United States Coast Guard Río Bayamón Housing Complex Photovoltaic System: Performance Review and Recommendations

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By:
Casey Arpin
Charles DeWitt
Drew Gelinas
Maryann O'Connell

Sponsoring Agency:
The United States Coast Guard Puerto Rico

Submitted to:
WPI Advisors: Frederick Bianchi, Karen Troy
Sponsor: Lt. Theodore Cetrulo

This report represents the work of four WPI undergraduate students submitted to the faculty as evidence of completion of a degree requirement. WPI routinely publishes these reports on its web site without editorial or peer review.

ABSTRACT

Our group worked with The United States Coast Guard in San Juan, Puerto Rico to evaluate the photovoltaic system installed at the Río Bayamón Housing complex. The goal of the project was to explain the specifications of the system, evaluate the performance of the system, provide recommendations based on findings, and find off-grid power alternatives. We used document and data collection and analysis to assess system performance, to analyze the costs associated with implementation of the system, and to determine if backup batteries were a feasible option to complement generators during power outages. We recommended accelerating acceptance of a net metering contract and continuing to utilize diesel generators for off-grid power use.

EXECUTIVE SUMMARY

"The average term of an ESPC task order is 17 years. The most common challenge during the post-acceptance performance period is personnel turnover, which leads to breaks in effective administration of the contract. Consistency in contract administration is required to keep the contract current." (DOE, 2016b). This quote from the Department of Energy summarizes the exact problem that the Coast Guard has with their current photovoltaic (PV) system at the Río Bayamón Housing complex. Due to the frequent personnel changes, many individuals are unaware of the system specifics, how it's performing compared to expectations, or even what the original expectations were. This gap of knowledge around the PV system has left the Coast Guard with unanswered questions regarding basic system specifications.

A result of the personnel disconnect is that the USCG has not been able to finish the pillar of their PV system contract, the net metering agreement. Based on limited consumption data, we know that the Coast Guard lost at least $380,000 for years one and two of the Energy Savings Performance Contract (ESPC) for the Río Bayamón Housing (RBH) complex alone, as a result of not having a net metering agreement in place. This is due to the net metering agreement process being very long, and new personnel not knowing how much of a negative impact not having a net metering agreement has on the Coast Guard.

Another one of the Coast Guard's concerns that we addressed, was whether or not the system had the potential to provide an energy backup system for the housing complex using the PV system, in the case of a power outage. This concern was brought forth as a result of the frequent power outages in Puerto Rico, which occur roughly once a week. The current system is a labor-intensive process, which still leaves individuals without power for outages lasting less than 4 hours. The possibility of the PV system providing a more reliable, renewable energy alternative was not looked into by the Coast Guard. This possibility was not further researched, as a result of individuals not knowing if it was a plausible idea based on the setup of the current system.

In order to address the Coast Guard's overarching issues, we created two goals. Our first project goal was to gain an understanding of the Coast Guard's PV system as well as the contract around it, in order to give a performance review and provide recommendations for possible system improvements. Our second, and final goal, was to look into the possibility of a reliable energy backup system powered by the PV system. Through accomplishing these goals, we provide information about the current contract and system the Coast Guard has in place. In addition to closing the gaps of knowledge created by the rapid personnel turnover, we provide insight into issues affecting current PV system performance, as well as contractual issues affecting potential Coast Guard savings.

METHODOLOGY

To accomplish the goal of evaluating and optimizing performance of the solar photovoltaic system at Río Bayamón Housing, we developed three primary objectives:

1. Assess the performance of the photovoltaic (PV) system.
2. Analyze the initial and ongoing costs associated with the PV system.
3. Examine potential backup battery options to improve reliability of electricity at Río Bayamón Housing.

We used document and data collection and analysis in order to complete our three main objectives stated above. Each objective was broken down into smaller more detailed objectives in order to address all aspects contributing to our project goals. When completing the more detailed objectives, key findings for our project were identified. A compressed list of the detailed objectives is listed below.

1. Identified the Coast Guard's expectations of the PV system performance and the system-level factors that affect the overall performance.
2. Identified adjustment factors applied to annual PV production data at Río Bayamón Housing.

3. Compared the expected, actual, and annual PV production of the system at Río Bayamón Housing.
4. Identified the annual costs to the Coast Guard using the Puerto Rico ESPC Task Order.
5. Compared the post acceptance performance period expenses to the cost of terminating the contract.
6. Analyzed the RESA rates with respect to historical crude oil rates.
7. Examined the benefits of a net metering contract.
8. Assessed the potential implementation of a backup battery source for use at the Río Bayamón Housing accounting for compatibility, safety risks, and potential environmental repercussions.
9. Analyzed the potential costs of purchasing, installing, and maintaining a compatible backup battery system.

FINDINGS AND ANALYSIS

Finding #1. **The photovoltaic system at Río Bayamón Housing produced less power annually than originally estimated.**

Based off of our findings, the PV system is not meeting the Coast Guard's production expectations overall. The majority of these factors are out of the Coast Guard’s control.

Finding #2. **The photovoltaic system at Río Bayamón Housing had the potential to produce more power Year 1 than originally estimated after adjustments were made. Years 2 and 3 did not have the potential to produce the estimated amount of power, even after adjustments were made.**

When taking into account the PV production, as well as the adjustments for solar irradiance, the PV system did in-fact have the potential to exceed the Coast Guard’s expectations. Contract Years 2 and 3 were similar in the fact that they did not meet the Coast Guard's expectations based on a raw data point of view. Adjustments were made as a result of lack of solar irradiance data based on clipping from high solar irradiance and pyranometer connection failure for Years 2 and 3.

Finding #3. **A signed net metering agreement would make it possible for the Coast Guard to generate savings from the ESPC. Without a net metering agreement, no money is saved.**

Without a net-metering agreement, the Coast Guard will continue to pay Schneider Electric for 100% of the electricity they produce and PREPA for 100% of the electricity they consume. If a net metering agreement were in place, the Coast Guard would pay the difference between their consumption and PV production.

Finding #4. **The RESA rates have exceeded the PREPA rates for contract Year 2 through Year 4**.

Schneider Electric's use of the varied rates ended up benefiting the Coast Guard, which allowed them to receive a lower inflation rate then PREPAs average. The reasoning as to why the kWh rate the Coast Guard is paying for PV production is higher the PREPA rates is due to multiple annual drops in crude oil pricing.

Finding #5. **Production and cost analyses for contract Year 1 through Year 4 did not provide sufficient evidence to support or oppose early contract termination through system buyout.**

Savings are difficult to determine because the benefits of system buyout are highly dependent on multiple factors, including but not limited to changing PREPA rates and the status of a net metering agreement. We recommend reassessing this option periodically as more production and expense reports becomes available.

Finding #6. **The most cost efficient battery to comprise the backup battery bank of is a 48V sealed lead acid battery.**

Based on the information we gathered, and calculations we made, we found that the most cost effective option was to use 48V sealed lead acid batteries. Even though the 12V sealed lead acid batteries are slightly cheaper when used in the same scenario, there are four times as many batteries, creating more labor, causing a need for more wiring and based on the average energy densities it would also require a larger storage container.

Finding #7. **A backup battery is not plausible based on the amount of batteries that would be needed to partially power RBH for four hours.**

Based on the calculations of size, it would not be plausible to have battery banks of these size and weight installed in the Río Bayamón housing complex. It would not only take up a large amount of space, but the cost and potential environmental impact of having battery banks of that size would potentially do more harm than good.

RECOMMENDATIONS

Based on the factors discussed in our findings, the two major recommendations we have for the Coast Guard are:

Recommendation #1. **The United States Coast Guard continues to use diesel generators in the case of a power outages, instead of implementing backup solar batteries.**

The Coast Guard already has generators set up at the Río Bayamón housing complex, as already having an infrastructure in place for allowing them to easily obtain large amounts of fuel. Because of this, it would be incredibly inefficient from a cost perspective to implement a battery backup system. If the Coast Guard were to use the diesel generators already in place, as opposed to implementing the best possibly battery we analyzed, they would save roughly $255,000 over a 20 year span.

Recommendation #2. **The United States Coast Guard should sign a net metering agreement with PREPA to reduce financial losses.**

By not having a net metering contract the Coast Guard is losing a large amount of money that they would have gotten a credit for, had the contract been set up. This contract was put in motion many years ago, but is still awaiting final approval. We recommend signing the net metering agreement in order to not miss out on further energy savings. Due to lack of bills we were unable to calculate the exact losses of the Coast Guard as a result of not signing the net metering contract. Based on the bills we were able to estimate a loss of at least $380,000 for RBH in just Years 1 and 2, very confidently.

AUTHORSHIP

Chapter 1: Introduction (Drew Gelinas)

Edited by: Casey Arpin, Charles DeWitt, Maryann O'Connell

Chapter 2: Background (Casey Arpin, Charles DeWitt, Drew Gelinas, Maryann O'Connell)

Edited by: Casey Arpin, Charles DeWitt, Drew Gelinas, Maryann O'Connell

Chapter 3: Methodology (Casey Arpin, Charles DeWitt, Drew Gelinas, Maryann O'Connell)

Edited by: Casey Arpin, Charles DeWitt, Drew Gelinas, Maryann O'Connell

Chapter 4: Findings and Analysis (Casey Arpin, Charles DeWitt, Drew Gelinas, Maryann O'Connell)

Edited by: Casey Arpin, Charles DeWitt, Drew Gelinas, Maryann O'Connell

Chapter 5: Recommendations (Charles DeWitt, Drew Gelinas)

Edited by: Casey Arpin, Maryann O'Connell

Chapter 6: Project Extensions (Drew Gelinas)

Edited by: Casey Arpin, Charles DeWitt, Maryann O'Connell

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ABBREVIATIONS

AC	Alternating Current
AGM	Absorbed Glass Mat
ASB	Air Station Borinquen
DC	Direct Current
DoD	Depth of Discharge
DOE	Department of Energy
ECM	Energy Conservation Measures
EIA	U.S. Energy Information Administration
ESCO	Energy Services Company
ESPC	Energy Savings Performance Contract
HVAC	Heating, Ventilation and Air Conditioning
IGA	Investment Grade Audit
kVA	Kilovolt-ampere
kW	Kilowatt
kWh	Kilowatt hour
kWp	Kilowatt Peak
M&V	Measurement and Verification
NREL	The National Renewable Energy Laboratory
PREPA	Puerto Rico Electric Power Authority
PV	Photovoltaic
RBH	Río Bayamón Housing Complex
RESA	Renewable Energy Services Agreement
STC	Standard Test Conditions
USCG	United States Coast Guard

1. INTRODUCTION

Reliable access to affordable electricity is desired by many populations. In today’s society, individuals rely heavily on electricity to power the items they use every day. Limited access to electricity in regions dependent on power decreases safety and results in economic consequences. Currently, electricity in Puerto Rico is both expensive and inconsistently available. A combination of economic and political factors contribute to Puerto Rico's growing energy crisis. The vast majority of Puerto Rico's energy sources are imported, which directly affects the cost of electricity. The population utilizing Puerto Rico's public utility grid is relatively small and on average, they use less electricity per capita than mainland United States (EIA, 2016c). In comparison with mainland United States, the demand for electricity is low, which decreases the Puerto Rico Electric Power Authority's (PREPA) potential profits. The cost of fossil fuels, costs incurred from low demand, and other factors lead to electricity rates that are nearly double those in mainland United States.

These issues illustrate that Puerto Rico is in dire need of reliable and affordable sources of energy; renewable energy sources could satisfy this need. From a financial perspective, Puerto Rico would benefit from increased energy independence. The public utility grid in Puerto Rico is structurally weak, and access to renewable energy sources could reduce dependence on this public utility (Allen & Peñaloza 2015). In September of 2016, the issue was magnified by an incident at a PREPA power plant that resulted in the loss of power for nearly 1.5 million people displayed in Figure 1 below (Acevedo, Quiñones & Berlinger, 2016).

