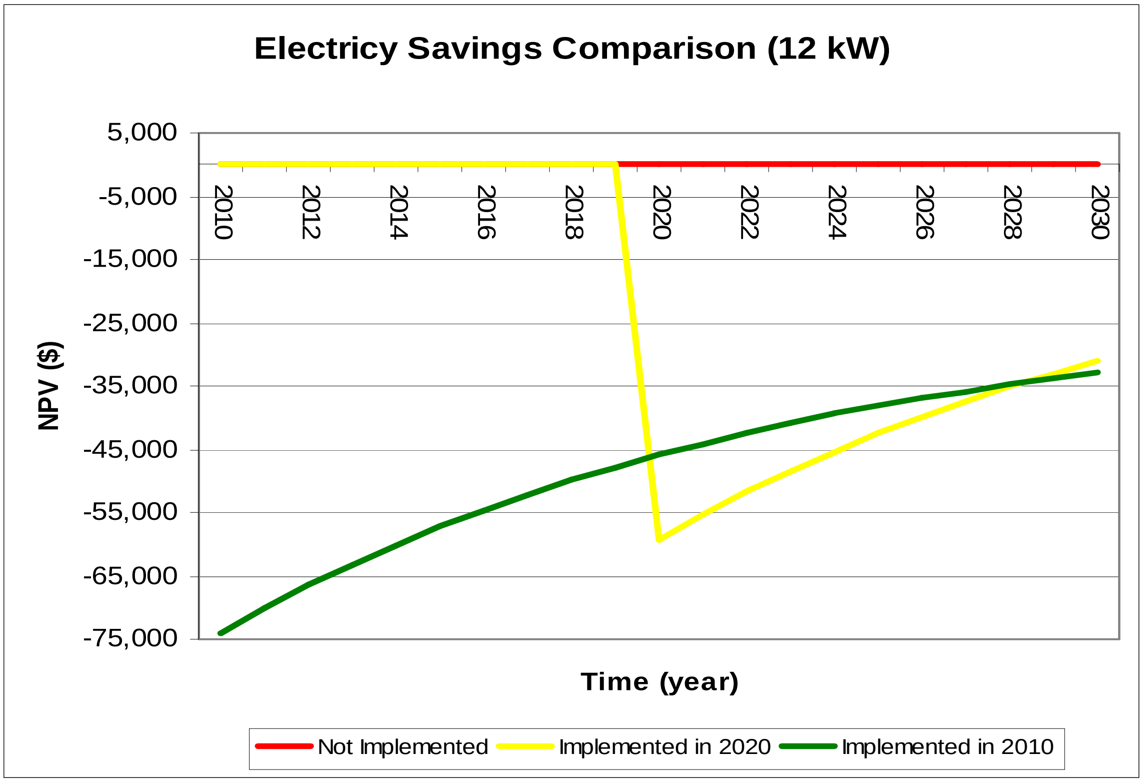

Figure 27: Electricity Savings Comparison of NPV for 12 kW System Through 2030 with an 8 Percent Prime Rate

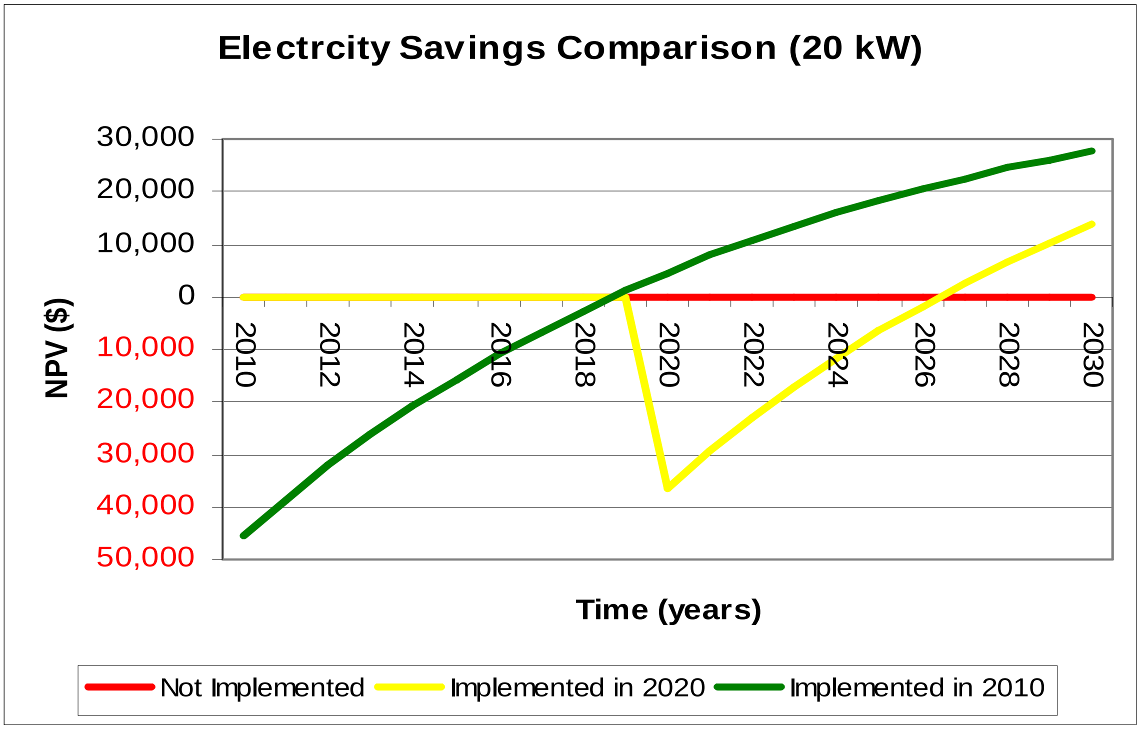

Figure 28: Electricity Savings Comparison of NPV for 20 kW System Through 2030 with an 8 Percent Prime Rate

In the case of the 20 kW electricity savings comparison (see Figure 28), a system implemented in 2010 has already reached its payback period before the implementation in 2020.

Analysis of Small- and Micro-Wind Turbines

Using a small wind system, like the 20 kW turbine explored in this cost-benefit analysis, could be beneficial in reducing the costs incurred by electricity. It has a greater benefit in treatment plants with smaller energy needs. The greater land area that a pumping station or treatment plant site has allows small wind systems to be a more feasible option.

In contrast to the 20 kW system, the 12 kW micro turbine architectural wind system is neither fiscally nor spatially feasible for water infrastructure. The cost is too high for the energy that is provided. Additionally, there are extra inverters needed if the turbine arrays will be spread among several buildings on a treatment plant site, thus further reducing the system's cost effectiveness. This option would be better for aesthetic purposes in a commercial setting.

The Electricity Savings Comparison graphs, Figures 27 and 28, show that implementation in 2010 instead of waiting till 2020 is a more financially viable option. Although the savings are higher and the initial cost lower in 2020, implementing the system in 2010 provides a greater savings for the 20 kW system by 2030 in an amount of nearly $20,000.

Mid-Size Wind Turbine Cost-Benefit Analysis

The characteristics of a range of mid-sized wind turbines are listed in Table 16.

Table 16. Current Generalized Mid-Size Turbine Breakdown*

System	**100 kW**	**250 kW**	**600 kW**
Rotor Diameter (m)	21	29.5	50
Height (m)	35	42 and 50	50 and 75
Efficiency (%)	20	20	20
Average Output (kWh/yr)	150,000 to 250,000	350,000 to 550,000	1.0 to 1.75 million
System and Installation Cost ($)	380,000	525,000	975,000
Life Expectancy (yrs)	25	25	25
Maintenance and Operation Costs ($/yr)	9,500	10,500	14,625

*(sources see Appendix C)

Pumping Stations.

Feasibility analysis for the use of mid-size wind turbines in pumping stations has not been included because there is not enough clear area free of tall objects around the site. Each system requires that the turbine be a distance of its height away from any other tall objects, which is not possible as noted in Appendix B.

Water/Wastewater Treatment Plants.

Tables 17 and 18 show the percentage of energy consumed that could be produced by the different mid-size wind turbine systems in water and wastewater treatment plants.

Table 17. Mid-Size Wind Feasibility in Water Treatment Plants

Water Treatment Plant	**% of Energy Consumed at Barranquitas**	**% of Energy Consumed at Humacao**	**% of Energy Consumed at Canóvanas**
Energy Produced by 100 kW System	38 to 64	10 to 17	5 to 8
Energy Produced by 250 kW System	89 to 140	23 to 36	11 to 17
Energy Produced by 600 kW System	255 to 446	66 to 116	31 to 54

Table 18. Mid-Size Wind Feasibility in Wastewater Treatment Plants

Wastewater Treatment Plant	% of Energy Consumed at San Lorenzo	% of Energy Consumed at Yabucoa	% of Energy Consumed at Fajardo
Energy Produced by 100 kW System	23 to38	20 to33	13 to 22
Energy Produced by 250 kW System	53 to 84	46 to 73	31 to 49
Energy Produced by 600 kW System	153 to 267	133 to 232	90 to 157

The Net Present Value (NPV) of a 100 kW system, a 250 kW system, and a 600 kW system at the current pricing of the systems (see Table 16) are shown in Figure 29, Figure 30, and Figure 31, respectively.

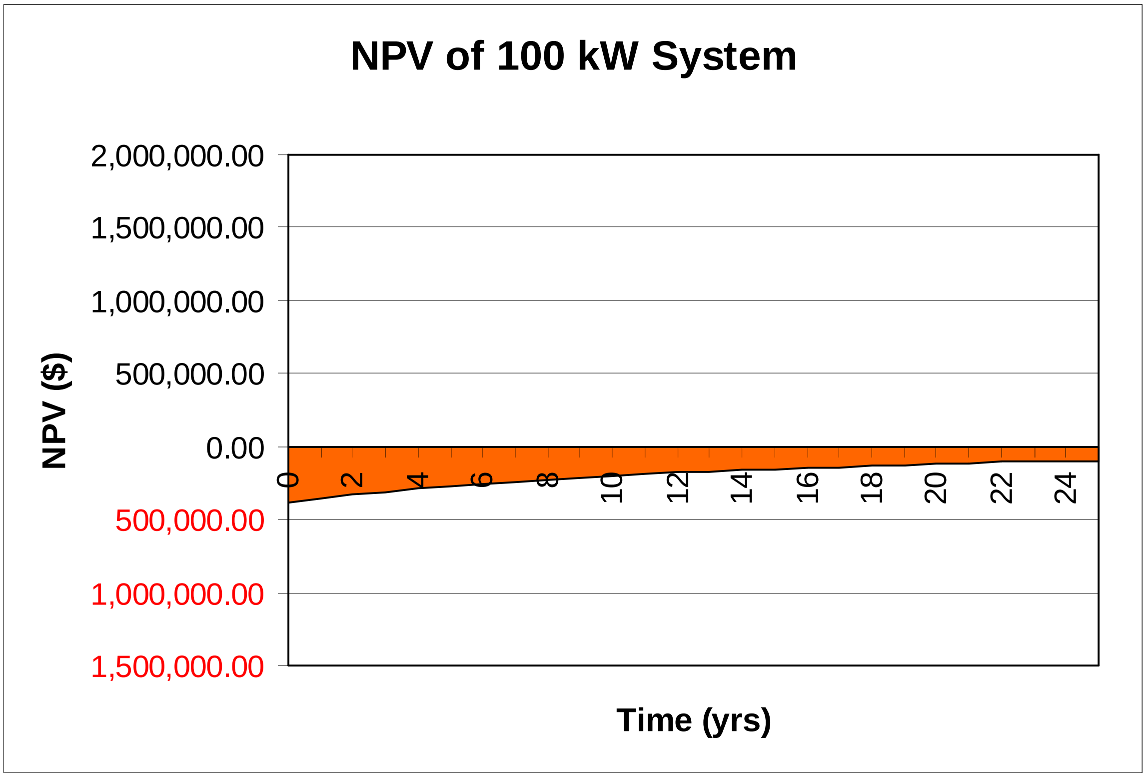

Figure 29. Net Present Value of a 100 kW System in 2010 with an Interest Rate of 8 Percent Over the System Lifetime of 25 Years

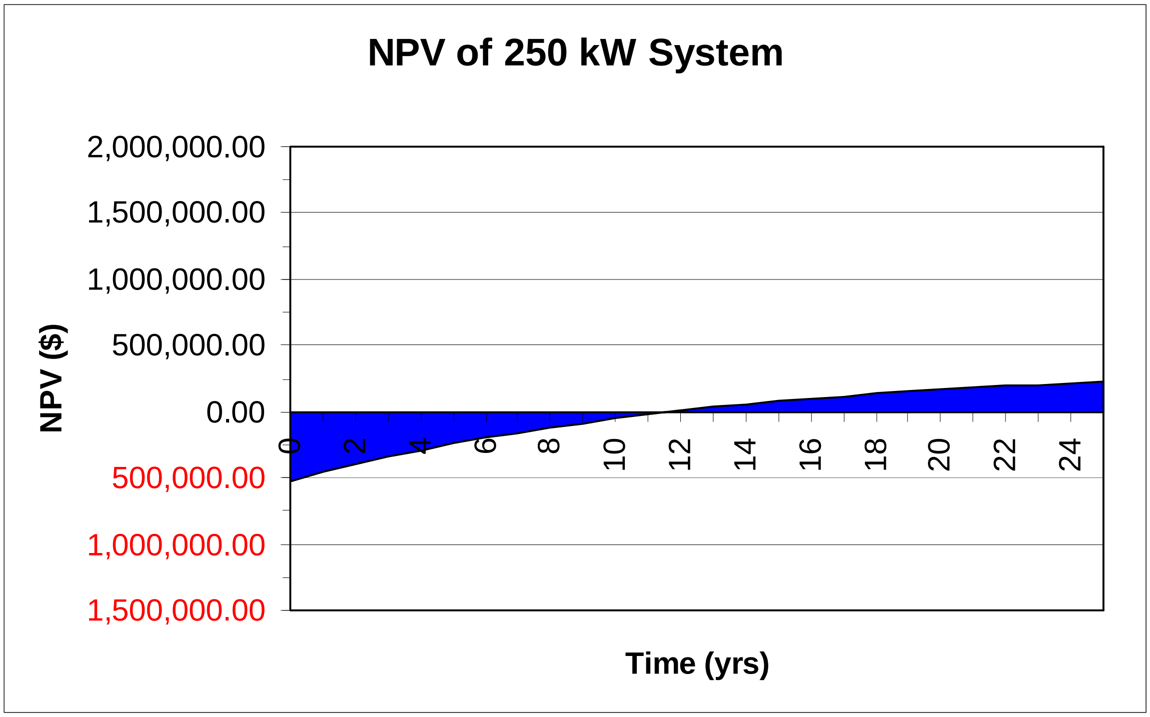

Figure 30. Net Present Value of a 250 kW System in 2010 with an Interest Rate of 8 Percent Over the System Lifetime of 25 Years

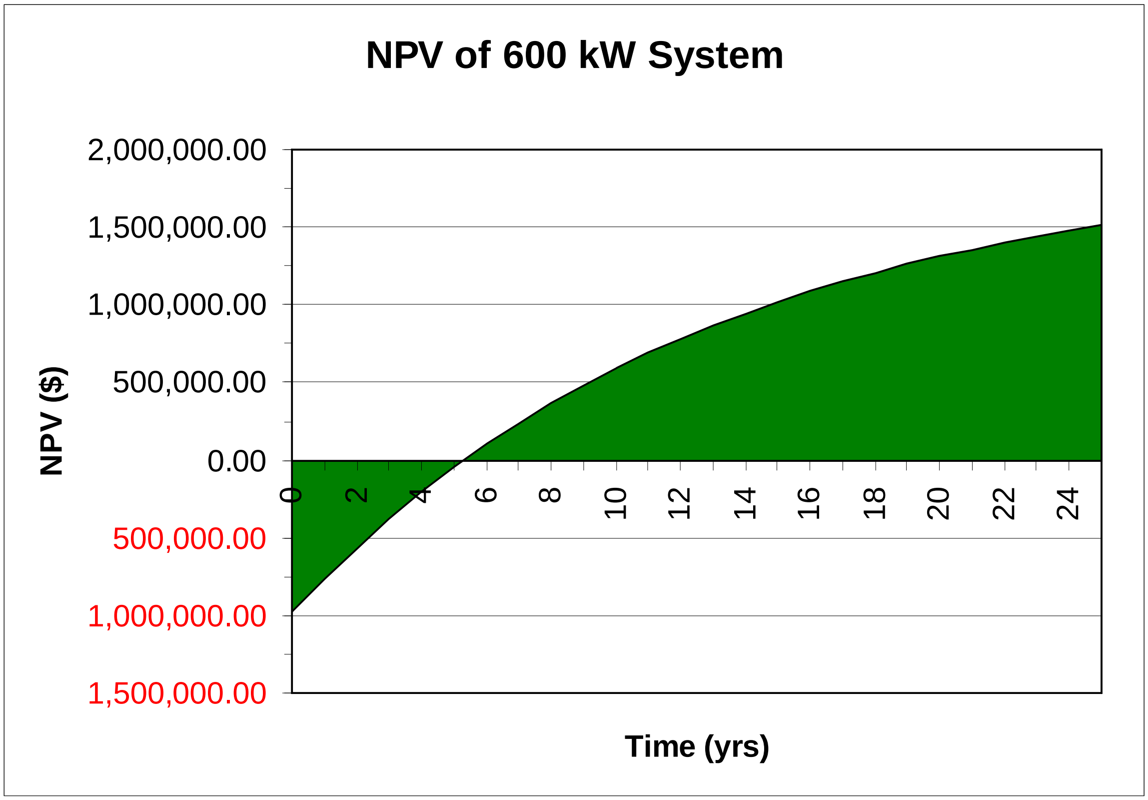

Figure 31. Net Present Value of a 600 kW System in 2010 with an Interest Rate of 8 Percent Over the System Lifetime of 25 Years

Table 19. Mid-Size Wind Turbine NPV Summary

Turbine Size	Initial Investment ($)	Payback Period (years)	Future Profit ($)
100 kW system	380,000	> 25	0
250 kW system	525,000	11.25	225,000
600 kW system	975,000	5.30	1.5 million

Table 19 shows a comparison of the initial investments, payback periods, and future profits of each system.

These calculations will change over the next decade as the cost of wind energy systems are expected to decline by 20 percent by the year 2020 (European Wind Energy Association, 2007), which will result in an increased future profit and decreased payback period. The NPV of the 100 kW, 250 kW, and 600 kW systems over the course of their life expectancies are shown in the corresponding Figures 32, 33, and 34.

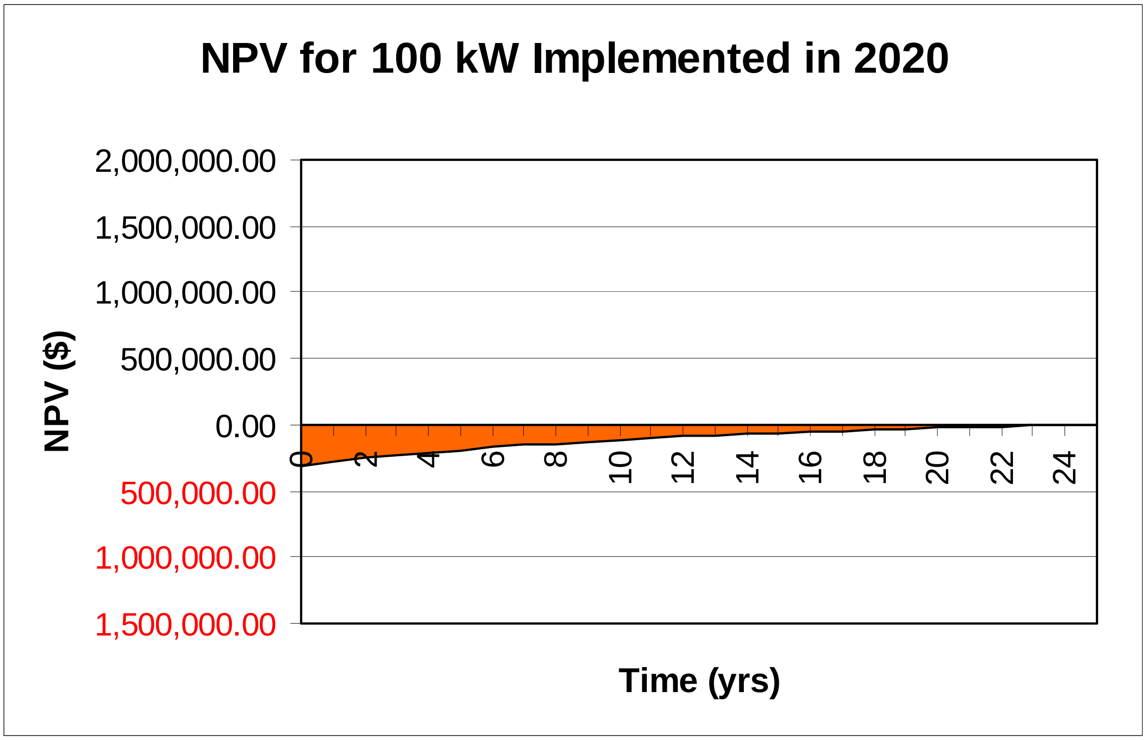

Figure 32. Net Present Value of a 100 kW System Implemented in 2020 with an Interest Rate of 8 Percent Over the System Lifetime of 25 Years