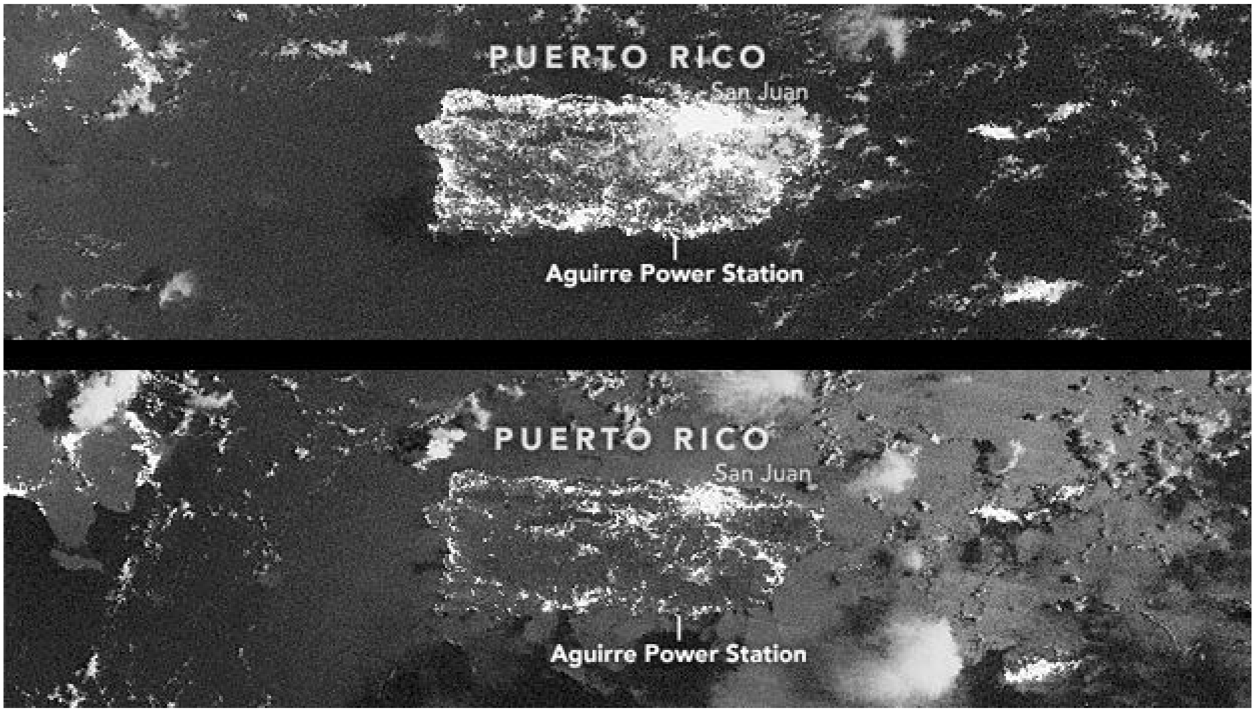


Figure 1. Satellite nighttime image of Puerto Rico Before and After the September 2016 Power Outage. Source: (CBS Miami, 2016)

Using more renewable energy sources would cut down the dependence on power provided by PREPA. Today, the four most common renewable energy sources are hydroelectric, biomass (wood, biofuels, and biomass waste), wind, and solar (EIA, 2016d).

In 2012, the United States Coast Guard (USCG) became a leader in Puerto Rico's renewable energy space by installing solar photovoltaic (PV) systems at two Coast Guard locations. The Coast Guard's Energy Savings Performance Contract, better known as the USCG Puerto Rico ESPC, reduced the initial PV system installation costs for the Coast Guard through third-party system ownership by Hannon Armstrong PR Solar LLC. For the duration of the twenty-three year contract, Schneider Electric is required to maintain the system and compensate for any performance level that falls below the outlined guarantees (Vaughn 2010a). Assuming annual consumption and estimated annual array production stayed consistent, the installed PV system could meet roughly 16% of the energy needs at Río Bayamón Housing. As an agency dedicated to preserving the environment, the Coast Guard is motivated to both optimize and potentially expand their use of renewable energy sources in Puerto Rico. Before attempting to implement any optimization strategies or considering expansion, the Coast Guard must understand the performance of the existing PV system installations, as well as the details of the various agreements.

Our evaluation includes investigating several components that have a direct impact on the performance of the PV system at the Coast Guard's Río Bayamón Housing complex. The expected performance metrics we cover include estimations of costs, electricity production and electricity consumption prior to the initial installation. We compare the expected performance metrics to the actual data recorded by the monitoring system on site at Río Bayamón Housing and published in the annual Measurement and Verification report. For each identified performance discrepancy, we investigate and analyze potential causes.

At the conclusion of our project, we state if the system is underperforming, meeting performance expectations, or overperforming. Based on the performance outcome, we make recommendations to the Coast Guard for potential improvements to the system and agreements between the Coast Guard and other parties. Independent of the recommendations, we conduct a battery cost analysis to see if batteries are a viable option to replace or assist existing energy backup systems in place. Based on the battery analysis, we offer recommendations for ways to change the energy backup system currently in place at the Río Bayamón Housing complex, in order to increase reliability and decrease environmental impact.

These steps are important to the Coast Guard's end goal: affirming the feasibility of renewable energy usage in Puerto Rico and amongst federal agencies. By achieving this goal, Puerto Rico can reduce their dependency on unreliable electricity and expensive fossil fuels.

2. BACKGROUND

The United States Coast Guard (USCG) has taken on efforts to implement green energy alternatives, such as photovoltaic systems, to reduce their natural resource consumption and decrease the cost for utilities. The Coast Guard installed 2.89 megawatts of photovoltaic arrays on newly renovated roofs at two project sites in Puerto Rico that were expected to reduce energy purchased from utilities by 40% (USCG 2010).

This chapter will discuss the causes and effects of the power crisis in Puerto Rico. It will explain renewable energy contracts and regulations, as well as green energy alternatives that help reduce utility costs. It will go through the history of photovoltaic (PV) cells and systems, as well as define the components of a photovoltaic system. It will also demonstrate the benefits of implementing these types of systems. The contract between the Coast Guard and Schneider Electric will be analyzed and discussed. The benefits of a net metering agreement will be addressed and how it affects the Coast Guard financially. Different types of backup batteries will be explored to provide an alternative electricity source. Finally, this chapter will examine the technical specifications of the PV system at Río Bayamón, as well as the energy modeling system in order to establish a basis for analyzing the performance of the system.

2.1 ENERGY IN PUERTO RICO

Puerto Rico relies heavily on imported fossil fuels such as petroleum, coal, and natural gas to meet their energy demands. Since Puerto Rico does not produce any of these sources of energy, they are forced to rely on importation in order to acquire the necessary goods for island operations (EIA, 2016c). A graph showing the breakdown of electricity produced from imported resources for all of Puerto Rico during the 2015 is shown in Figure A4, in the appendix.

Imported resources are used to create electricity for residential, commercial, and industrial use (EIA, 2016a). Puerto Rico incurs additional costs importing these resources, especially when importing from the United States. The combination of relying on imported resources and paying a large tariff for those resources is a financial burden for Puerto Rico.

According to data available through the U.S. Energy Information Administration (2016c), electricity rates in Puerto Rico have been, and still are, substantially higher than those in mainland United States (See Figure 2 and Appendix Figure A1-A2). As seen in Figure 2, electricity rates in Puerto Rico have decreased significantly in 2015 and 2016 due to the drop in oil prices. Despite this decrease, Puerto Rico continues to pay higher electricity rates than mainland United states (EIA, 2016c).

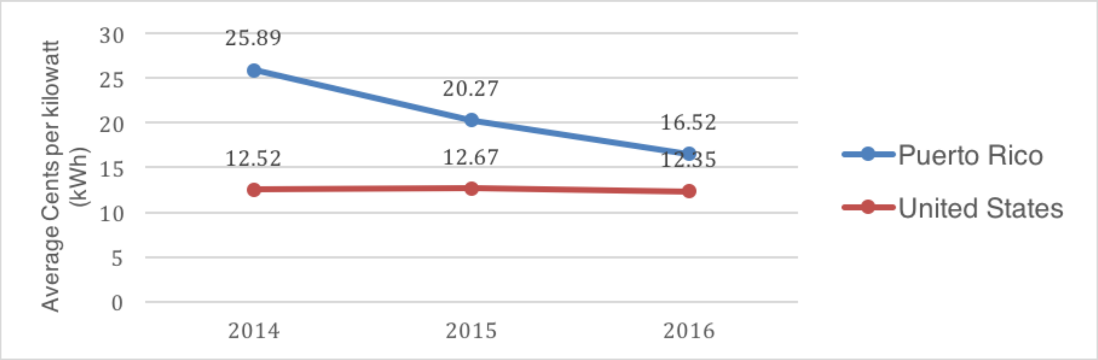


Figure 2. Average Residential Electricity Prices (in cents) in Puerto Rico versus the United States from 2014 to May 2016. Source: Data obtained from U.S. Energy Information Administration (EIA, 2016c)

PREPA has commercial, residential, and industrial electric service rates. The commercial rates are broken down into many categories such as, general service at primary distribution voltage and general service at secondary distribution voltage (PREPA, 2000). The character of service, which is determined by quality of service received, dictates which rate category is utilized (Hawaiian Electric, 2016) . For each kilowatt hour received at a primary distribution voltage, customers are charged a consumption charge, energy purchase, fuel purchase, and provisional rate, as illustrated in Figure 3. After the first 215,775 kWh, the consumption charge decreases from $0.036 to $0.028 per kWh (PREPA, 2016).

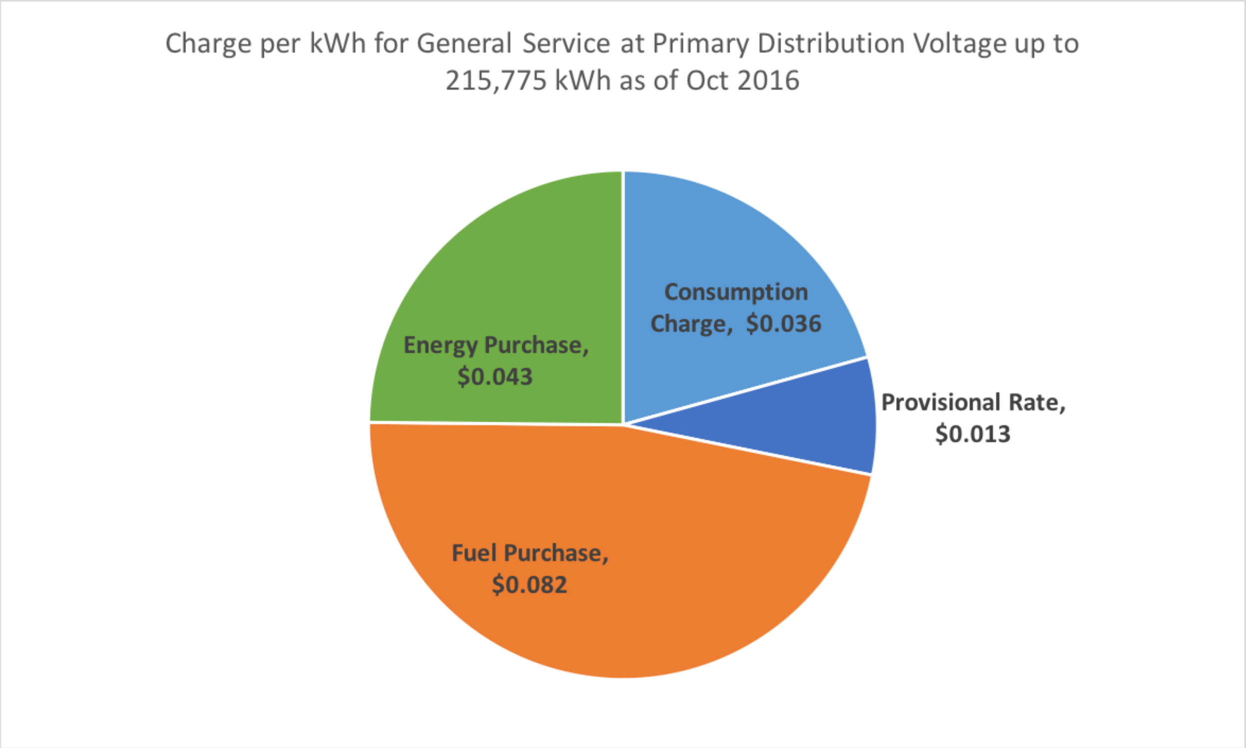


Figure 3. Charge per kWh for General Service at Primary Distribution Voltage up to 215,775 kWh as of October 2016. Source: Data obtained from Puerto Rico Electric Power Authority (PREPA, 2016)

In addition to the kWh charges, a fixed monthly service charge, corresponding to the character of service. The fuel and energy purchase charges applied to the bill vary monthly. The provisional rate applied to the bill is new as of 2016 (Alvarado Leon, 2016). This additional charge was instated in attempt to increase PREPAs income. PREPAs need to make debt payments to reduce their overall debt continues to be a factor for increased electricity prices (Alvarado Leon, 2016).

Puerto Rico's increased price rate for electricity has been a prominent factor in the utility debt currently facing the Puerto Rico Power Authority (PREPA) (Allen & Peñaloza, 2015). In 2015, PREPA "negotiated with private creditors, as well as bank lenders and insurers, in an effort to avert default" (Park & Samples, 2016). This deal was created to "restructure US $5.7 billion of PREPAs outstanding debt" showing that Puerto Rico's reliance on importation and poor financial status has contributed to a severe economic crisis on the island (Park and Samples, 2016). These economic factors demonstrate a need for more energy production on the island to minimize importation needs. The transition to renewable energy sources provides a realistic solution that could lower the amount of imported fossil fuels needed to supply the island with energy.

2.2 RENEWABLE ENERGY REGULATIONS AND CONTRACTS

Events of national and global concern have shaped today's energy policies in the United States. In response to the energy crisis of the 1970s, the United States Federal Government established the Department of Energy (DOE), which included the creation of a department dedicated to renewable energy (Laird & Stefes, 2009). Since then, renewable energy laws and regulations have grown extensively in both quantity and scale. The Energy Policy Act of 2005 set forth "to ensure jobs for our future with secure, affordable, and reliable energy." The policy required electric energy from federally owned renewable sources to account for at least 7.5% of the Federal Government's electricity consumption annually by fiscal year 2013. In 2015, President Barack Obama signed "Executive Order 13693—Planning for Federal Sustainability in the Next Decade", expanding on the Energy Policy Act of 2005. According to Executive Order 13693, executive agencies are expected to use renewable energy sources for at least 30% of total building electricity consumption by 2025. To make progress towards these goals, federal agencies will need to install renewable energy sources and implement other energy saving measures.