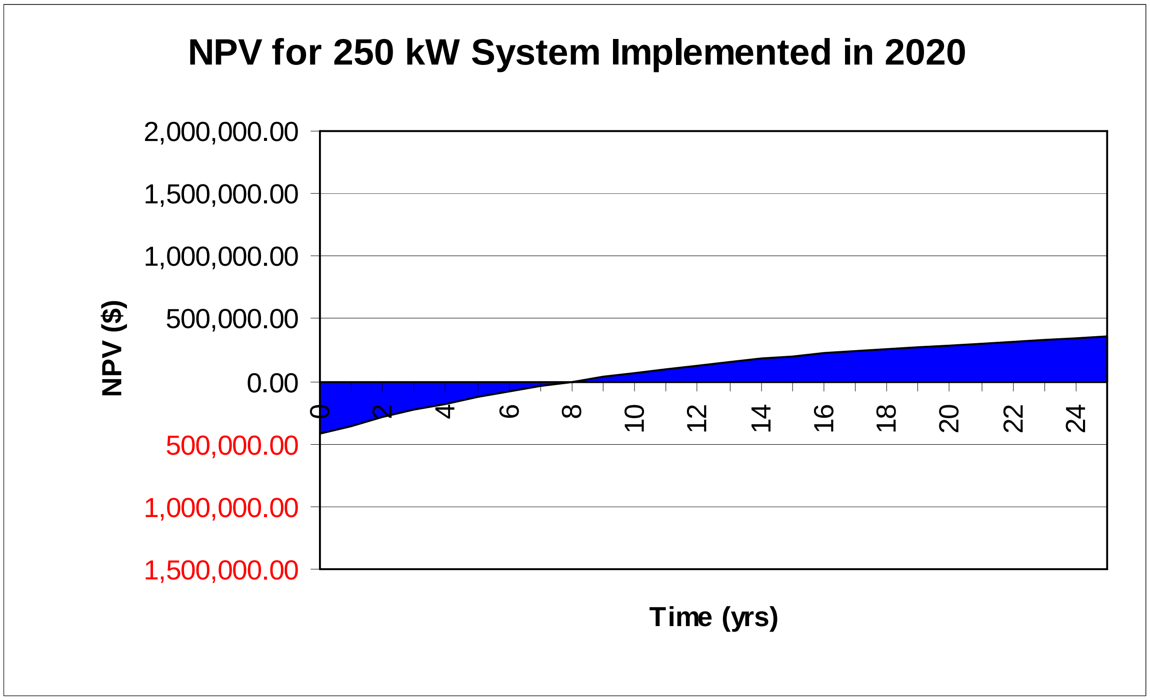

Figure 33. Net Present Value of a 250 kW System Implemented in 2020 with an Interest Rate of 8 Percent Over the System Lifetime of 25 Years

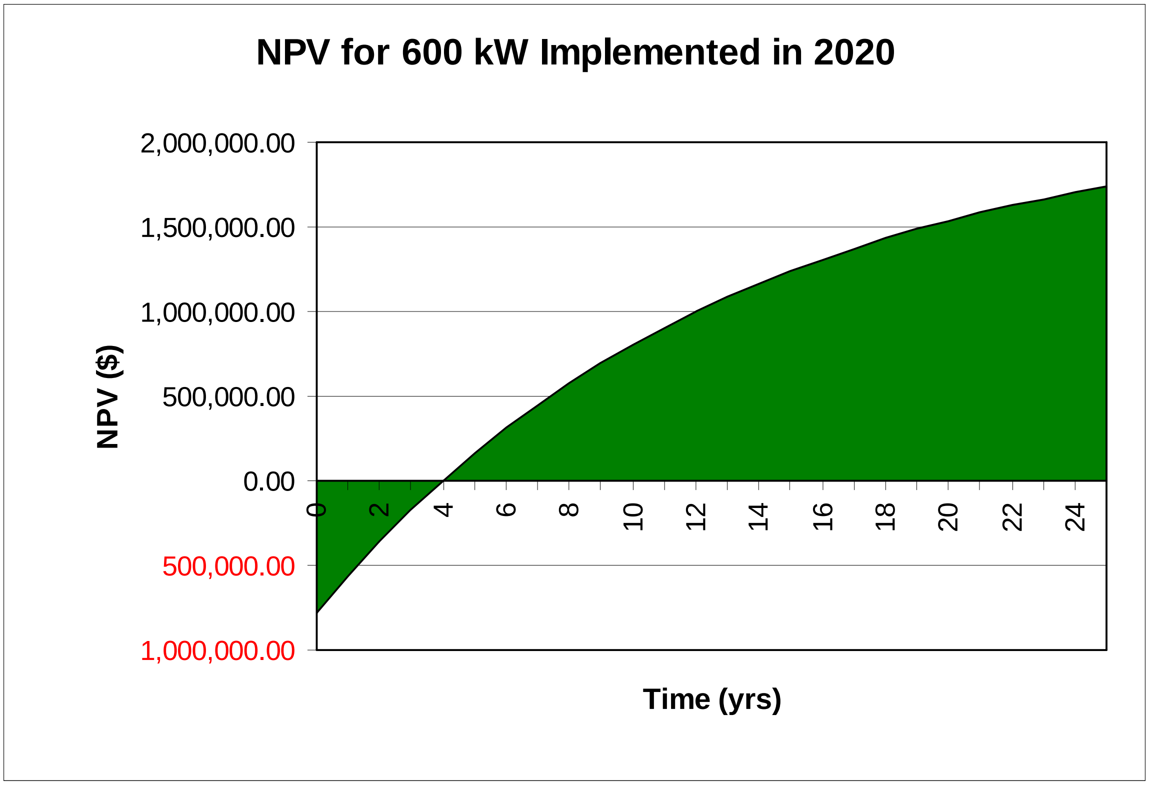

Figure 34. Net Present Value of a 600 kW System Implemented in 2020 with an Interest Rate of 8 Percent Over the System Lifetime of 25 Years

Table 20. 2020 Mid-Size Wind Turbine NPV Summary

Turbine Size	Initial Investment ($)	Payback Period (years)	Future Profit ($)
100 kW system	304,000	> 25	0
250 kW system	420,000	8.20	350,000
600 kW system	780,000	4	1.75 million

Table 20 shows a comparison of the initial investments, payback periods, and future profits of each system if they were to be implemented in 2020.

Figures 35 and 36 show the electricity savings comparison for each system when the system is never implemented, implemented in 2010, and implemented in 2020. The 100 kW system has been omitted from this part of the cost-benefit analysis because that system will not pay off the initial investment of the system in either case.

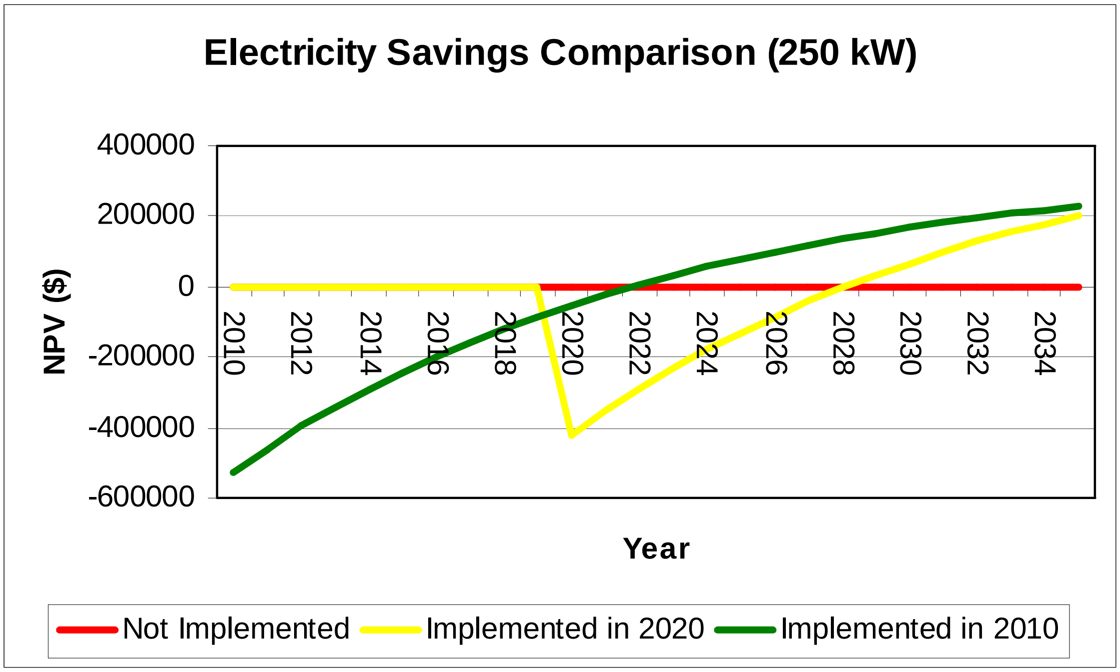

Figure 35. Electricity Savings Comparison (250 kW)