Insufficient finances are a primary barrier to increasing residential, commercial, and industrial renewable energy sources. Installing renewable energy sources often provide financial benefits over the long-term, however, the upfront costs associated with installing a new renewable energy source are often substantial. Energy Saving Performance Contracts (ESPCs) are employed to lower this barrier to entry for federal agencies (DOE, 2016d). ESPCs create a partnership between a federal agency and an energy service company (ESCO). Prior to installation, the ESCO conducts an energy audit throughout the federal agency and determines areas in which energy efficiency could be improved. In addition to installing the system, the ESCO maintains the system and provides performance guarantees. ESPC projects often include renewable energy systems, in addition to Energy Conservation Measures (ECMs), such as lighting, HVAC system, and power system measures.

In order to properly verify the performance of the renewable energy source and measure savings, the ESCO performs a Measurement and Verification (M&V) report. The objective of a M&V report is to review that the guaranteed energy and cost savings match or are close to the estimated savings (DOE, 2016a). These reports are generally completed annually so that the performance of the renewable energy source can be monitored closely to reduce the "uncertainty of savings estimates" (DOE, 2016a). ESPC projects also use this report to assess potential problems, as well as identify maintenance needs by evaluating the performance of the renewable energy source (DOE, 2016a). Once the M&V report is completed, ESCO creates an M&V plan to be revised by the agency, to address any maintenance needs and any factors that would contribute to underperformance (DOE, 2016b). This process continues until the end of the contract.

The majority of financing for the ESPC is constructed in an Energy Services Agreement (ESA). The ESA includes all the M&V procedures, savings guarantees, production guarantees, and maintenance plans as well as payment plans for the renewable energy source (Metropolitan Area Planning Council, 2014). ESAs define payment methods for long term periods that are based off of system performance that can be monitored through M&V reports (Metropolitan Area Planning Council, 2014). The agency pays a rate close to the utility rate as well as maintenance and service fees for the energy produced (Institue for Market Transformation, 2016). Through this process, ESCO receives payments from the user for all the energy the agency produces.

2.3 ENERGY CONSERVATION MEASURES

In context, Energy Conservation Measures (ECMs) are "measures that are applied to a Federal building that improve energy efficiency and are life cycle cost effective and that involve energy conservation, cogeneration facilities, renewable energy sources, improvements in operations and maintenance efficiencies, or retrofit activities" (DOE, 2016e; 42 USC §8259, 2016). An effective ECM project must take the environment into account. In Puerto Rico and other tropical climates, the ECM must take heat into account. Cool roof technologies are an example of an ECM appropriate for warm climates.

The ultimate goal of installing cool roofs is to decrease energy consumption. Cool roofs are designed to lower roof temperatures efficiently (Urban & Roth, 2010). Traditional roofs can reach temperatures of 150°F or more when exposed to direct sunlight, while cool roofs tend to be at least 50°F cooler (Urban & Roth, 2010). Traditional roofs absorb more sunlight causing the temperature of the roof to increase, which allows a greater amount of heat to flow into the building. Cool roofing technologies reflect more sunlight and emit heat more efficiently, decreasing the heat flow into the building and reducing the overall temperature. By implementing cool roof technologies, air conditioners can operate for shorter time intervals. When air conditioners operate for shorter time intervals to maintain a comfortable temperature, energy bills decrease. Cool roofs also have environmental benefits such as reducing local air temperatures, greenhouse gas emissions, and the demand on the electric grid (Urban & Roth, 2010).

Other energy saving practices consist of using Energy Star appliances, retrofitting light fixtures, adding occupancy sensors, upgrading heating, ventilation, and air conditioning (HVAC) systems to variable refrigerant volume systems, and retrofitting plumbing systems. Installing Energy Star appliances helps to increase efficiency and cost savings as well as reduce greenhouse gas emissions. Using energy efficient light bulbs and implementing photocell sensors can save anywhere from 25-80% of the energy used in traditional incandescent lighting (DOE, 2016c; Ye & Seidel, 2012). Occupancy sensors are used to detect the occupancy of a space. The system controlled by the occupancy sensor turns on and off based on detection of people in that space. Using occupancy sensors can help reduce overall energy costs by turning off extraneous lights. Converting HVAC systems to variable refrigerant volume systems reduce energy consumption by using refrigerant as the cooling agent instead of air or water. Updating to water efficient faucets reduces the amount of water flow by 30 percent, without having an effect on the overall operation (EPA, 2016). Water efficient faucets flow at a rate of 1.5 gallons per minute, while standard sinks flow at a rate of 2.2 gallons per minute (EPA, 2016). Implementation of energy saving practices increases costs savings while decreasing environmental repercussions.

2.4 PHOTOVOLTAIC SYSTEMS OVERVIEW

The earliest form of photovoltaic (PV) research began well before electricity became accessible to the public. In 1839, a French scientist Edmond Becquerel discovered the photovoltaic effect, the process that converts sunlight to electricity (DOE, 2001). Research in this space continued, and widespread recognition was achieved in 1921 when Albert Einstein won the "Nobel Prize for his theories explaining the photoelectric effect" (DOE, 2001). Selenium was one of the first elements used for PV experiments, but converting sunlight to electricity was inefficient with selenium (DOE, 2001). The discovery of silicon was a major breakthrough in PV history because silicon cells were proven more efficient in both capturing and converting sunlight than selenium (DOE, 2001). With the discovery of silicon cells, Daryl Chapin, Calvin Fuller, and Gerald Pearson produced the first silicon PV solar cell in 1954 (DOE, 2001). From then on, research was conducted to improve the efficiency and reduce the cost of the silicon PV solar cell systems so that this process could power satellite, residential, and commercial needs (DOE, 2001). As time went on, solar arrays became more readily available to businesses and residents, leading to the expansion of renewable energy sources. Current PV cell research focuses on improving the efficiency of PV cells within a PV array, and improving the efficiency of other PV system components that convert, collect, and distribute the electricity (Razykov et. al, 2011).

Solar photovoltaic (PV) systems consist of several components performing different tasks to generate electricity from sunlight. This process converts direct current (DC) electricity to alternating current (AC) for use by consumers. Figure 4 lists the components of a general solar PV system and their basic function.

Modules	• Collects the sunlight • Converts sunlight into DC electricity
Inverters	• Converts the DC electricity to AC electricity
Utility Meter	• Registers the amount of electricity generated
Usable Electricity	• The product used to satisfy electronic needs for the customer.
The Grid	• Collects the usable electricity that wasn't consumed and stores it for later use

Figure 4. Components of a Typical Solar Photovoltaic System and their Basic Functions. Source: (Samlex Solar, 2016)

PV modules, made up of PV cells, capture solar light and then convert the solar light into electrical energy. This process is known as the photovoltaic effect (Carts-Powell, 2014). During this process, some solar light cannot be captured and converted. This loss can be attributed to the amount light reflecting off the surface of the module and the “layer thickness” of the module (Mitchell & Tatro, 2014). “To obtain higher power and higher voltage, a number of cells must be assembled in panels or arrays” (Mitchell & Tatro, 2014). After the solar light is converted to DC, the inverter converts the DC electricity that solar panels produce into AC electricity (The Engineer, 2008). In general, public utility grids utilize AC electricity (The Engineer, 2008). Once the electricity is converted to AC it is either stored in a battery where it is converted back to DC, or it is fed into the grid for later use (The Engineer, 2008). A visual representation of the process from initial solar light absorption to grid feedback can be seen in Figure B2 of the appendix.

Two other components that make up a PV system, that aren’t as common as the pieces above are charge controllers and pyranometers. The charge controller regulates the amount of electricity that flows from the “generation source” to the rest of the system (U.S. Department of Energy, 2005). This component is very important, as it stops the system from being over loaded with electricity. Another component that is important to the PV process is the pyranometer. The pyranometer measures the total amount of solar irradiance a system receives (Meydbray, Emery & Kurtz, 2012). This component measures solar irradiance by monitoring temperature change on a certain surface (Meydbray, Emery & Kurtz, 2012). Solar irradiance is a measure of the amount of the sun's energy hitting a unit area (Sandia Corporation, 2014). These components describe the amount of sunlight that the PV panels obtain, as well as controls the electrical current that goes to the inverter, which are two very important aspects of a PV system.

2.5 POST INSTALLATION INFORMATION

Due to the fact that photovoltaic systems are a fairly new technology, there is little documentation on common issues (Salasovich & Mosey 2011). As a result of the age of the systems, there are concerns with the lifetime performance of photovoltaic modules. An example of this issue can be found in a study conducted by Salasovich and Mosey. They investigated the reliability of BP Solar PV systems.

Salasovich and Mosey's (2011) study stated the following:

> "Today, BP Solar offers a 25-year warranty on most of its crystalline silicon PV modules…while the modules have to last for 25 years of outdoor exposure, we cannot wait 25 years to see how they perform… no BP/Solarex module has been in the field longer than ten years. Even the oldest 20-year warranty modules have only been in the field 15 years." (Salasovich & Mosey 2011).

Although it is difficult to know what to expect in terms of reliability of commercial photovoltaic systems, there are some specific concerns. General reliability issues across all PV technologies are: corrosion of wires, fracture of module glass, and moisture seeping into the interior of the modules. (Kurtz, 2013). In addition to the potential mechanical issues, maintenance is often a concern when looking to upkeep a PV system.

Fortunately for owners of PV systems, the maintenance is fairly minor and infrequent (Walker, A & Ardani, K, 2016). The National Renewable Energy Laboratory (NREL) divides the methods of maintenance for a system into two categories: preventative maintenance and corrective maintenance. Both categories vary in terms of recommended frequency (Walker, A & Ardani, K, 2016). Preventative maintenance is scheduled maintenance that occurs periodically to check for potential system issues caused by the environment, such as corrosion of wires or the seeping of water into internal areas of the solar arrays (Walker, A & Ardani, K, 2016). NREL recommends that this maintenance be performed on an annual basis, but the period may vary based on the details of the specific contract (Walker, A & Ardani, K, 2016). "Condition based" maintenance is the replacing or repairing of a failed component (Walker, A & Ardani, K, 2016). These include factors that cannot be avoided through preventative maintenance, like the fracturing of glass on the PV arrays (Walker, A & Ardani, K). These two types of maintenance are all that is recommended in order to keep your PV system functioning optimally, according to NREL (Walker, A & Ardani, K, 2016).

2.6 NET METERING

Net metering permits electric customers with a renewable energy source, commercial or residential, to offset their electricity usage. A bi-directional meter allows electricity to flow from the customer to the grid and from the grid to the customer (Shah, 2014). When the renewable energy system's production exceeds the customer's consumption, the excess electricity flows back into the electric company's grid. The net excess generation would be applied as a credit in kilowatt-hours to the customer on the following month's bill. If the customer's electricity consumption is greater than the system's production, the customer would pay for the net consumption. Net consumption is the electricity consumed by the customer minus the electricity produced by the system that was put back into the grid (Shah, 2014). This formula is demonstrated below:

$$\text{Net Consumption (kWh)} = [\text{CEC} - \text{EP}] \qquad (1)$$

where: CEC = Customer Electricity Consumption (kWh)

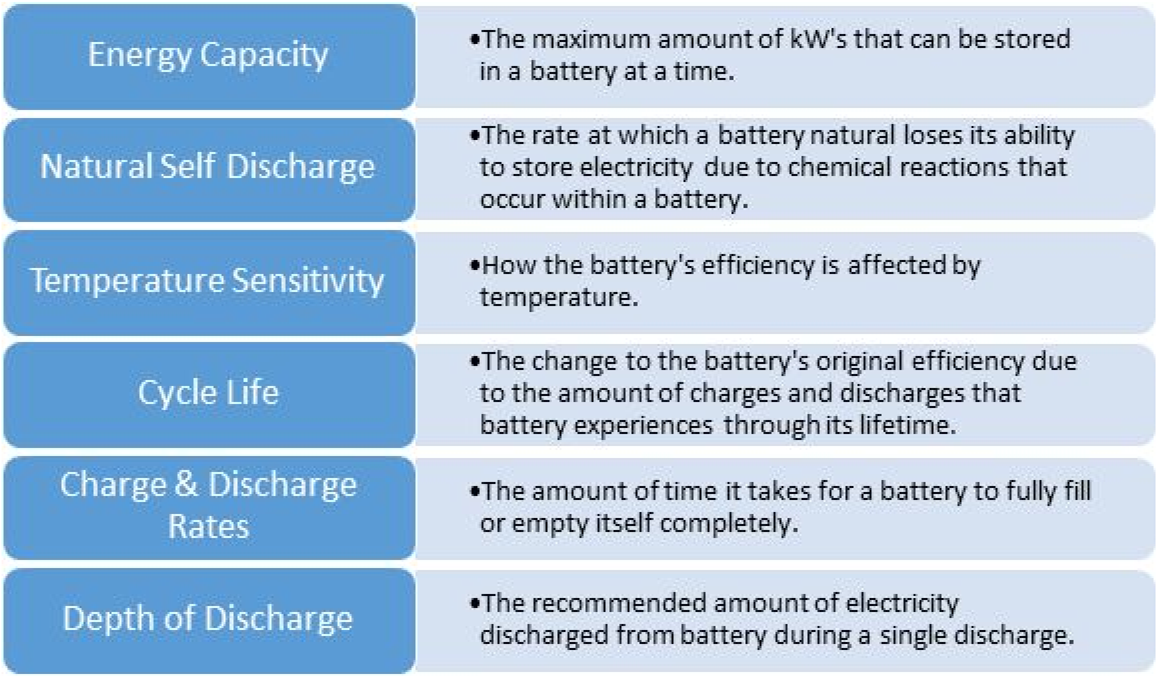
EP = Electricity Produced by the PV system (kWh)

Puerto Rico established a net metering law in 2007. In order to qualify, residential systems must have the capacity to generate 25 kilowatts of power while non-residential systems must have the capacity to generate one megawatt of power (DOE, 2016f). Customers with net metering in Puerto Rico are limited to a credit for net excess generation of 300 kWh for residential systems and 10 megawatt-hours for commercial systems per day (DOE, 2016f). PREPA will purchase 75% of the excess electricity credits from the customer at the greater of two rates. The other 25% of the electricity credits will be distributed to reduce the electricity bills of public schools (DOE, 2016f). With net metering, installing and maintaining a renewable energy source is more affordable. However, without a net metering agreement installing and maintaining a renewable energy source would be significantly more expensive. Without a net metering agreement the consumer would put electricity into the grid without receiving an electricity credit for the amount of electricity the consumer's system generated. This would result in the consumer not receiving the benefit of providing the grid with the renewable energy that their system generated. As a result they would essentially be giving away free electricity by having a grid-tied system, without a net metering agreement.