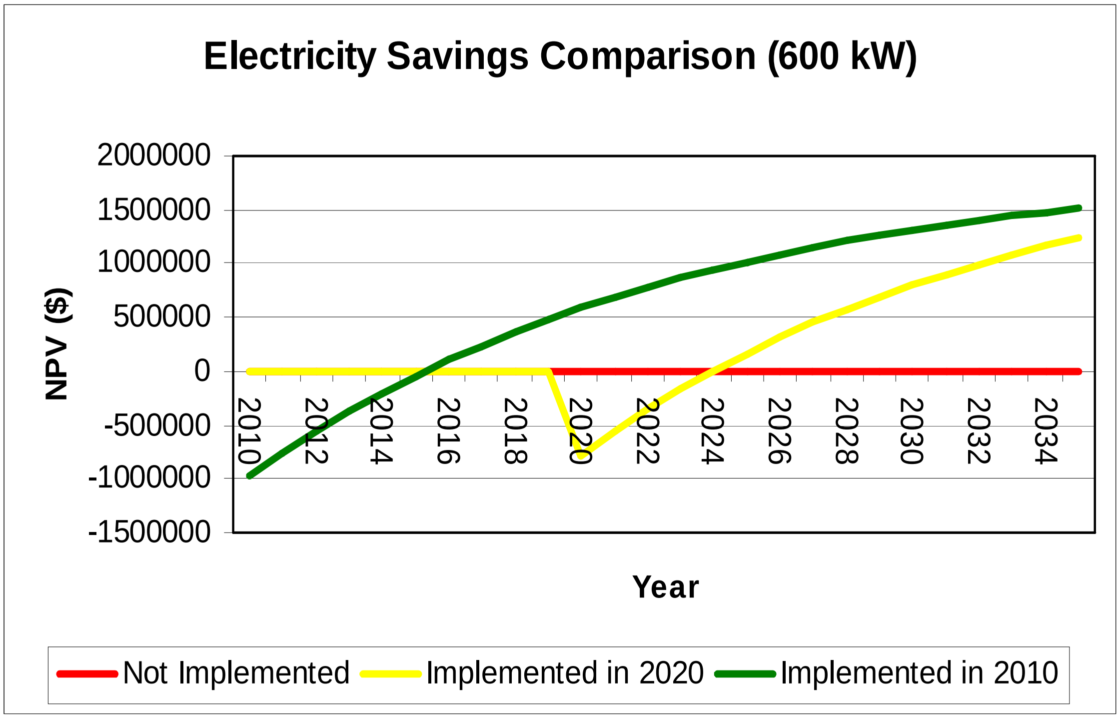

Figure 36. Electricity Savings Comparison (600 kW)

Analysis of Mid-Size Wind Energy Systems.

The NPV results (see Figures 29, 30, 31, 32, 33, and 34) show that both currently and in the future, the 600 kW system is the most cost-efficient because it has the smallest payback period and largest profit at the end of the lifetime of the system. The 250 kW system is also a very financially viable system currently and in the future because it will reach its payback period and will create a profit before the end of the lifetime of the system. However, the results show that the 100 kW system will not pay back its initial investment before its expected lifespan has passed. Therefore, it is not a cost-effective system.

The electricity savings comparison graphs (see Figures 35 and 36) show that for both the 250 kW and 600 kW systems a profit is made sooner if they are implemented currently despite the payback period decrease and profit increase with the pricing in 2020.

These results refute some of the perceptions held by professionals about the infeasibility of wind power in Puerto Rico because of the size of the systems. Although mid-size wind turbines cannot be applied in the pumping stations because they are too large, they do meet the size requirements for water and wastewater treatment plants (see Appendix B) and are a viable option there. The cost-benefit analysis refutes the concern that this energy would not be cost-effective.

METHANE POWER FEASIBILITY

Another form of renewable energy being used is methane gas. From the information we collected in our interviews, we found that four professionals we interviewed about anaerobic digesters approved of this technology's potential use. The experts we interviewed used the example of this technology applied in the Bacardi wastewater treatment plant in Puerto Rico, as discussed in Chapter Two, to demonstrate the success of this type of system.

Through an interview with the designer of the Bacardi Plant system Dr. M. Szendrey (personal communication, April 19, 2007), we found that wastewater treatment facilities that process waste from alcohol production have a higher chemical oxygen demand (COD) (see Glossary) than sanitary wastewater treatment plants. This means that anaerobic digestion is not as efficient in sanitary treatment plants. However, he also stated that if an existing plant pumps enough waste, the process can be cost-efficient because the only initial costs of the system that will be installed in an existing plant are the tank and turbine costs. In order to establish this financial feasibility, we completed a cost-benefit analysis for this system. The cost-benefit analysis was applied to treatment plants that have secondary treatment processes.

Methane Power Cost-Benefit Analysis

The average electricity producing anaerobic digester costs approximately $1.5 million with an annual operations and maintenance cost of $30,000 (see Appendix C). The amount of methane the system is able to produce is dependent on how many million gallons per day (mgd) the wastewater treatment plants pumps. Because we do not have information about the pumping capacities for every wastewater treatment plant in Puerto Rico, we computed the NPV for plants that pump approximately 1 mgd and 3 mgd. The energy producing capabilities of these systems are shown below in Table 21.

Table 21. Potential Electricity Production in Wastewater Treatment Plants*

Pumping Capacity of Plant (mgd)	Methane Produced (ft3/day)	Electricity Produced (kWh/day)	Annual Electricity Produced (kWh/yr)
1	14,688	4,305	282,812
3	44,064	12,914	848,437

*(see Appendix D)

The net present values for wastewater treatment plants that pump 1 mgd and 3 mgd are shown in Figures 37 and 38, respectively.

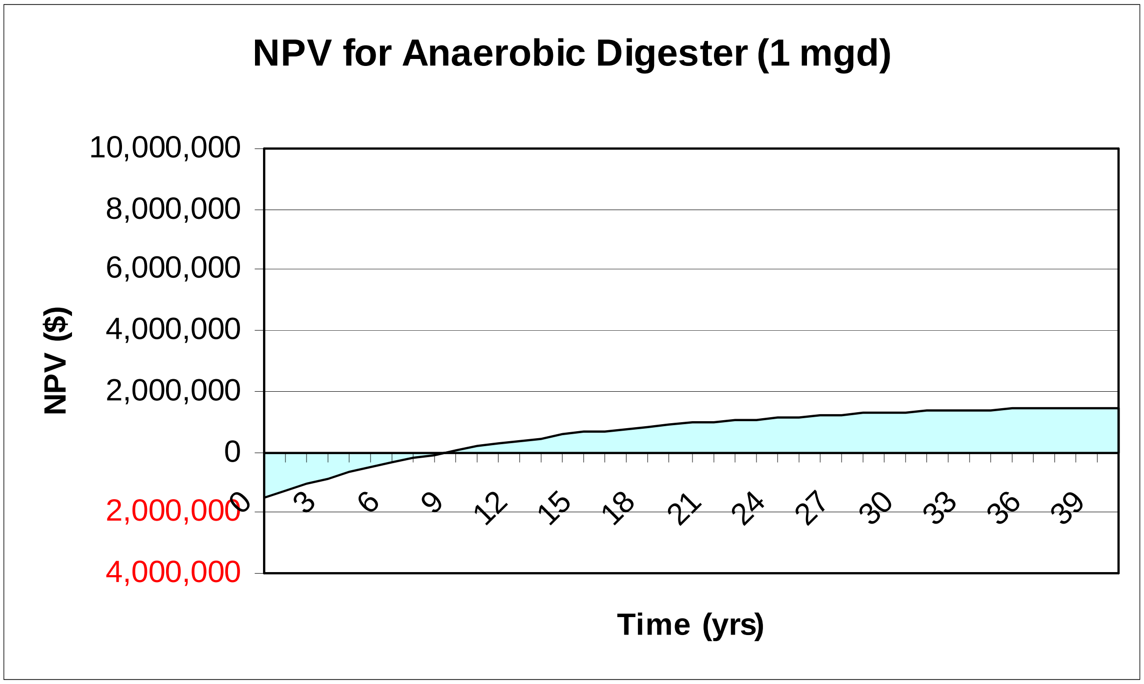

Figure 37. NPV for Anaerobic Digestion in 1 mgd Plant with an Interest Rate of 8 Percent Over the System Lifetime of 40 Years

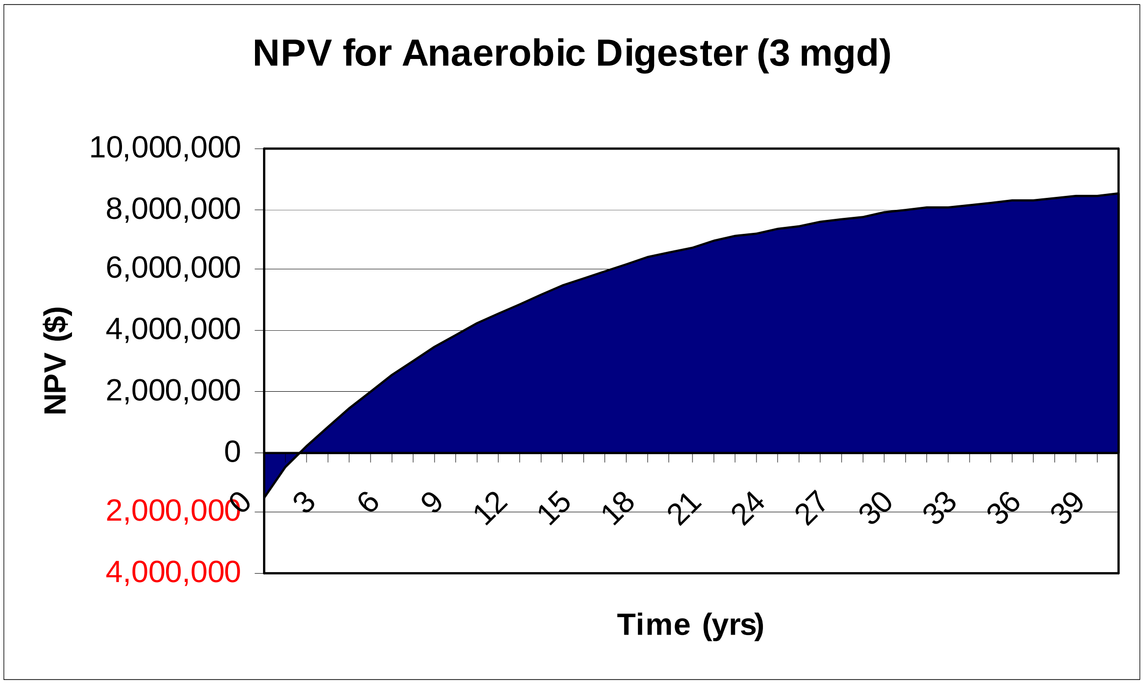

Figure 38. NPV for Anaerobic Digestion in 3 mgd Plant with an Interest Rate of 8 Percent Over the System Lifetime of 40 Years

Analysis of Methane Energy Systems

The NPVs shown in Figures 37 and 38 show that anaerobic digestion is a cost-effective option in wastewater treatment plants that pump both 1 mgd and 3 mgd of sanitary wastewater. However, there is a significant decrease in the payback period and increase in the total savings of the system in plants that pump 3 mgd in comparison to those that pump only 1 mgd. Because of these changes and the constant initial investment, using anaerobic digestion as a source of electricity is much more financially viable in plants that process 3. Additionally, the payback period will decrease and the future profit will increase further for a wastewater treatment plant that pumps greater than 3 mgd of waste.

HYBRID SYSTEMS FEASIBILITY

After completing the cost-benefit analysis for single renewable energy systems, our group explored several options of hybrid systems, which combine wind turbines and solar panels. We decided to take the most viable single renewable energy system from each facility, one 20kW wind turbine for pumping stations and one 600kW wind turbine for treatment plants, and combine them with solar panels since this would allow for the use of the available land and rooftop area at each facility.

We started with the implementation of a wind turbine in 2010 and followed that with the implementation of solar panels in 2020 since, according to the solar energy cost-benefit analysis, solar panels will produce an eventual profit if implemented in 2020.

The 250 kW turbine options were not considered for the hybrid systems because it does not have a payback period before 2020 (see Figure 28), when the new investment needs to be made for the solar system. Likewise, the 100 kW and 12 kW turbine systems will not be implemented because they cannot pay themselves off before the end of product's lifetime (see Figures 27 and 21).

Additionally, anaerobic digesters were not considered for hybrid systems due to their high upfront cost and energy output.

Pumping Stations

Our group only considered a hybrid system at the low and medium energy pumping stations because the 20 kW wind turbine was feasible only for these two stations (see Table 7). The hybrid system our group decided upon was the implementation of one 20 kW wind turbine in 2010 followed by a 6 kW solar system for low energy stations or 37 kW system for medium energy stations in 2020. The NPV for these systems are shown in Figures 39 and 40.

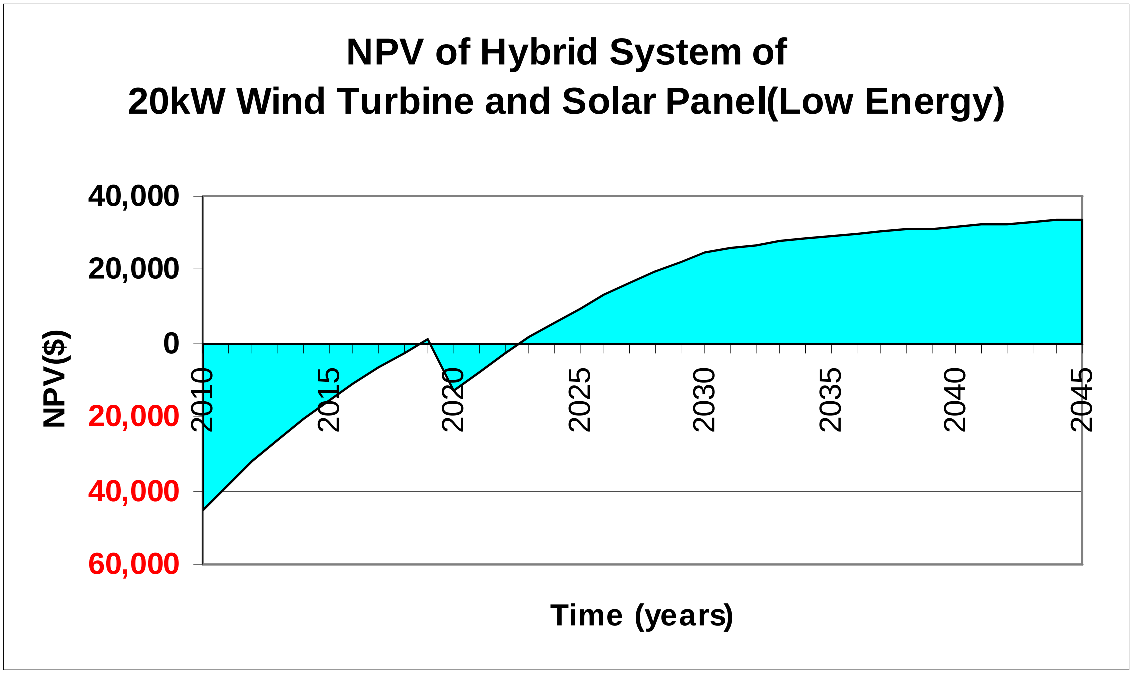

Figure 39. NPV of Hybrid 20 kW Turbine and 6 kW Solar System at Low Pumping Station

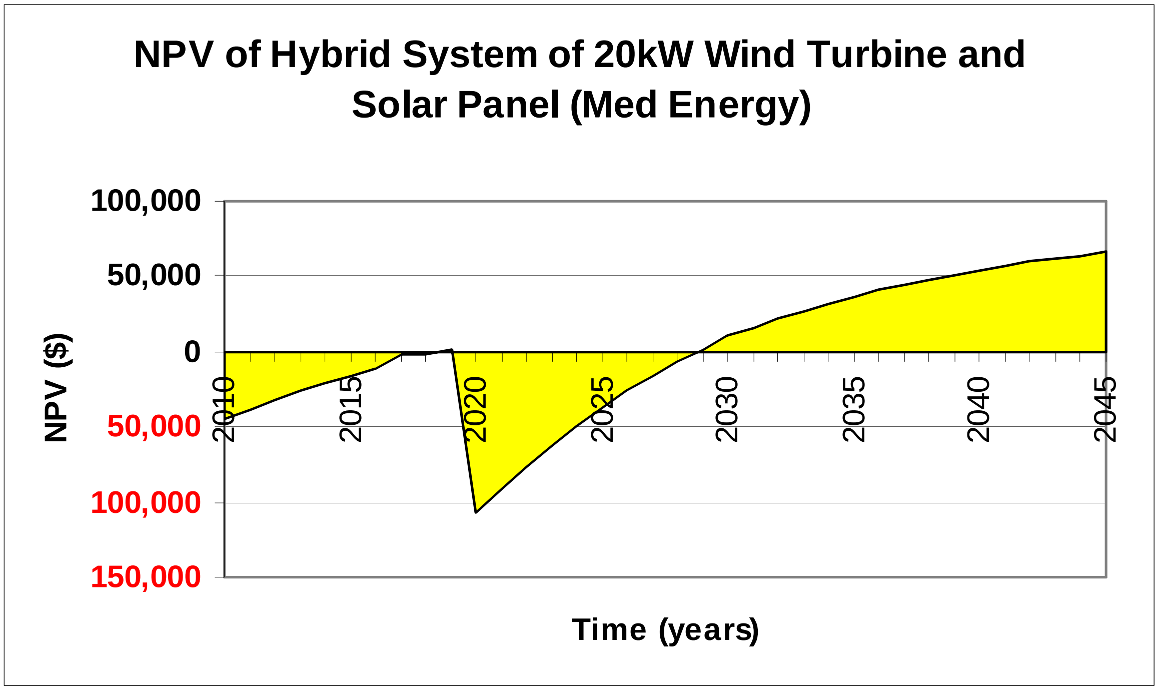

Figure 40. NPV of Hybrid 20 kW Turbine and 37 kW Solar System at Medium Pumping Station

Water and Wastewater Treatment Plants

Another hybrid system that our team assessed was a 600 kW wind turbine in combination with a 71 kW solar panel system at treatment plants. The 600 kW wind turbine will be implemented in 2010 and the solar panel system will be implemented in 2020. The NPV for this hybrid system is shown in Figure 41.

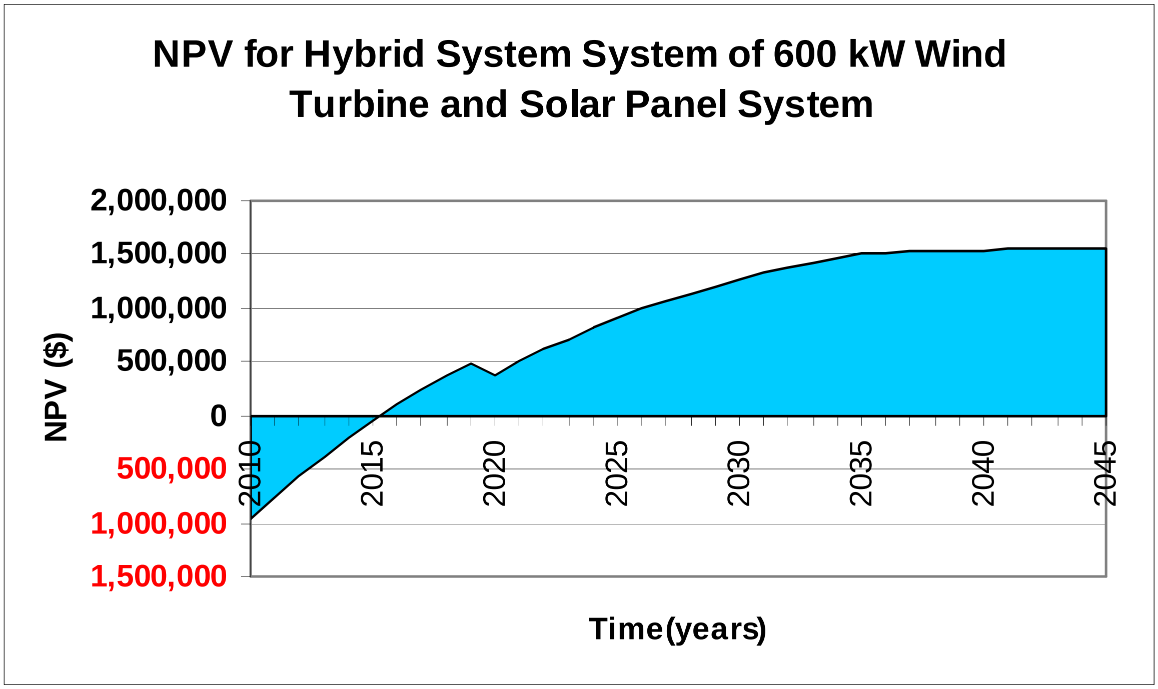

Figure 41. NPV of Combined 600 kW Turbine and 71 kW Solar System at Treatment Plants

Hybrid Systems Analysis

The first negative value on each NPV graph at year 2010 represents the initial investment of the wind turbine, while the decrease in 2020 represents the initial investment of the solar panel system. Table 22 shows the NPV of each of the hybrid systems at the end of their respective lifetimes.