2.7 SOLAR BATTERIES OVERVIEW

Due to an unreliable Puerto Rican grid, the Coast Guard averages roughly one power outage a week. Although they have backup generators in place, there is a labor intensive procedure that needs to be carried out. This procedure requires someone to go to the generator, grab the generator wire, and plug the wire into the house, for every housing block. The Coast Guard only uses the backup generators when the power goes out for more than 4 hours. As a result, the housing complex is frequently left without power when short power outages occur. The Coast Guard would like to explore options for potential installation of a small backup battery to cover these gaps during the frequent outages.

Electricity produced from a solar photovoltaic (PV) system can either be stored in a battery for later use or sent to the grid in exchange for an energy credit (The Engineer, 2008). A battery is designed to take in DC electricity, also known as charging the battery, and store that electricity until it is used, known as discharging the battery (Bloomfied, 2016). This process is applicable to solar PV systems because when PV arrays produce electricity, the electricity is in the form of DC electricity which does not have to be converted to charge a battery (Bloomfied, 2016; The Engineer, 2008). Figure 5 lists and defines factors that contribute to a battery's performance.



Energy Capacity	•The maximum amount of kW's that can be stored in a battery at a time.
Natural Self Discharge	•The rate at which a battery natural loses its ability to store electricity due to chemical reactions that occur within a battery.
Temperature Sensitivity	•How the battery's efficiency is affected by temperature.
Cycle Life	•The change to the battery's original efficiency due to the amount of charges and discharges that battery experiences through its lifetime.
Charge & Discharge Rates	•The amount of time it takes for a battery to fully fill or empty itself completely.
Depth of Discharge	•The recommended amount of electricity discharged from battery during a single discharge.

Figure 5. Battery Capacity and Lifetime Characteristics. Source: (ReVision Energy, 2016)

The factors above describe the efficiency and performance of a battery; these factors contribute to the cost of a battery (ReVision Energy, 2016). The process of implementing solar batteries is similar to the process shown in Figure 5. The current generated by a PV system with a battery bank wired in parallel passes through the charge controller before reaching a two way split (The Engineer, 2008). Half of the current travels to the battery field and the other half travels to the inverter. Once the battery bank is fully charged, the inverter receives the remainder of the current produced by the PV arrays before it is sent to the grid. The majority of buildings use the grid to power their electrical needs. A battery bank is useful in situations when the grid cannot meet this demand.

Within the past twenty years, solar PV system designers in the U.S. have strayed away from using batteries to store the electricity produced by the system. They have defaulted to utilizing grid power and net metering agreements to supply electricity (ReVision Energy, 2016). This process is effective if the owner of the PV system has access to reliable grid output and a favorable net metering agreement. A favorable net metering agreement guarantees an energy credit for the amount of electricity the PV system puts into the grid (ReVision Energy, 2016). During the billing period the PV system user pays the difference between the amount of electricity consumed by the user and the amount electricity generated by the user (ReVision Energy, 2016).

2.7.1 General Lead Acid Batteries

Lead acid batteries are the most commonly used solar battery on the market (Albright, Edie & Al-Hallaj, 2012). Lead acid batteries can be broken down into two subcategories: flooded and sealed lead acid batteries (Albright, Edie & Al-Hallaj, 2012). Both types of batteries have one major setback in common when considering them for use in a residential setting—temperature sensitivity. Temperature sensitivity affects all lead acid batteries, however, there are some major factors that separate the subcategories. One difference in subcategories is the containment system of the battery itself, which will be discussed in more depth later on in this section.

Temperature sensitivity is the degrading of a battery's ability to produce its theoretical maximum electricity discharge at certain temperatures. This is due to the chemical reactions that occur within the battery during charge and discharge periods, which in the case of lead acid occurs at 77 degrees Fahrenheit (Zhang, T.S. Zhao, Xu, An & G. Zhao, 2015; Albright, Edie & Al-Hallaj, 2012). Because of the high temperature sensitivity of lead acid batteries, temperature regulated containment units are often required. Not only does a temperature regulated containment system create an additional cost for installing a backup system, it also complicates the installation process.

Flooded and sealed lead acid batteries have similar chemical reactions occurring inside of them. A major difference between the two battery types batteries is their containment system

(Albright, Edie & Al-Hallaj, 2012). Flooded batteries have two limiting factors, the need for a ventilated environment and frequent maintenance, which sealed lead acid batteries do not (Albright, Edie & Al-Hallaj, 2012). These factors will be discussed in greater depth later in this section. These limitations stem from the need for water in a flooded lead acid battery. Flooded lead acid batteries require water to be poured into the casing unit. For the chemical reaction to occur in flooded lead acid batteries, it requires water to allow the battery to store a charge. Flooded lead acid batteries have a different chemical reaction than sealed lead acid batteries. As a result of the chemical reaction, flooded lead acid batteries emit a harmful gas.

The complications of a flooded acid battery not only create a need for a temperature regulated containment system, but also requires ventilation and easy access to each battery in the bank allowing for addition of water. These additional requirements of flooded lead acid batteries, when considering installation in warmer environments, result in a more expensive and complicated installation process.

2.7.2 Sealed Lead Acid Batteries

There are two common types of sealed lead acid batteries—absorbed glass mat (AGM) and gel batteries (Albright, Edie & Al-Hallaj, 2012). Both of these options are effective for deep cycles, which refers to the discharge of less electricity over a longer period of time. Deep cycle batteries are often used for the backup systems, because they are able to hold electricity for a long period of time (Albright, Edie & Al-Hallaj, 2012). Ability to slowly discharge, as well as, store electricity for an extended period of time are two ideal characteristics of a solar backup battery.

2.7.3 Lithium Ion Batteries

Lithium ion is one of the newer battery technologies and has been rapidly increasing in usage, from cell phones to computers to solar batteries (Henley, Newman & Rodgers, 2012). Some properties of lithium ion batteries that contribute to its rising popularity are its smaller size, better cycle life, decreased temperature sensitivity and virtually no required maintenance. An additional benefit of lithium ion batteries is that all lithium ion cells are deep cycle, so they work well with any amount of discharge the battery would need to produce (Albright, Edie & Al-Hallaj, 2012).

2.8 THE UNITED STATES COAST GUARD

The United States Coast Guard Station in San Juan was established in 1993 outside Old San Juan to serve Puerto Rico and the U.S. Virgin Islands region (USCG, 2014). Approximately 355,074 people reside in San Juan as of 2015 based on population estimates from the United States Census Bureau (2015) for Puerto Rico.

The United States Coast Guard mission statement addresses environmental preservation and protection efforts. The Coast Guard’s shore-based operations, better known as Sector San Juan, is the site of an on-going effort to dramatically increase energy efficiency and promote sustainable practices (Ye & Seidel 2012). The Coast Guard’s energy-saving project in Puerto Rico, echoes their mission statement by creating a cleaner energy procedure and decreasing the need for fossil fuels.

2.9 PUERTO RICO ENERGY SAVINGS PERFORMANCE CONTRACT

The Puerto Rico Energy Savings Performance Contract (ESPC) was designed to meet federal mandates and incorporate renewable energy sources that lower the Coast Guard's energy costs in a region where reliable electricity is scarce and expensive (Ye & Seidel, 2012). Schneider Electric, a global company that specializes in energy management and automation solutions, and Hannon Armstrong PR Solar LLC, a limited liability company, entered into a twenty-three year ESPC with the Coast Guard. Hannon Armstrong PR Solar LLC, referred to as "Owner", financed the project and remains the owner of the system for the duration of the contract. As an energy services company, Schneider Electric, referred to as "ESCO", performed the investment grade audit (IGA) and installed the system. Schneider Electric used a smaller company, Blue Oak Energy, for the actual installation process as well as maintenance services.

Due to budget and time constraints, the ESPC was implemented in two phases (Schneider Electric, 2016; Ye & Seidel, 2012).

The first phase consisted of photovoltaic system installations across two locations owned by the Coast Guard in Puerto Rico—Río Bayamón Housing and Air Station Borinquen (See Appendix Figure A3). The IGA for phase one included an energy audit, extensive technical assessment, and pricing information. The Coast Guard chose to implement both the roof renovations and photovoltaic systems, as recommended by Schneider Electric. 10.5 million dollars were allocated to roof repairs (USCG, 2010). The installation of 2.89 megawatts of photovoltaic power was completed in 2011 (Vaughn, 2011).

The second phase included Energy Conservation Measures (ECMs) traditionally present in ESPC projects, including HVAC efficiency upgrades, lighting retrofits, and water conservation retrofits. Adding ECMs to these locations was intended to reduce the Coast Guard's energy use (Vaughn, 2010b).

To finance the project, the Coast Guard entered a Renewable Energy Services Agreement (RESA). This unique financing method enables the Coast Guard to pay off the system via renewable energy production payments. It also permits the system owner, Hannon Armstrong PR Solar LLC, to benefit from tax incentives (Vaughn, 2011). Schneider Electric calculated rates for the electricity production per kilowatt hour (kWh) that the PV system produced, known as the RESA rates (USCG and Schneider Electric, 2010). This incremental payment method continues throughout the duration of the contract.

2.10 RIO BAYAMON HOUSING COMPLEX

In 1997, the Río Bayamón Housing complex was constructed to house Coast Guard personnel and their families. The complex is comprised of 149-housing units, a community center, a childcare center, as well as a maintenance building. Río Bayamón Housing is situated between the city of Bayamón and Guaynabo, approximately eleven miles away from Sector San Juan.

Historically, the living conditions at Río Bayamón Housing were poor. The United States Coast Guard found that more than half of the roofs at the Río Bayamón Housing complex contained asbestos, a known human carcinogen (Ye & Seidel, 2012). Prior to the cool roof installation, the conditions warranted a twenty-five percent discount to those living in the complex. The roof renovations implementing in phase one of the Puerto Rico ESPC benefited Coast Guard personnel and families at Río Bayamón Housing by improving safety.

2.11 TECHNICAL SPECIFICATIONS OF THE PV SYSTEM

The PV system at Río Bayamón Housing consists of 2,451 PV modules divided among twenty-seven housing unit buildings, a community center, a carport ground mount, and a maintenance building (Vaughn, 2010b). The total capacity of the installed PV arrays at Río Bayamón Housing is 576 kilowatt peak (kWp, DC) (Vaughn, 2010b). Details pertaining to the inverters used are summarized in Appendix Table B1.

Prior to the installation, the existing peak demand was 11,374 kilovolt-amperes (kVA) (Vaughn, 2010b). Annual consumption prior to the installation was approximately 5.9 million kWh (Vaughn, 2010b).

2.12 SOLAR PHOTOVOLTAIC ENERGY MODELING METHODOLOGY

To estimate the annual base energy yield and annual electricity generation, Schneider Electric utilized PVsyst, a photovoltaic (PV) system computer software program (Vaughn, 2010b). PVsyst is used throughout the photovoltaic technology industry "for sizing, simulation, and data analysis" (Vaughn, 2010b). Figure 6 provides an overview of the solar PV energy model methodology applied by Schneider Electric during the analysis phase of the ESPC.