Table 22. Combined System Payback Period, Initial Costs, and End NPV in 2045

	Payback (years)	Wind Initial Cost ($)	Solar Initial Cost ($)	End NPV in 2045 ($)
600 kW Wind Turbine and 71 kW Solar Panels at Treatment Plants	5	975,000	214,065	27,743
20 kW Wind Turbine and 6 kW Solar Panels at Low Energy Pumping Stations	12.5	45,500	18,090	166,460
20 kW Wind Turbine and 22 kW Solar Panels at Medium Energy Pumping Stations	25	45,500	111,555	221,947

The hybrid systems take advantage of all available area at a facility. This combination of systems would generate more clean energy as well as a higher future profit than a single system would.

PREVENTIVE MAINTENANCE PLAN FEASIBILITY

In our four interviews with professionals who have been involved in water infrastructure projects, we asked about the current maintenance procedures followed by PRASA. In each interview, we were told that, in the past, PRASA has held maintenance as a low priority and has waited until major breakages occurred to fix any leakage problems. The information gathered in the interviews shows that up until this point the water infrastructure maintenance procedures have been reactive, not proactive. However, we were also told that PRASA has changed management and intends to change many of its practices.

In our group's interview with PRASA representative J. Colignon (personal communication April, 13, 2007), we learned about PRASA's new maintenance plan. He confirmed what we discussed in Chapter Two about the high percentage of water pumped that is lost to leaks in pipelines each year. He also explained that they are just now implementing a new plan to attempt to decrease this high percentage. He stated that the first part of the plan is to locate where the major leaks are in the water infrastructure and that the second part of the plan is to find out what the causes of these leaks are. For instance, they could be a result of aged piping, poor quality piping, or corroded metallic piping. Although we cannot complete a cost-benefit analysis of implementing preventive maintenance techniques because we were not able to obtain a specific amount of money spent on maintenance each year, we will provide information through case studies showing the economic effects of implementing a preventive maintenance plan.

Economic Effects of a Predictive and Preventive Maintenance Plan

In our research, we found that although there is not a budget for run-to-failure (see Glossary) maintenance plans, there are high costs associated with this method. Run-to-failure maintenance techniques result in high spare parts inventory cost, high overtime labor costs, and high equipment down time (Inmotiononline.com, 2005; Wright, 2003).

Predictive and preventive maintenance combat some of these costs by regularly repairing problem areas before the damage is severe. After about five years, equipment downtime reductions reach and remain permanently at 90 percent (Inmotiononline.com, 2005; Koelsch, 2003). Although in some cases the cost of maintenance within the first year of implementing a predictive/preventive maintenance plan can increase by 10 to 15 percent, an eventual decrease in maintenance costs of approximately 35 percent can be expected due to reduced labor and material costs (Inmotiononline.com, 2005; Koelsch, 2003).

Mergelas, Atherton, and Kong (2002) believe that water system maintenance, including pipeline monitoring, is essential in reducing costs of a system. Because of the implementation of consistent leak prevention and detection methods, there will be fewer unbudgeted expenses, improved reliability, and an extended system life expectancy (Mergelas, Atherton, and Kong, 2002). This is demonstrated by the Detroit Sewer and Water Department’s (Cascos and Delaura, 2003) use of SCADA (see Glossary), a sensory and leak detection software system, as a means to implement energy management strategies. Some of the benefits that Detroit obtained were a reduction in bill disputes, accurate metering, and a payback period of less than two years (CellNet, 2006).

Another example of how predictive and preventive maintenance plans can reduce leaks, which reduces water loss and energy costs, is the implementation of a leak detection and abatement program implemented in Romania, which ultimately reduced water volume loss by 8 million cubic meters and created a savings of $3 million per year (Regia Autonoma Jedteana Apa-canal Isai, 1999). Considering Puerto Rico loses 43 percent of the water it pumps out of treatment plants to leaks, as discussed in Chapter Two, leak detection and abatement would also create savings there.

Low-friction coatings are another preventive maintenance technique that can increase energy efficiency in water pipelines. Because the water ideally flows at a high velocity, it tends to create an uneven surface due to deterioration on the interior of the pipe. Low-friction coatings aid in the sustainability of pipelines and reduce energy costs by improving energy efficiency (SBW Consulting, Inc., 2006). With the addition of a low-friction coating within pipes, energy consumption is expected to drop 1 to 3 percent (SBW Consulting, Inc., 2006).

Analysis of Predictive and Preventive Maintenance

This information regarding predictive and preventive maintenance when compared to run-to-failure maintenance shows that although there will be some increased initial costs, there will be an overall savings through implementation of predictive and preventive maintenance.

CHAPTER FIVE: CONCLUSIONS AND RECOMENDATIONS

In each of the following sections, we will discuss our recommendations for the most feasible renewable energy system as well as recommend a hybrid system in each facility based on our cost-benefit analysis in Chapter Four. Additionally, this section will conclude with our recommendations for different pipeline maintenance methods and procedures as well as a recommendation about education assessment.

RECOMMENDATIONS FOR RENEWABLE ENERGY SYSTEMS

Pumping stations, water treatment plants, and wastewater treatment plants each have different recommendations of the best-suited types of energy available and analyzed in this report. Where the possibility is available, a secondary recommendation has also been presented.

Pumping Stations Recommendation: 20 kW Wind Turbine

The two renewable energy options for pumping stations are solar power and wind power using small size wind turbines. Based on results calculated in Chapter Four, our group recommends the small-size wind turbines in the low and medium energy pumping stations. The data, shown in Chapter Four, for each system at both of these facilities supports our recommendation.

Since the results show that it is better to implement the small wind turbines in 2010, we further recommend that this system be implemented in 2010 and not in 2020.

However, if the small-size wind turbine’s space restrictions prevent implementation we recommend implementing solar panels in 2020.

Pumping Stations Hybrid System Recommendation: One 20 kW Wind Turbine

Our group recommends the implementation of one 20 kW system in 2010 followed by a 6 kW solar system in 2020. This implementation is recommended for low energy pumping stations based on results shown in Figure 39 of Chapter Four.

Water Treatment Plant Recommendation: 600 kW Wind Turbine

Based on results calculated in Chapter Four, our group recommends a 600 kW wind turbine to be applied to the water treatment plants we researched. Additionally, we recommend the wind turbine to be implemented in 2010, as Figure 35 shows there is a shorter payback period with an earlier execution.

Our group chose the 600 kW wind turbine because it has the shortest payback period with the highest future profit. However, if the initial cost prevents the use of the 600 kW turbine our group recommends the six and eight 20 kW wind turbines as an alternative option based on payback period and future profit.

Water Treatment Plant Hybrid System Recommendation: 600 kW Wind Turbine System and 71 kW Solar System

We recommend a hybrid system of one 600 kW wind turbine combined with a 71 kW solar panel system based on the 600 kW wind turbine being the most financial viable single system for treatment plants, while solar panels are the most feasible for rooftops.

Wastewater Treatment Plant Recommendation: Anaerobic Digester or One 600 kW Wind Turbine

Our group recommends the implementation of an anaerobic digester in 2010 as the most financially beneficial option for a wastewater treatment plants treating 3 mgd or more, based on payback period and future profit. The results found in Chapter Four support our recommendation. However, for a wastewater treatment plant that pumps less than 3 mgd or that only performs primary treatment, our group recommends the implementation of a 600 kW wind turbine in 2010.

Wastewater Treatment Plant Hybrid System Recommendation: One 600 kW Wind Turbine System and 71kW Solar System

Since the anaerobic digester has such a high initial cost and energy output, our group recommends the implementation of a hybrid system containing a 600 kW wind turbine and a 71 kW solar system. The 600 kW wind turbine will be implemented in 2010 and the solar system will put into operation in 2020, which will provide a higher future profit than a single system. Figure 41, of Chapter Four supports our recommendation.

Pipeline Maintenance Recommendation: Predictive and Preventive Maintenance Plan

Based on the case studies discussed in Chapter Four, we recommend the implementation of a computerized leak detection system such as SCADA. We also recommend the application of low-friction coatings beginning with the pipelines that experience water flow with higher velocity and pressure. The energy savings experienced in other water infrastructure systems that used these techniques support further investigation of this recommendation.

Recommendation: Assess Knowledge and Education of Employees

If CSA Group plans to promote renewable energy systems in water infrastructure to clients, it is important that employees possess enough knowledge of renewable energy systems to be able to market the benefits to clients and to assure those clients that the systems they buy will fit their needs. Therefore we recommend that CSA Group evaluate the current knowledge of employees in the company. Also, we recommend the continual development and refinement of professional development programs that specifically address renewable energies.

CHAPTER SIX: SOCIAL IMPLICATIONS OF RENEWABLE ENERGY

In this section, we will discuss the social impacts that the recommendations our group made regarding renewable energy and pipeline maintenance will have within Puerto Rico as well as the need for education about renewable energy technology and its benefits.

REDUCED FOSSIL FUEL CONSUMPTION

If renewable energy systems as well as a predictive and preventive maintenance plan are implemented in Puerto Rico, this will reduce the amount of electricity produced by fossil fuels on the island. This is important because, as discussed in the Chapter Two, fuel and water resources are depleting as populations grow. The U.S. Department of Energy (2004) expects the world demand for oil to increase by 50 percent by the year 2025. Eventually, the use of renewable energy will be a necessity instead of a choice. Solar Energy International (2005) points out that renewable energy has the potential to produce at least 40 percent of the electricity needs of the United States by 2020 if implemented proactively. If fossil fuel consumption in Puerto Rico is reduced, there will be additional environmental, health, and economic implications.

Reduced Greenhouse Gas Emissions

Combustion of fossil fuel, especially oil and coal, releases a considerable amount of carbon dioxide into the atmosphere. Burning fossil fuels to produce energy creates 33 percent of the greenhouse gas emissions worldwide (Massachusetts Technology Collaborative, 2007). More specifically, 40 percent of the carbon dioxide and 15 percent of the methane are emitted worldwide each year when fossil fuels are burned to create electricity (Massachusetts Technology Collaborative, 2007). This emission is a factor in global warming, which is considered to be a serious environmental threat (Pimentel, Rodrigues, Wane, Abrams, Goldberg, Staecker, Ma, Brueckner, Trovato, Chow, Govindarajulu, Boerke, 1994).

Since solar and wind energy systems do not need to burn fuel to produce energy, neither system produces emissions. Additionally, anaerobic digesters use methane, an environmentally harmful gas, in a process that does not emit greenhouse gases. Therefore, the use of renewable energy systems reduces the emission of both carbon dioxide and methane.

The reduction in greenhouse gas emissions that would be an effect of implementing our recommendations made in Chapter Four is particularly important for the island of Puerto Rico. This is because, although Puerto Rico as a whole uses less electricity than the United States, it consumes six times more electricity per land area (kWh/ km^2) than the U.S. does. As a result, the greenhouse gas emissions produced by burning fossil fuels to create electricity will be more concentrated in the atmosphere of the small island of Puerto Rico.

Environmental Implications.

The United Nations (2005) states that as a Small Island Developing State (SIDS), Puerto Rico struggles more with effects of global warming and climate change than larger countries (United Nations, 2005). The National Wildlife Federation (2006) discusses the effects global warming has already had within Puerto Rico’s environment.

The climate change has affected many ecosystems within Puerto Rico, including forests and coral reefs.

For instance, the ecosystem within the Karst Forest, located on the northwest quarter of the island, which is home to more than 1,300 species of plants and animals including thirty threatened and endangered species, is at risk. Climate change is putting the variety of plants and animals in danger by making the Karst Forest an area unsuitable for these native species.

Also, global warming has caused damage to the coral reefs of Puerto Rico. Currently, 90 percent of the coral reefs are dead or dying because the rising temperature of the ocean has caused algae imperative to the coral’s survival to die (National Wildlife Federation, 2006).

Additionally, the National Wildlife Federation (2006) lists the future problems Puerto Rico could experience due to global warming. For example, rising sea levels could put endangered sea turtles on the island at risk and altered rainfall patterns could cause a decline in the amphibian species inhabiting the Island (National Wildlife Federation, 2006).

In addition to putting animals in danger, the climate change is affecting the Island’s population. Global warming is creating hurricanes with greater intensities, which will be detrimental to the economy of Puerto Rico (De Souza, 2004).

Health Implications.

The reduction of fossil fuel use would have not only environmental benefits on the island of Puerto Rico, but also a tremendous positive effect on the health of its population. It is estimated that several hundred thousand deaths around the world each year are attributed to air pollution. A study done by Dudek, Golub, and Strukova (2002) shows that by aggressively reducing the carbon dioxide emissions, the health risk can be cut in half, which would save about 35,000 lives each year. Additionally, these authors mention that health risks like asthma, bronchitis, pneumonia, and even premature death can be attributed to air pollution.

Loyo-Berríos, Irizarry, Tao, Matanoski and Hennessey (2007) report that there is an increase in asthma among children in Cataño, a neighborhood in the metropolitan area of San Juan, because of air pollution. They found that 45 percent of children between the ages of five and six and 27 percent of children between the ages of thirteen and fourteen had asthma due to exposure to air pollution. The study also showed that residents living near a major emissions source, as they do, increased their risk of asthma by 108 percent. Because of the decrease in emission of harmful greenhouse gases provided by renewable energy implementation and improved energy efficiency in pipelines, individuals will experience decreased health problems. The decrease in health problems will also have economic benefits.

Economic Implications.

Reduced fossil fuel consumption will reduce the money spent on electricity. If the implementation of renewable energy systems causes this reduction, electricity will be available for a much lower price, as shown in the cost-benefit analysis in Chapter Four. Also, if the predictive and preventive maintenance plan is implemented, the amount of electricity consumed will be reduced.

In addition to the savings due to reduced consumption of electricity, the environmental impacts of reduced fossil fuel use also have economic benefits. For example, on an island where a large portion of economy is dependent on tourism, the destruction of ecosystems could lead to economic problems (United Nations, 2005). Global Warming's impending climatic change, due to the aforementioned CO_2 emissions, can have indirect effects on industries that take advantage of the environment (Pelling and Uitto, 2001). Pelling and Uitto (2001) note that tourism is one sector that potentially faces major setbacks economically, as the erosion of beaches and bleaching of coral reefs could deter visitors. As tourism is a major area of the Puerto Rican economy, this loss could potentially be devastating to the island's tourism-based workforce (National Wildlife Federation, 2006). Additionally, Caribbean islands in general are suffering from lack of investment in the tourism industry because it is so reliant on the environmental stability that cannot be guaranteed.

De Souza (2004) notes that another economic effect from the climatic change and growing intensity of hurricane strength is cost associated with cleaning up the aftermath of the disaster. Especially in the case of a predominantly urban island like Puerto Rico, there is a greater vulnerability to destruction of large scale infrastructure damage and need for overall rehabilitation (De Souza, 2004).

In addition to the economic benefits due to the environmental impacts, the decrease in health problems will also have an economic effect within Puerto Rico. Dudek, Golub, and Strukova (2002) state that reducing emissions can create significant savings in healthcare costs. Blanes (2007) explains in the article *Falta el aire a 2 de cada 10 boricuas* in El Nuevo Dia, that asthma is a serious problem that can incur extensive medical costs. Blanes (2007) gathers statements from Puerto Rican citizens who say that they take multiple trips to the doctor's office and emergency room for asthma related problems, which generate a cost of about $100 a month. Further, this cost is not covered by medical insurance. A decrease in the number of healthcare problems reduces the money spent on medication and treatment bills. Additionally, with a healthier population, the citizens will lead more productive lives than if they were unhealthy.

EDUCATION

Although our project has proven that renewable energy is financially feasible and a benefit to Puerto Rico, this analysis is just the first step in the process of renewable energy adoption. President of the Institute of Civil Engineers M. Torres Díaz (personal communication, April 5, 2007) notes that the education of engineers is essential to beginning the process of implementation of green technology, especially renewable energies. Friedrichsen (2003) confirms this opinion.

The theoretical construct of diffusion of innovations explains the diffusion process as the spread of a new technology from its inventor to the potential users (Rodgers, 1983). The adoption theory is broken down into five stages. The first is awareness when a person is exposed to a new form of technology, but does not have complete information about it. The second is the interest stage when an individual gathers more information due to interest in a new technology. The third stage is evaluation when the individual thinks about the use of a new technology applied to their life. The fourth is a trial stage when an individual incorporates the new technology in their life, and the final stage is adoption. This stage is when the individual decides to continue use of the new technology (Rodgers, 1983).

This theory applies to the adoption of energy-efficient methods within Puerto Rico. Engineers at CSA Group and their clients need to be informed of the advantages of green technology as well as the financial benefits in order to begin using more sustainable methods. Educating engineers and clients about green technology will shorten the awareness and interest stages, which would move them to the evaluation stage sooner. Once informed of these benefits engineers and clients may be more willing to implement green technologies into their lives. Once implemented, the stages of adoption can continue. Engineers and clients could then encourage further adoption of green technology by increasing public awareness of the opportunities that these technologies present (Johansson, McCormick, Neij, and Turkenburg, 2004).

APPENDIX A: CSA GROUP

CSA GROUP CORPORATE VISION

To be the firm of choice for professional services in markets where Hispanics have a growing influence in Private and Public Sectors.

CSA GROUP BACKGROUND

CSA Group is the sponsor of a project examining the information gaps in engineering and constructing infrastructure in San Juan, Puerto Rico. They are hoping to develop a research database to convince clients to start to implement more environmentally friendly technologies into their designs.

CSA Group is a forty-five year old multi-location business, with nine offices in the United States, Caribbean, and Central America. The history of CSA Group begins in 1956, as the subsidiary of Burns & Roe began Puerto Rican operations. In 1981, the company merged with Custodio & Associates. Within the next eleven years, the company, then recognized as Custodio, Suárez & Associates, had grown and expanded tremendously. Reorganization in 1994 saw the company renamed CSA Architects & Engineers. Within another four years, what became known as CSA Group expanded into the Cincinnati, Ohio area. More offices in the US were opened in cities like Philadelphia, Miami, and Atlanta. A new Panama City, Panama office was opened as well. The most recent addition to CSA Group was in Chicago in 2002.

The company prides itself on being a “one stop, full project delivery service provider” and “results oriented project delivery organization,” as noted on the company website (www.csagroup.com). Among the forty-eight technical and scientific disciplines that CSA Group practices, the specifics fall under several main services including engineering, architecture, program and project management, environmental services, construction management, and operations and maintenance.

CSA Group's services cover four different kinds of industries, including facilities, industrial, transportation, and utilities, which each have their own niches. Facilities that CSA Group is involved with include those in the commercial, education, hospitality, housing, and institutional sectors. Industrial projects typically include areas encompassing manufacturing, metals, and pharmacy. Transportation is a broad area for CSA Group, covering major categories like airports, highways, ports, rail, and telecommunications. However, the San Juan office's recent focus has been more in the areas of water utilities, hospitality facilities, housing facilities, and educational facilities.

Among others in their industry, CSA Group appears well regarded, appearing on the Engineering News Record (ENR) Top 500 Design Firms at number 236 and Top 200 Environmental Firms list at number 158. CSA Group is also listed as number eight in the Top 25 Transmission Lines and Aqueducts Design Firms by ENR.

CSA Group prides itself on its highly qualified employees, who bring their best work and highest level of dedication to every project on which they work. A firm of over five hundred employees, CSA Group has 125 licensed professional engineers and architects. Additionally, CSA Group is the largest Hispanic-owned company in the industry with 85 percent bilingual employees.

APPENDIX B: WATER FACILITY BACKGROUND

Background information about three water infrastructure facilities, including pumping stations, water treatment plants, and wastewater treatment plants, was provided by CSA Group Cost Estimator, R. Green (personal communication, April 2, 2007).

For pumping stations, we were provided with a small pumping station's emergency generator as well as drawings for two additional stations with emergency generator capacities. From the information provided to us, we determined the amount of energy consumed per year at each station. CSA Group Cost Estimator, R. Green (personal communication, April 13, 2007) stated that approximately 80 percent of the generator capacity is used by a facility. In addition to this figure, PREPA Department Head Maribel Franco stated the average cost of electricity in the past year was about \$0.18/kWh. With these figures, our group calculated the annual cost of electricity for each station, as seen in Table 23.

Table 23: Background Electricity Information about Pumping Stations

Station	Size of Facility (gpm)	Emergency Generator Capacity (kWh)	Electricity Used (kWh/yr)	Cost of Electricity ($)
Low Energy	50	75	657,000	98,550
Medium Energy	150	225	1,971,000	295,650
High Energy	850	1275	11,169,000	1,675,350

Also, from the drawings, our group was able to gather data on the available rooftop area at each plant (see Table 24). These drawings show that at each pumping station there are two common buildings, an emergency generator building (4.3 m x 5.64 m) and a pumping station building (4.5 m x 5.93 m). We used these two buildings for our analysis.