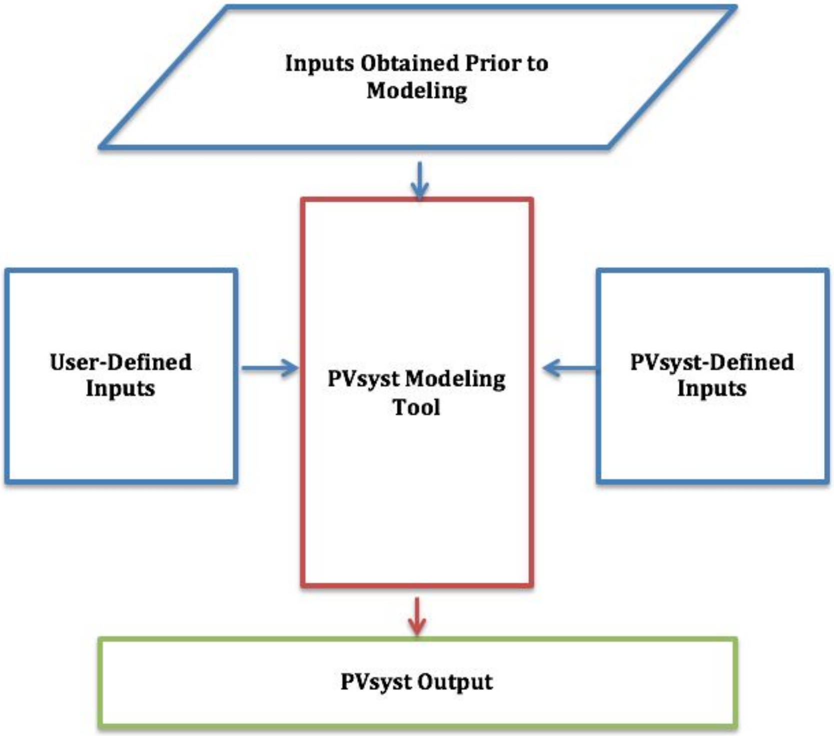


Figure 6. Overview of Solar PV Energy Model Methodology. Source: Adapted from USCG Puerto Rico ESPC - Investment Grade Audit: Volume I Technical Assessment (Vaughn, 2010b)

Six model variations were created to simulate the energy output at Río Bayamón Housing. The modeling process is expressed in greater detail in Appendix Figure B1.

The inputs obtained prior to modeling are the “NREL TMY3 weather data” and the “applicable manufacturer’s data” (Vaughn, 2010b). TYM3 weather data contains the hourly values of solar radiation and meteorological elements collected for one year by NREL (Vaughn, 2010b). The dataset used is dependent on the installation site and helps determine the amount of solar irradiance—a measure of the amount of the sun’s energy hitting a unit area—the modules will collect (Sandia Corporation, 2014). The manufacturing data needed for the model is the solar photovoltaic module information and inverter information, specifically the model number (Vaughn, 2010b). To begin a model, the user inputs the TYM3 weather data and the manufacturing data into PVsyst.

The user-defined inputs for the PVsyst modeling tool are divided into two categories:

1. General project and site parameters
2. Loss factors

The general project parameters include location, module type, number of modules, inverter type, and module plane orientation. Location is defined by latitude, longitude, and altitude. All models for the Río Bayamón Housing PV system used San Juan International Airport location data. The module types remained the same for each model, while the number of modules and inverter types varied.

The user-defined loss factors applied to the Río Bayamón Housing site models include:

1. Array soiling loss
2. Module quality loss
3. Module array mismatch loss
4. Ohmic wiring loss
5. AC ohmic loss
6. Shading loss

The soiling loss defines system loss resulting from accumulation of dirt. (PVsyst, 2016b). Naturally, in rainy environments, this loss factor is minor (PVsyst, 2016b). Module quality loss is a subjective value that reflects the level of confidence pertaining "to the real module's performance, with respect to the manufacturer's specifications" (PVsyst, 2016a). Including this value reduces some of the uncertainty associated with manufacturer specified module performance, ultimately improving the level of accuracy of the simulation (PVsyst, 2016a). When modules are strung together to create a module array, mismatch loss can occur. The lowest current dedictates the current of the entire array (PVsyst, 2016c). Real modules are almost never identical, therefore it is important to adjust for this in simulation (PVsyst, 2016c). The ohmic wiring loss parameter accounts for losses "between the power available from the modules and that at the terminals of the array" (PVsyst, 2016e). AC Ohmic loss is "the distance between the inverter output and the injection point" (PVsyst, 2016d). This loss parameter is especially important when considering weak grids because greater voltage drops can occur when power is injected into a weak grid (PVsyst, 2016d). Optimal power systems aim to minimize voltage drops. The final user-defined loss factor is shading loss. As the name implies, shading loss accounts for shade from all the usual sources including trees. These loss factors are of value because differences between the model input and the actual system losses impacts the accuracy of the annual base yield energy and electricity energy estimates.

The PVsyst-defined inputs are also divided into two categories “equipment parameters” and “other inputs determined by PVsyst” (Vaughn, 2010b). Equipment parameters include:

1. Array nominal energy at standard test conditions (STC)
2. Inverter losses (Vaughn, 2010b)

Array nominal energy at STC is the “starting point of the array energy evaluation in the loss diagram” (Mermoud & Wittmer, 2014). It is usually the efficiency multiplied by the irradiance on the collectors. Standard test conditions are normal conditions set for testing the model such as 25 degrees Celsius for temperature (Mermoud & Wittmer, 2014). Inverter losses occur when the voltage is below the minimum value or exceeds the maximum value specified by the user in PVsyst (Mermoud & Wittmer, 2014). The inverter clips causing the production of the system to be stopped and lost.

The other inputs determined by PVsyst include:

1. Global horizontal irradiance
2. Near shading factor on global
3. IAM factor
4. PV loss due to irradiance level
5. PV loss due to temperature.

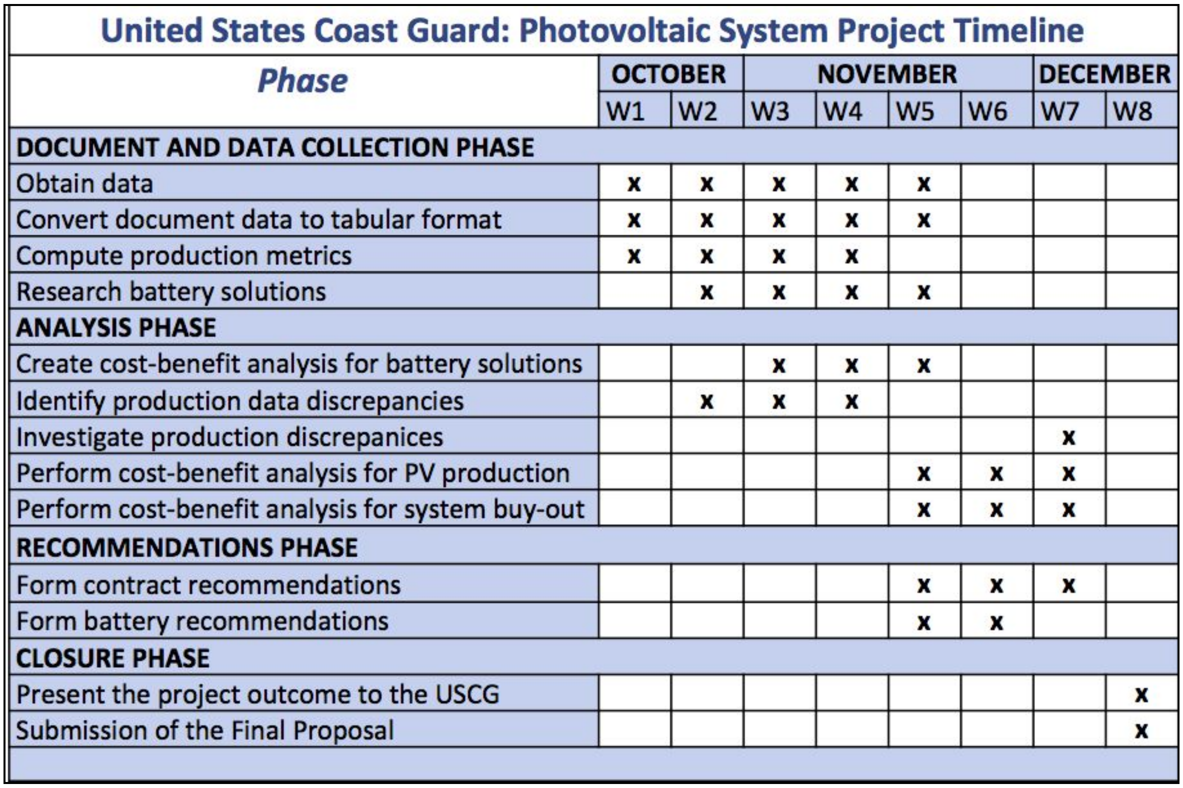
Global horizontal irradiance is the total solar radiation collected by the panels and can be represented as the sum of direct beam radiation, diffuse radiation, and ground reflected (NREL, 2016). Near shading factor takes into account the objects such as trees, buildings, and roofs that cast a shadow on the photovoltaic panels causing the irradiance level to decrease (Mermoud, 2013). PVsyst creates a table for the near shading factors in order to determine in the panels will be shaded based on height and azimuth angle (Mermoud, 2013). Lower irradiance levels causes a decrease in efficiency which leads to PV loss due to irradiance level (Mermoud & Wittmer, 2016). The end goal of the simulation is to output the estimated annual base energy yield in kWh/kWp/year and the annual electricity generation in kWh/year.

3.0 METHODOLOGY

To accomplish the goal of evaluating and optimizing the performance of the solar photovoltaic system at Río Bayamón Housing, we developed three primary objectives. They are as follows:

1. Assess the performance of the photovoltaic (PV) system.
2. Analyze the initial and ongoing costs associated with the PV system.
3. Examine potential backup battery options to improve reliability of electricity at Río Bayamón Housing.

In this chapter, we describe the methods we used to evaluate the PV system, examine the associated costs, and determine options for backup batteries for Río Bayamón Housing. Steps for all the methods are summarized in the timeline (see Figure 7).



United States Coast Guard: Photovoltaic System Project Timeline

Phase	OCTOBER		NOVEMBER				DECEMBER	
	W1	W2	W3	W4	W5	W6	W7	W8
DOCUMENT AND DATA COLLECTION PHASE								
Obtain data	x	x	x	x	x			
Convert document data to tabular format	x	x	x	x	x			
Compute production metrics	x	x	x	x				
Research battery solutions		x	x	x	x			
ANALYSIS PHASE								
Create cost-benefit analysis for battery solutions			x	x	x			
Identify production data discrepancies		x	x	x				
Investigate production discrepanices							x	
Perform cost-benefit analysis for PV production					x	x	x	
Perform cost-benefit analysis for system buy-out					x	x	x	
RECOMMENDATIONS PHASE								
Form contract recommendations					x	x	x	
Form battery recommendations					x	x		
CLOSURE PHASE								
Present the project outcome to the USCG								x
Submission of the Final Proposal								x

Figure 7. RBH Photovoltaic System: Performance Review and Recommendations Timeline

3.1 OBJECTIVE 1: COLLECT AND ANALYZE PRODUCTION DATA

One of the Coast Guard's major concerns was whether the PV system was performing as expected. To determine if the PV system performed according to the Coast Guard’s initial expectations upon implementation of the project, the team completed the following steps:

1. Identified the Coast Guard’s expectations of the PV system at Río Bayamón Housing with respect to performance.
2. Identified the system-level factors that affect the overall performance of generic PV systems.
3. Compared the expected annual PV production to the actual annual PV production at Río Bayamón Housing.
4. Identified adjustment factors applied to annual PV production data at Río Bayamón Housing.
5. Compared the expected annual PV production to the adjusted annual PV production at Río Bayamón Housing.

3.1.1 Identify System Expectations

To identify the Coast Guard's expectations of the system, we utilized pre-installation metrics determined by Blue Oak Energy—a subcontractor of Schneider Electric—through a combination of simulations and historical data. These metrics were available in the Investment Grade Audit (IGA) and Renewable Energy Services Agreement (RESA). We assumed production from Río Bayamón Housing (RBH) accounted for approximately 20% of the production from all project sites. This factor was partially determined based on the size of the PV system at RBH relative to the size of the PV system across both project sites. Additionally, we considered the Year 1 estimated production for RBH, reported in the IGA Technical Assessment, relative to the Year 1 estimated production reported for both ESPC project sites.

3.1.2 Identify Key Performance Metrics

To identify system level factors that affected the performance of the Coast Guard’s PV system, we looked at how generic PV systems operate in order to get a better sense of what these factors do for the system. As explained in Section 2.4, the main components of a PV system are modules, an inverter, a utility meter, and a grid-tie. After identifying the components that make up the system, we examined the performance factors of each component and targeted the components that influenced the system's performance the most. Since solar production is highly dependent on sunlight, we investigated issues that stemmed from solar irradiance. We explored mechanical factors pertaining to solar irradiance data, such as module and inverter malfunctions, as well as pyranometer connection failure. We researched the uses of Schneider Electric's solar irradiance data and production data to estimate how much electricity the PV modules at RBH were expected to produce. During the Annual Measurement and Verification (M&V) Reports, Schneider Electric noted if the guaranteed data points differed from the values selected for the PV system models during the Investment Grade Audit, as explained in Section 2.11. We collected data from the IGA and M&V reports to form the basis of our analysis.

3.1.3 Analyze Photovoltaic System Actual Production

Actual annual PV production data was obtained from the annual M&V reports and converted to tabular form. The actual PV production for Year 1 through Year 4 was compared to the estimated annual PV production to determine if the actual annual PV production exceeded expectations or failed to meet expectations. The analysis enabled us to classify the PV system at RBH for each contract year as underperforming, meeting performance, or exceeding performance expectations. Table 1 describes our classification process.

Table 1

Actual Performance Classification Methodology for RBH PV System

Performance Classification	**Actual Production ÷ Estimated Production × 100%**
Exceeded Expectations	> 100%
Met Expectations	= 100%
Underperformed	< 100%

3.1.4 Identify Photovoltaic System Production Adjustment Factors

The annual M&V reports are used to assess if the guaranteed annual PV production, outlined in the RESA, was met. To reduce biases, adjustments were made to the actual production for factors such as solar insolation, loss of PV production due to power outages, and shading from vegetation. In line with the contract, no adjustments were made for equipment and system failure covered by product warranties or backed by the contract. To identify the adjustment factors impacting Río Bayamón Housing, we referenced the Year 1 through Year 4 M&V reports.

3.1.5 Analyze Photovoltaic System Adjusted Production

To analyze the impact of the adjustment factors applied to RBH production, we converted the annual adjusted PV production to tabular form. We then compared the annual adjusted PV production to the estimated annual PV production to determine if the PV system had the potential to meet or exceed expectations. We computed the difference between the adjusted and estimated PV production for each reporting year. Table 2 describes how we classified the system's potential.

Table 2

Adjusted Performance Classification Methodology for RBH PV System

Performance Classification	Adjusted Production ÷ Estimated Production × 100%
Had Potential to Exceed Expectations	> 101%
Had Potential to Meet Expectations	> 99% and < 101%
Expected to Underperform	< 99%

Key performance metrics identified through Section 3.1.4 were applied to our analysis. We examined the impact of each adjustment factor, such as grid outages and solar insolation, on the overall adjusted production for RBH. As shown in Table 2, we built in a one-percent range of error to account for potential human error made during Schneider Electric's adjustment process.

3.2 OBJECTIVE 2: COLLECT AND ANALYZE COST DATA

The second objective helped our team offer recommendations for system improvements, as well as contract alterations. In particular, we were interested in investigating costs incurred for PV production at Río Bayamón Housing and examining how electricity savings are presented to the Coast Guard. Based on contract Year 1 through Year 4 expenses and estimated future expenses, we sought to determine the potential savings of a net metering agreement. To provide feedback regarding the project contracts and agreements, our team completed the following steps:

1. Identified the annual costs to the Coast Guard using the Puerto Rico ESPC Task Order.
2. Compared the post acceptance performance period expenses to the cost of terminating the contract.
3. Analyzed the RESA rates with respect to historical crude oil rates.
4. Examined the benefits of a net metering contract.

3.2.1 Identified Annual Cost to the Coast Guard

The annual cost to the Coast Guard, contractually known as post-acceptance performance period expenses, includes RESA services payments and *regular* post-acceptance performance period expenses.

$$\text{Post-Acceptance Performance Period Expenses (\$)} = [S + P] \qquad (2)$$

where: S = RESA Services ($)

P = Regular Post-Acceptance Performance Period Expenses ($)

Regular post-performance period profit expenses covered management and administration, measurement and verification, and maintenance. A 15% interest and 15% post-acceptance performance period profit were included in the total regular post-acceptance performance period expenses.

Total Regular Post-Performance Period Profit Expenses (\$) = [((A + V + M) × 15%) × 15%] (3)

where:
A = Management and Administration (\$)
V = Measurement and Verification (\$)
M = Maintenance (\$)

The RESA services payment is the product of the adjusted annual production (kWh) and the RESA rate per kWh as defined in the RESA.

RESA Services (\$) = [Adjusted Actual Production (kWh) × RESA rate per kWh (\$)] (4)

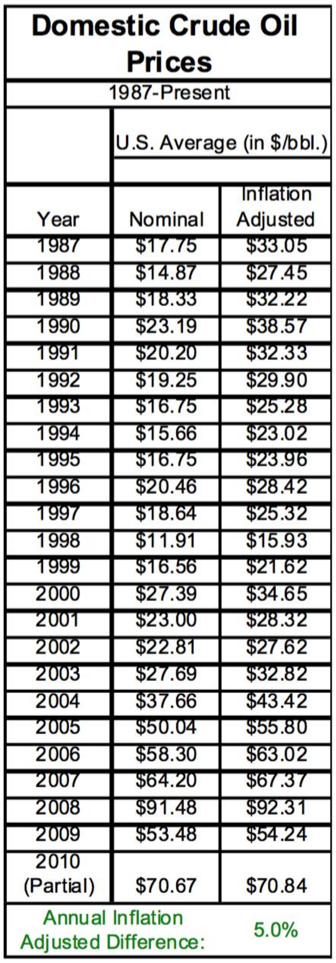
Post-acceptance performance period expense data was obtained from the annual M&V reports and Puerto Rico ESPC Task Order, within the IGA Price Proposal.

3.2.2 Analyzed RESA Rates

The RESA rates were determined by Schneider Electric and defined in the RESA. Schneider Electric examined crude oil prices for the past 23 years and came to the conclusion that a 5.0% increase per year was a fair rate. This crude oil breakdown used by Schneider Electric can be seen in Table 3.

Table 3

Historical U.S. Crude Oil Prices, Accounting for Inflation, used by Schneider Electric in the Calculation of RESA Rates



Domestic Crude Oil Prices

1987-Present

	U.S. Average (in $/bbl.)	
Year	Nominal	Inflation Adjusted
1987	$17.75	$33.05
1988	$14.87	$27.45
1989	$18.33	$32.22
1990	$23.19	$38.57
1991	$20.20	$32.33
1992	$19.25	$29.90
1993	$16.75	$25.28
1994	$15.66	$23.02
1995	$16.75	$23.96
1996	$20.46	$28.42
1997	$18.64	$25.32
1998	$11.91	$15.93
1999	$16.56	$21.62
2000	$27.39	$34.65
2001	$23.00	$28.32
2002	$22.81	$27.62
2003	$27.69	$32.82
2004	$37.66	$43.42
2005	$50.04	$55.80
2006	$58.30	$63.02
2007	$64.20	$67.37
2008	$91.48	$92.31
2009	$53.48	$54.24
2010 (Partial)	$70.67	$70.84
Annual Inflation Adjusted Difference:		5.0%

Source: (Vaughn, 2010c)

The price of electricity in Puerto Rico is highly dependent on the rate of crude oil, as a result of their fuel cost adjustment act (Vaughn, 2010c). To determine if the RESA rates were scheduled to increase at a fair rate, we ran through the same calculation stated in the IGA Price Proposal, and checked the listed sources. We examined the rates of crude oil in the U.S. that were available on a blog website, which Schneider Electric used to calculate the rate of increase. The website, inflationdata.com, is operated by a single individual, who upon research did not appear to be a noteworthy individual in the economics field.

To verify the quality of the source, we gathered historical crude oil rates from the U.S. Energy Information Administration (EIA) for 1987-2010, and compared them to the rates shown in the IGA Price Proposal (EIA, 2016a). We then used an inflation calculator available on usinflationcalculator.com to determine the average cost of crude oil with respect to the 2010 inflation rate. When using the inflation rate calculator, we inputted the crude oil averages obtained from the EIA to determine the cost of the crude oil in 2010. We choose to use the 2010 inflation rate to align our calculations with the IGA Price Proposal, which was completed in 2010. To verify the accuracy of the inflation calculator, we performed a sample calculation following the steps outlined by the Mathematical Association of America (Appelbaum, 2016):

$$\text{Inflation Adjusted Rate for 1987 (\%)} = [((218.06-113.6) \div 113.6) \times 100] = 92\% \quad (5)$$

This calculation was done using the consumer price indexes (CPI) for the base year and the year that required inflation rate calculations. The difference of the two years CPIs was then divided by the non-base year CPI in order to get the rate of change. This was then multiplied by 100 in order to convert the rate of change into a percentage to show the inflation adjusted rate between those two years. This rate was simply multiplied by any cost in the year 1987 in order to get the cost in 2010.

Once we calculated our own average inflation rate of US crude oil prices, we compared it to the 5% inflation rate used in the IGA Price Proposal computation. We compared the two inflation rates in order to find what the total difference in costs would be, had they used the EIA rates, rather than the rates gathered from the previously stated blog.

3.2.3 Compared Post-Acceptance Performance Period Expenses and Termination Costs

As stated in Section 3.2.1, post-acceptance performance period expenses include regular post-acceptance performance period expenses and the RESA services payment. To determine the viability of early termination of the RESA, we compared these annual expenses to the costs associated with early termination through system buy-out. We considered the cost of ongoing maintenance and system monitoring services that the PV system would require post-contract. The results of our RESA rate determination analysis were also a factor in our buyout comparison. This comparison was limited by our inability to predict future PREPA rates.

3.2.4 Examined Net Metering Contract Benefits

As of 2016, a net metering agreement has not been signed by both the Coast Guard and PREPA. We reviewed the drafted net metering agreement and discovered potential reasons for the delayed acceptance. We closely examined the Coast Guard's energy bills to determine if the Coast Guard was receiving an alternate type of energy credit for the electricity fed to the power grid. After understanding the current status of the agreement, we explored the benefits of completing the agreement. Using a small sample of monthly PREPA bills for RBH, we obtained a rough estimate for monthly consumption and electricity costs. We applied the results of our production cost analysis and RESA rates analysis to determine the losses attributed to the absence of a net metering agreement. To obtain a conservative estimate for the annual savings the Coast Guard could have received by adding a net metering agreement, we performed the following calculation:

$$\text{Estimated Loss (\$)} = [\text{Average Cost per kWh} * \text{Annual Photovoltaic Production (kWh)}] \quad (6)$$

The precision of our findings was significantly limited by the sporadic sample monthly PREPA bills for RBH and absence of monthly production data. It is important to note the goal of these estimates to convey the potential benefits of a net metering contract.

3.3 OBJECTIVE 3: BATTERY RESEARCH AND ANALYSIS

After completing the first and second objective, the Coast Guard will understand the historical performance of the PV system at Río Bayamón Housing and the associated costs. To assist Coast Guard personnel with future planning, we examined batteries as a potential option to provide power during power outages and reduce dependence on diesel generators. To determine if batteries were a viable option, the team completed the following steps:

1. Assessed the compatibility of available backup batteries with PV System at the Río Bayamón Housing.
2. Identified safety risks, required maintenance, and potential environmental repercussions the batteries would pose if installed.
3. Analyzed the potential costs of purchasing, installing, and maintaining a compatible backup battery system.

3.3.1 Assess Compatibility of Batteries with PV System at Río Bayamón Housing

As of 2016, Río Bayamón Housing loses electricity roughly four hours a week due to grid outages. To address this lack of reliability, we explored backup battery systems. The size and specifications of the PV system at Río Bayamón Housing are unique and identifying compatible backup batteries required substantial research. The tropical climate posed additional constraints as temperature and humidity impact a battery's ability to discharge power. In order to find potential backup battery options for the PV system at Río Bayamón Housing we examined the following factors:

1. Efficiency in deep cycle situation, as defined by 100% depth of discharge (DoD).
2. Performance variance in warmer climates.
3. Ability to hold electricity for extended periods of time.
4. Loss of battery capacity over twenty year period.
5. Voltage of the batteries.

We specifically chose these factors for our examination because they vary greatly depending on the type of battery. The specifics of these factors will be further explained in section 3.3.3 during the battery analysis.

3.3.2 Identify Safety Risks, Environmental Repercussions, and Required Maintenance

Safety and environmental concerns, as well as maintenance requirements, vary across types of batteries. These variations are the result of battery characteristics such as chemical composition and casings. To determine the safety risks and environmental repercussions, we examined the disposal process of the batteries identified through the steps outlined in Section 3.3.1. Ventilation requirements were also taken into consideration. Maintenance requirements were evaluated based on the frequency and time required to complete each task. Maintenance associated with underground battery placement and containment systems were factored into the analysis, with respect to the tropical climate. The number of batteries required to meet the Coast Guard's needs were also considered during this process. The specifics of these calculations are shown in the battery analysis of Section 3.3.3.

3.3.3 Analyze Cost of Compatible Batteries

We considered the potential costs to purchase and install batteries for three scenarios. Each scenario in the analysis was designed to support a different load factor for a four hour time span once a week, to address the current pattern of power outages. Load factor is essentially the number of kilowatts required to meet power requirements, which varies in the case of each scenario. In the first scenario we evaluated a battery bank with the capacity to provide enough electricity to meet all the power needs at RBH. The power required was estimated based on historical consumption. In the second scenario, we evaluated a battery bank which would power air conditioning, lighting and refrigeration. The final scenario included a battery bank capable of providing electricity to power only lighting and refrigeration.

For all scenarios, we calculated the efficiency of each battery, as determined through Section 3.2.1, in that specific environment. This enabled us to choose a cost-effective battery that would function as expected, after accounting for loss of efficiency. After finding a suitable battery type for each scenario we researched prices for a single battery that matched the specifications calculated. We then used the voltage of the system in order to find out how many batteries would be needed to match the PV system’s voltage, which was documented in the wiring diagrams in the ESPC Pre-Final Submittal. Using the results of the previous calculation, we computed the cost of the battery bank required for each housing block. Based on the cost of a battery bank per housing block, we estimated the cost of the total amount of batteries required for the entire housing complex in each scenario, while taking into account the varying amount of PV modules on some housing blocks. Below is a walkthrough of each calculation we took into account during the entirety of our battery cost-benefit analysis.