Table 24. Pumping Station Dimensions

Station	Available Rooftop Area (sq. meters)	Avg. Tank Area (sq. meters)	Total Perimeter (m)
Low Energy	48.357	0	40.72
Medium Energy	48.357	262.889	40.72
High Energy	48.357	121.440	40.72

CSA Group Cost Estimator R. Green (personal communication, April 13, 2007) also provided our group with information on water and wastewater treatment plants. A list showing the annual energy cost from July 2005 to June 2006 for three water treatment and three wastewater treatment plants was given to us. These values can be seen in Table 25 and 26 below.

Table 25: Electricity Background for Wastewater Treatment Plants

Wastewater Treatment Plant	Electricity Used (kWh/yr)	Cost of Electricity ($/yr)	Available Rooftop Area (sq. ft)
San Lorenzo	98,137	17,664	6,386
Yabucoa	113,021	20,343	6,386
Fajardo	166,851	30,033	6,386

Table 26: Electricity Background for Water Treatment Plants

Water Treatment Plant	Electricity Used (kWh/yr)	Cost of Electricity ($/yr)	Available Rooftop Area (sq. ft)
Barranquitas	53,872	9,696	6,386
Humacao	482,560	86,860	6,386
Canóvanas	226,733	40,811	6,386

Also seen in Tables 25 and 26 is the available rooftop area, which our group calculated from a set of drawings for a water treatment plant in Yauco. Since we were unable to obtain drawings for a wastewater treatment plant, we used the same available area for both water and wastewater treatment plants. The decision to use the same figure was based on the information gathered from the cost estimation department, stating that generally wastewater treatment plants are larger that water treatment plants.

Table 27 shows the buildings located in the Yauco water treatment plant and the perimeters of these buildings.

Table 27. Yauco Filtration Plant Rooftop Side Lengths and Perimeters

Building	Length 1 (m)	Length 2 (m)	Total Perimeter (m)
Electrical	7.01	3.2	20.42
Chlorination	9.75	15.24	49.98
Pump Station	9.75	11.27	42.04
Chemical	8.2	12.8	42
Generator	8.86	5.94	29.6
Switchboard	4.32	3.81	16.26
Filter Press	11.89	11.58	46.94

APPENDIX C: RENEWABLE ENERGY SYSTEM COST BACKGROUND

This appendix explains where the background information used to complete the cost-benefit analysis of each system was collected and how it was used.

SOLAR ENERGY SYSTEMS

The general information and cost for solar energy systems (see Table 1) were generated using an average of numbers for a 1 kW panel (Recycle Works, 2007; State Energy Conservation Office, 2007; Carlson, 2006; U.S. Department of Energy, 2003 and Solar Energies Industry Association, 2004).

The pricing for 2010 and 2020 were determined using the information in Table 28, the percent decrease was determined from the cost/kWh, and this decrease was applied to the system and maintenance costs (Navigant Consulting, Inc, 2006).

Table 28. Future Price of Solar Energy

	2008	2010	2020	2030
Price ($/kW)	0.18-0.20	0.12	0.06	0.03
Decrease (%)	33	50	50	50

SMALL- AND MICRO-WIND TURBINES

The general information regarding the capabilities and costs of small-size wind turbines (see Table 6) was gathered from manufacturers representatives contacted through AeroVironment, Inc. (2007) and Wind Turbine Industries (2007).

Since the expected lifetime was not given for the Micro-Size wind turbine, it was assumed to be the same as other small turbines to be able to complete a cost-benefit analysis comparison between the two sizes.

The pricing for 2020 was determined to have a 20 percent reduction in capital and maintenance and operations costs as predicted by the European Wind Energy Association (2007).

MID-SIZE WIND TURBINES

The general information regarding the capabilities and costs of mid-size wind turbines (see Table 16) were acquired from DuPont (2005).

The pricing for 2020 was determined to have a 20 percent reduction in capital and maintenance and operations costs as predicted by the European Wind Energy Association (2007)

METHANE ENERGY SYSTEMS

The information regarding system cost and operation and maintenance costs we used to compute the cost-benefit analysis we collected from Geisy, R., Wilkie, A. C., de Vries, A. and Nordstedt, R. A. (2005) and from Gooch, C., Inglis, S., and Ludington, D. (2005).

The information we used to calculate the amount of methane that can be produced from sanitary waste was provided by Dr. M. Szendrey (personal communication, April 19, 2007) and confirmed by Newbio E Systems (2005).

APPENDIX D: CALCULATIONS

GENERAL CALCULATIONS

Net Present Value

To determine the net present value of each solar system at each facility, Equation 1 found in Chapter Three, was used.

Electricity Savings Comparison

To determine the electricity savings comparison charts for each facility, we used the explanation of the comparison in Chapter Three.

SOLAR ENERGY CALCULATIONS

Size of Solar System

In order to determine the size of a system at each facility we used Equation 2, which calculated the number of panels (see Tables 2, 3, and 4) that would fit on the available rooftop area (see Tables 24, 25, and 26) at each facility.

Equation 2. Solar Panels at Each Facility

$$\text{Number of Panels on Rooftop} = \frac{Available\_Rooftop\_Area}{Panel\_Area}$$

Since each panel we used was 1 kW, the size of the system was calculated using Equation 3.

Equation 3. Size of Solar System

Size of System = 1 kW * Number of Panels on Rooftop

Percentage of Energy Each System Produces

The percentage of energy the system at each facility produced was determined using Equation 4. The facility consumption (kWh/yr) can be found in Table 23, 25, 26 of Appendix B.

Equation 4. Percentage of Energy Solar System Produces

Percentage of Energy = $\frac{Facility\_Consumption}{Size\_of\_System}$

SMALL- AND MICRO- WIND TURBINE CALCULATIONS

Area Required for System

The area needed to determine how much room a small-size turbine would need was determined by Equation 5, the area of a circle.

Equation 5. Area Needed by a Turbine

Area needed by a turbine = Πr^2

Pi is the constant 3.14159 and r is the radius represented by half of the combined height of the tower and the length of a blade.

Number of Turbines at Each Facility

To determine how many turbines could fit on a site, Equation 6 was used, using 8,000 m^2 as the land area.

Equation 6. Number of Turbines on One Site

$$\text{Number of Turbines on One Site} = \frac{Land\_Area}{Area\_Needed\_by\_Turbine}$$

To determine how many 12 kW systems could fit on the roofs of the buildings, Equations 7, 8, and 9 were used.

Equation 7. Average Length of a Building Side

$$\text{Average Length of a Building Side} = \frac{Sum\_of\_Building\_Perimeters}{4 \times Number\_of\_Buildings}$$

Equation 8. Number of 12 kW Systems to Fit on Roof

$$\text{Number of 12 kW Systems to Fit on Roof} = \frac{Equation\_7}{Roof\_Length\_Needed\_by\_Systems}$$

Since two 12 kW systems need to be purchased together, “Roof Length Needed by Systems” is 72 linear feet. The number of 12 kW systems that can fit on the rooftops is rounded down to the nearest multiple of two to figure the number of systems possible based on available space.

MID-SIZED TUBINE CALCULATIONS

Area Required for System

In order to see if the system could be implemented at a plant, we calculated the area free of tall objects necessary surrounding the turbine based on the tower height rule stated in the previous section. Equation 5 is also used in this instance. If the area of the plant is smaller than this area, the turbine cannot be implemented there.

Percentage of Energy Each System Produces

The percentage of energy the system at each facility produced was determined using Equation 10. The facility consumption (kWh/yr) can be found in Table 23, 25, and 26 of Appendix B.

Equation 9. Percentage of Energy Wind Turbine Produces

$$\text{Percentage of Energy} = \frac{Facility\_Consumption}{Energy\_Output\_of\_System}$$

METHANE ENERGY CALCULATIONS

Area Required for System

The land area required for an anaerobic digester system is smaller than that of an aerobic digestion system, which wastewater treatment plants currently use. Therefore, if the anaerobic system is replaced the aerobic digester system, there would be enough space.

Annual Electricity Produced

COD of Sanitary Waste: 400 mg/l

Percent COD Converted (in Puerto Rico and Caribbean) $\approx 80\%$

Pounds of COD per day = $COD * Pumping\_Capacity\_of\_Plant$

Methane Produced (ft^3/day) = $Pounds\_of\_COD * 5.5 * Percent\_COD\_Converted$

Conversion: One cubic foot of methane produces .29307 kWh of electricity

GLOSSARY

Anaerobic digestion – A wastewater treatment process where organic matter is broken down by bacteria in the absence of air producing a gas (methane) and solid (digestate).

Chemical Oxidation Demand (COD): The amount of oxygen required for chemicals to oxidize an organic compound. This is a test used to measure the amount of organic compounds in water.

Fuel cells- A device for generating electricity by the chemical combination a fuel and oxygen.

Green Technology- the implementation of practices intended to control negative human and societal impacts. Sustainable development is often considered the core of green technology. Sustainable development is a collection of methods used to meet the needs of the current population while avoiding irreversible long term damage to the environment.

Hydrocarbon Fuels- fuels using organic compounds consisting of only hydrogen and carbon.

Micro-Size Wind - A new turbine technology by AeroVironment that uses green energy production methods with 600 to 1000 W of power produced by each individual unit that is only six feet tall.

Microturbines - A very small turbine, fueled by natural gas or some other energy source, that generates electricity for use in homes or commercial establishments.

Mid-Size Wind - A green energy turbine production method that produces 100 kW to less than 1 MW of power.

Photovoltaic Cell- Photovoltaic (PV) Cells or solar cells are devices that convert sunlight to direct current (DC) electricity. Groups of PV cells are combined to form modules or arrays. This is done to produce higher voltage, currents and power levels.

Reclamation pump station – a pump station used in water reclamation. This is the process in which wastewater drained from homes and businesses is collected so that it can be transported to treatment plants and cleaned.

SCADA - Supervisory Control and Data Acquisition. This is a computer system that has the ability to monitor and control a plant or industrial equipment.

Secondary Treatment- A wastewater treatment process in which bacteria are used to digest organic matter in the wastewater.

Small-Size Wind Turbine - A green energy turbine production method that produces up to 100 kW of power.

Stirling engines - An external combustion engine in which air is alternately heated and cooled to drive a piston up and down.

Turbine- a type of machine in which the energy of a moving fluid is converted to power by passing through an array of blades.

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