Step 1: Identify the voltage of the system.

The voltage of the system was calculated using the number of PV modules on each housing block, as shown in the wiring diagrams provided by Schneider Electric (Schneider Electric, 2010). Based on the information shown in the wiring diagram, we calculated the average number of PV modules on each housing unit (Schneider Electric, 2010). We then found the voltage of each individual PV module provided in the PV System Wiring Diagram (Schneider Electric, 2010; Vaughn, 2010b). This voltage was summed for each panel on a housing unit in order to get the average voltage of each system, since they are wired in series.

$$\text{System Voltage} = [V_1+V_2 + \ldots V_n] \quad (7)$$

Step 2: Calculate the required number of batteries.

In order to calculate the number of batteries needed, the voltage of the system needed to be matched. Also, the batteries must maintain the amount of amp-hours needed to power desired appliances (Albright, Edie & Al-Hallaj, 2012). We decided to research batteries with the proper amp-hours required and wire them in series in order to match the system's voltage. We chose to wire the batteries in series because it was significantly easier to find large amp-hour batteries than it was to find batteries with a high enough voltage to match each housing block's system.

After deciding to wire in series, we calculated the necessary amount of batteries for two battery options: 12-volt and 48-volt. We calculated the amount of batteries needed by taking the voltage of the total system as calculated in Step 1, and dividing it by the voltage of each battery type.

# of Batteries Required = [System Voltage ÷ Voltage of Battery] (8)

Step 3: Account for battery charge time.

We wanted to make sure that the batteries in every scenario had sufficient time to fully charge to avoid unnecessary degradation of battery efficiency, as well as making sure our estimated battery size was as accurate as possible. As a result, we found data for the average amount of sunlight per week in the general area of the Río Bayamón housing complex. We then calculated the average weekly sunlight for the area in order to compare the necessary charging time of each option. We calculated the average sunlight on a weekly basis in order to account for an estimated backup system use of one time a week, for a four hour period.

Charging Time (Hrs) = [Amp-Hours ÷ System Current (A)] (9)

We then needed to make sure that the battery had sufficient time to charge, taking into account the length of discharge and amount of sunlight.

Extra Charge Time Buffer (Hrs) = [WSH - Charge Time - Discharge Rate] (10)

where: WSH = Weekly Sunlight Hours

If a battery did not have more than 20 hours worth of extra charging time, we did not include it in our analysis. This was to ensure that even in the case of a week with below average amounts of sunlight, the batteries would still be fully charged.

Step 4: Calculate Amp hours of batteries needed to power desired appliances.

In order to find the correct sized batteries corresponding to each analysis scenario we created, we first calculated the electricity used by each desired appliance. We did this using a combination of the Schneider Electric Air Conditioner Specifications, and online usage calculators (Vaughn, 2010c; Consumer Power Incorporated, 2016). We then used the following formula to convert the kWh being used into Amp hours (AH) needed for a battery to power the corresponding appliances.

$$\text{Required AH} = [\text{Total kWh} \times (1000 \times \text{System Voltage})] \quad (11)$$

Step 5: Calculate any inefficiencies of batteries.

Different types of batteries had varying inefficiency rates for distinct pieces of the charging and discharging process. The first calculation made was regarding the natural self-discharge of lithium ion batteries, which is as follows.

$$\text{NSD} = [((5\% \div 24 \text{ hours}) \times (\text{\# of hours}) + (1.5\% \times \text{\# of months}) + (3\%))] \quad (12)$$

where: NSD (%) = Natural self-discharge rate

We also calculated the natural self-discharge of lead acid batteries using the following formula.

$$\text{NSD} = [(5\% \times \text{\# of months})] \quad (13)$$

where : NSD (%) = Natural self-discharge rate

This calculation was used in combination with each battery rate for discharge efficiency, in order to find the necessary battery capacity after efficiency loss was added and to properly power the required appliances. The formula we used to calculate the necessary capacity, or amount of amp hours needed for each battery is shown below.

$$\text{Required Battery Capacity (AH)} = [(\text{Required AH} + \text{NSD} + \text{DE})] \quad (14)$$

where : NSD (%) = Natural self-discharge rate

DE (%) = Discharge efficiency rate

Step 6: Calculate total Battery Costs.

In order to calculate the total battery cost for the entirety of the housing complex, we found batteries that matched the electrical capacity size, which was calculated in step 5. We then found the number of housing blocks that have PV systems, as well as the parking structure as stated in the PV System Wiring Diagram (Schneider Electric, 2010). We used the following formulas to calculate the total cost of the batteries needed for the entire housing complex.

$$\text{BCPHB} = [(\text{Cost of battery} \times \text{\# of batteries})] \qquad (15)$$

where: BCPHB ($) = Battery cost per housing block

\# of batteries = number of batteries required to match system voltage

Finally, we used the following formula to estimate the cost of batteries for the entire housing complex.

$$\text{RBH Cost} = [(\text{BCPHB} \times 28)] \qquad (16)$$

Where: BCPHB ($) = Battery cost per housing block

RBH Cost ($) = Cost of implementation across Río Bayamón housing complex

We used 28 batteries for our formula due to the amount of housing blocks, including the parking garage, based on the 11 module average for each housing block's system.

4. FINDINGS AND ANALYSIS

Through a combination of research, document review, and the creation of multiple cost-benefit analyses, we classified the performance of the PV system at Río Bayamón Housing (RBH), determined the costs associated with the existing contracts, and completed a thorough assessment of backup battery options. Each key finding is presented in this chapter along with a summary of evidence, explanation, and an analysis which reflects our insight. This chapter is divided into three parts:

1. Photovoltaic System Production
2. ESPC Cost Analysis
3. Battery Research and Cost-Benefit Analysis

4.1 PHOTOVOLTAIC SYSTEM PRODUCTION

Finding #1. The photovoltaic system at Río Bayamón Housing produced less power annually than originally estimated.

Summary of Evidence. Descriptive data analysis was applied to annual production data sets obtained from Annual Measurement and Verification (M&V) Reports delivered to the Coast Guard by Schneider Electric. Comparing actual production data for Río Bayamón Housing for Year 1 through Year 4 to estimated production data indicated that the photovoltaic system is underperforming. The actual production was approximately 2.5%, 9.5%, 10.8%, and 8.8% less than estimated for Year 1 through Year 4 respectively. The actual and estimated annual production is depicted in Figure 8.

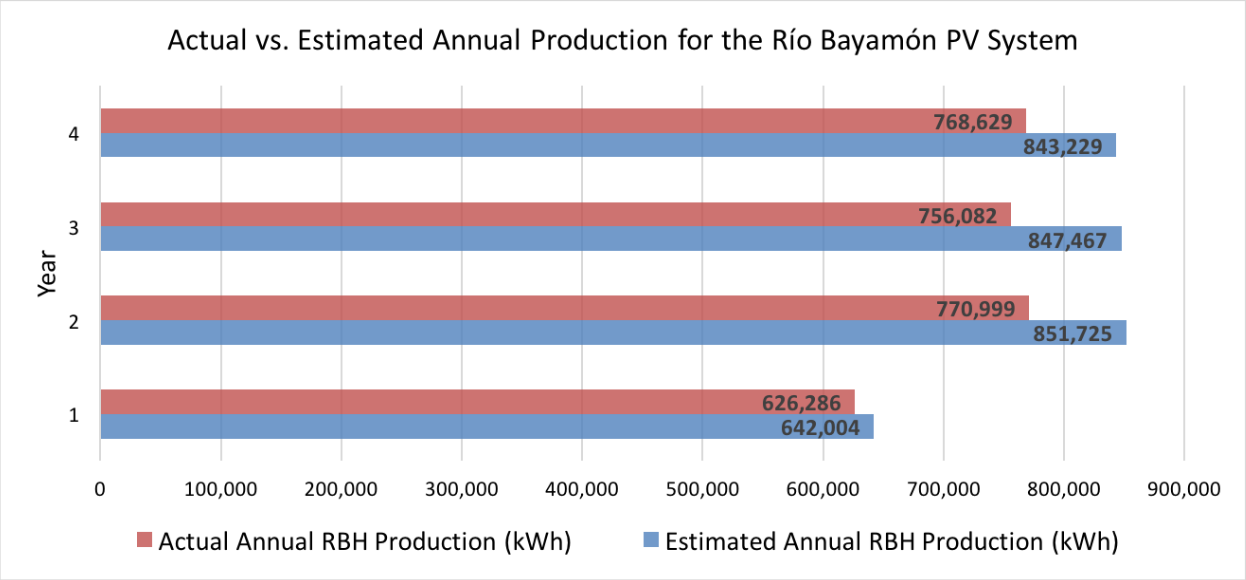


Figure 8. Actual vs Estimated Annual Production at RBH for the First Four Contract Years

Explanation. The annual M&V reports provided by Schneider Electric included required savings adjustments as well as performance, operations, and maintenance issues. All reporting years experienced occasional inverter failure and sub-system downtime. During Year 1 and Year 2, these mechanical issues were less of an issue than expected. Reports from subsequent years indicate only some of the inverter failure and sub-system downtime was anticipated. Additionally, all solar panel and inverter combinations experienced clipping at high irradiance values every reporting year. When clipping occurs, the photovoltaic system produced less power during peak sunlight hours. The reports indicated the impact of clipping on production is minimal, and it is hypothesized that these issues are related to the weak utility grid.

Analysis. Based off of our findings, the PV system is not meeting the Coast Guard's production expectations overall. The majority of these factors are out of the Coast Guard's control. Future M&V reports may provide more insight regarding hindering factors.

Finding #2. The photovoltaic system at Río Bayamón Housing had the potential to produce more power Year 1 than originally estimated after adjustments were made. Years 2 and 3 did not have the potential to produce the estimated amount of power, even after adjustments were made.

Summary of Evidence. The annual M&V reports include adjusted annual production data to account for factors influencing decreased production. The Year 1 M&V Report included an adjustment for solar insolation (irradiance). The adjustment accounted for 38,728 kWh, or 6% of the estimated annual production. The adjusted annual production and estimated annual production for Year 1 is depicted in Figure 9.

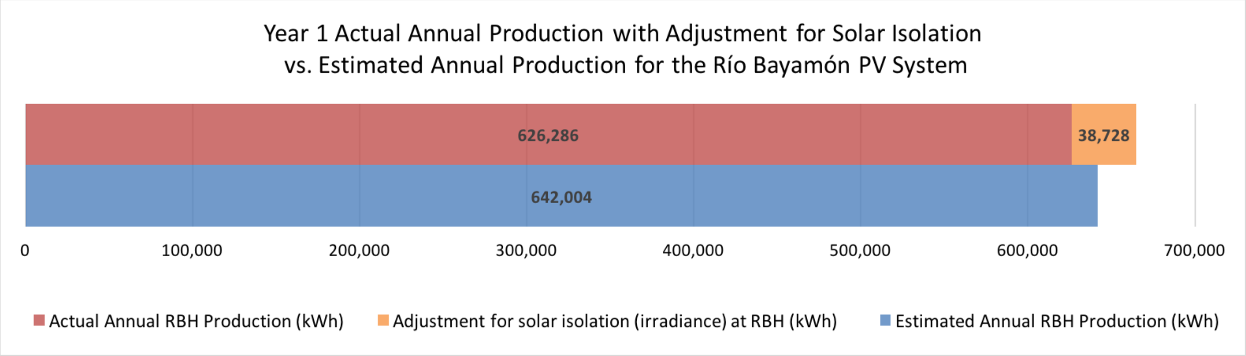


Figure 9. Year 1 Actual Annual Production with Adjustment for Solar Insolation vs. Estimated Annual Production for the Río Bayamón PV System

Years 2 and 3 included adjustments made for solar irradiance as well. The Year 2 adjustment of 74,366 kWh accounts for 8.7% of the expected annual production at RBH. The Year 3 adjustment of 10,871 kWh accounts for only 1.3% of the expected annual production. The adjusted annual productions and estimated annual productions for Year 2 and Year 3 are depicted below in Figure 10.

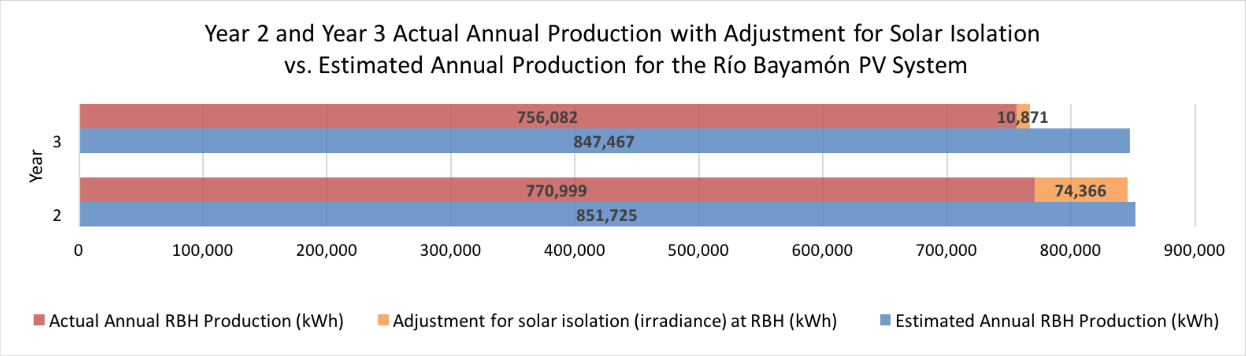


Figure 10. Years 2 and 3 Actual Annual Production with Adjustment for Solar Insolation vs. Estimated Annual Production for the Río Bayamón PV System

Explanation. The expected solar irradiance was based on a simulation ran by Schneider Electric in the Investment Grade Audit (IGA) Technical Assessment. Schneider Electric used the original simulation as a baseline, as explained in Section 2.11, and then adjusted for factors that fell outside of the pre-defined range. The production as needed based on the actual measurements received. The adjustments are made based on a certain range of variance away from the expected radiance. Low irradiances lead to a decrease in the efficiency of the system lowering the system output (Mermoud & Wittmer, 2016). In all the cases of Years 1 through 3, the housing complex was out of the calculated range on the lower side of production, causing the annual adjustments to be made. Clipping due to high solar irradiance and pyranometer connection failure as described in the M&V report, were a primary factor in decreased production for contract Years 1 through 3. These issues created gaps in solar irradiance data making the process of calculating production impossible without omitting these gaps.

Analysis. Based off our findings, during the first year of production, the PV system did not meet the Coast Guard's expectations based on a raw data point of view. The issue, however, was caused by a factor outside of the Coast Guard's control. As a result of the varying factor causing the difference in actual and expected values being out of the Coast Guard's control, Schneider Electric made an adjustment to account for it. When taking into account the PV production, as well as the adjustments for solar irradiance, the PV system did in-fact have the potential to exceed the Coast Guard's expectations. Contract Years 2 and 3 were similar, in the fact that they did not meet the Coast Guard's expectations based on a raw data point of view. Adjustments were made as a result of lack of solar irradiance data based on clipping from high solar irradiance and pyranometer connection failure for Years 2 and 3, however even with these adjustments the PV system did not have the potential to meet the Coast Guard's expectations.

4.2 ESPC COST ANALYSIS

Finding #1. A signed net metering agreement would make it possible for the Coast Guard to generate savings from the ESPC. Without a net metering agreement, no money is saved.

Summary of Evidence. During our research we discovered that a net metering agreement was never signed by both the Coast Guard and PREPA. The IGA and RESA were assembled with the assumption a net metering agreement would be signed between PREPA and the Coast Guard. The process was initiated, yet has not been completed to date.

Explanation. We utilized the Puerto Rico ESPC Net-Metering Contract Status Executive Summary (2016) to assess the status of the net metering agreement between PREPA and the Coast Guard. During our research, we found that a net metering agreement was provided to the Coast Guard by PREPA in 2011 and was ready for review by the Coast Guard legal team. The agreement was then revised by the Coast Guard legal team and comments were made revising the contract in 2012. More revisions to the contract were made in 2014 by the Sector San Juan Logistics Department Head. In 2015, the updated net metering agreement reflected these revisions. The agreement is still under review to date. Based on limited consumption data, we determined the Coast Guard could have saved approximately $380,000 during contract Year 1 and 2, had a net metering agreement been in place. This estimate was determined by comparing a four month span of consumption data obtained from monthly PREPA bills to the actual annual production data for corresponding contract years. Based on estimated production published in the Investment Grade Audit, we estimate that the Coast Guard could save at least $100,000 annually if a net metering agreement were in place at both RBH and ASH. This conservative estimate assumes they are able to receive energy credits for 100% of the electricity they produce, that they produce at least 90% of the estimated production as stated in the RESA, and that PREPA rates stay above \$0.03/kWh. This calculation was performed based on the last final contract year's estimated production, which has the lowest estimated production. If the production exceeds consumption, no credit is received for the excess consumption. Additionally, PREPA has varying rates per kWh as discussed in Section 2.1. As a result, the average price per kWh could differ for total consumption and net consumption. An exact annual savings calculation would require consumption data for a consecutive twelve month period and corresponding monthly production data since the total net consumption is computed monthly. Based on our conservative estimate, we predicted that over the course of the contract, the absence of a net metering agreement could result in millions of dollars lost.

Analysis. Without a net-metering agreement, the Coast Guard will continue to pay Schneider Electric for 100% of the electricity they produce and PREPA for 100% of the electricity they consume. If a net metering agreement were in place, the Coast Guard would pay the difference between their consumption and PV production. If consumption exceeds PV production, a net metering agreement leads to monthly savings. Electricity consumption at RBH consistently exceeded the electricity produced by the PV system. As a result, without a net metering the Coast Guard essentially pays twice for the electricity produced by the PV system. By signing a net metering agreement the Coast Guard would stop paying twice for the electricity they produce. Additionally, if the PREPA rates exceed the rates determined in the RESA, the Coast Guard would pay less for a portion—matching the electricity they produce—of the electricity they consume. In summary, a net metering agreement would reduce the amount the Coast Guard pays to PREPA for electricity.

Finding #2. The RESA rates have exceeded the PREPA rates for contract Year 2 through Year 4.

Summary of Evidence. We broke down the steps shown by Schneider Electric in the RESA rate calculations, in order to create an assessment of the RESA rates. We looked through all of the claims, calculations and data used to generate the RESA rates in order to better understand how Schneider Electric came to the final calculations. We then completed our own calculations based on PREPA pricing, and compared the rates we calculated to the RESA rates.

Explanation. Schneider Electric first bases the rate calculation on the fuel cost adjustment (FCA) clause, put into place by PREPA. This formula is what PREPA used to determine their costs kWh. The formula relies heavily on crude oil, in order to calculate the current cost of electricity (PREPA, 2012). Due to this fact, Schneider Electric used the average US crude oil rates pulled from a website blog (McMahon, 2015), in order to calculate the average rate of energy inflation in general. After doing background research on the source, and the author, we felt that it was not a completely reliable source. We then pulled up the government recorded rates from the U.S Energy Information Administration (EIA) and compared the rates for each site (EIA, 2016a; McMahon, 2015). Upon comparison, we found that after inflation, the historical costs of crude oil on the website used by Schneider Electric was approximately $5.70 more expensive per barrel than the EIA page, on average. Although that amount may seem insignificant, it actually caused a 7.8% increase in the 2010 price of crude oil alone.

The historical rates Schneider Electric pulled from the blog stated previously were then used to calculate the average rate of inflation, to be applied to future years of the contract. Based on the historical crude oil prices, Schneider Electric calculated a rate of 5% inflation per year. This is the reasoning behind why the Coast Guard's rate of kWh increases 5% for each year of PV system contract. This rate is actually more than fair when comparing it to the inflation rate of PREPA. Although the oil prices stated by the EIA were lower than the rates found by Schneider Electric, due to extreme fluctuations from year to year, the oil prices on the EIA website experienced an inflation of roughly 16% during the same time period.

Analysis. Based on our calculations and walkthrough of the RESA rate determination, we did find the historical data used by Schneider Electric varied greatly from the data kept by the U.S.

government. With that in mind, Schneider Electric's use of the varied rates ended up benefiting the Coast Guard, which allowed them to receive a lower inflation rate then PREPAs average. The reasoning as to why the kWh rate the Coast Guard is paying for PV production is higher the PREPA rates is due to multiple annual drops in crude oil pricing.

Finding #3. **Production and cost analyses for contract Year 1 through Year 4 did not provide sufficient evidence to support or oppose early contract termination through system buyout.**

Summary of Evidence. Early termination through system buyout is an option at the conclusion of contract Year 5. We examined the RESA, IGA, annual M&V reports, and a sample of PREPA bills to assess the benefits and consequences of this option. The cost analysis considered the early termination fees, RESA and PREPA rates, as well as recurring costs such as maintenance by a third-party. However, this cost-analysis was inconclusive. It is difficult to predict how PREPA rates will change in the future. Therefore, it is not plausible to accurately measure how the RESA rates and PREPA rates compare. The monitoring services provided by Schneider Electric are one of the greatest benefits to the Coast Guard of upholding the contract. Currently there are no Coast Guard personnel stationed in San Juan trained to operate, maintain, and monitor the PV system. The annual M&V reports provide extensive insight regarding the system's performance, and it may be difficult to obtain this service from another party. Furthermore, without a net metering contract no actual savings can be obtained, with or without system buyout.

Explanation. Under the existing contract, maintenance, operations, administration, and performance verification are the responsibility of Schneider Electric. Regular post-performance period expenses, as discussed in Section 3.2.1, and RESA services expenses combined pay for these services and indirectly pay for the PV system in installments. The RESA services expenses make up the majority of the total annual expense to the Coast Guard. Since these services are billed per a kilowatt hour, a net metering agreement would significantly change the outcome of any cost analysis pertaining to system buyout. If a net metering contract is implemented and the RESA rates are similar to or less than the PREPA rates, buying out the system would likely result in additional costs to the Coast Guard.

Analysis. It is difficult to determine the savings because the benefits of system buyout are highly dependent on multiple factors, including but not limited to changing PREPA rates and the status of a net metering agreement. We recommend reassessing this option periodically as more production and expense reports becomes available.

4.3 BATTERY RESEARCH AND COST-BENEFIT ANALYSIS

***Finding #1*:** Only batteries providing partial electricity for less than eight hours a week are plausible to implement at RBH.

Summary of Evidence. We analyzed multiple scenarios regarding discharge time and battery capacity. We researched backup battery power capabilities for RBH electronic needs. We calculated the amount of power needed to provide enough electricity to completely power the housing complex. We investigated other scenarios where only certain electronic needs would be met.

Explanation. A backup battery bank that can provide large amounts of electricity for extended periods of time is not a viable option due to cost and charge time of this type of battery. Although the price per amp hour of a battery decreases as the size of the battery bank increases it is not worth the investment to get a larger battery bank, because the Coast Guard only needs to provide power for short outages.

Charging time is a restriction due to the amount of energy produced by the solar panels on each housing block. The charging time is limited due to the maximum current which is flowing through the system, the current being 8.55Amps. If the battery was installed in parallel to increase the cycle life, then the battery would only receive a current of 4.27Amps. Below is a graph, that shows the battery charge time in each scenario, compared to the average amount of weekly sunlight in the area of the housing complex.

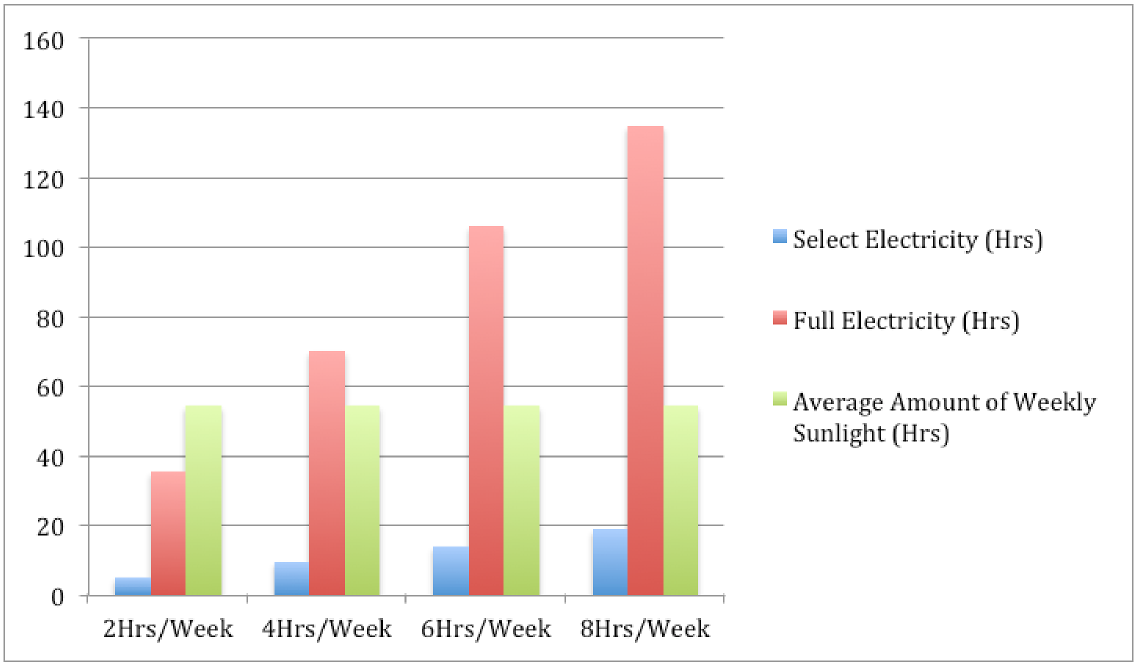


Figure 11. Sunlight Hours vs Necessary Battery Charging Time. Source: (Time and Date, 2016; MIT Electric Vehicle Team, 2008)

In Figure 11 shown above, the selected electricity refers to a scenario where only the lights, refrigerator and air conditioner would be powered by a battery. The graph shows the partial electricity option is more cost efficient than using a battery to completely power a housing block. Fully charging the battery affects the efficiency of the battery. Repeatedly partially charging a battery would continue to decrease the potential electricity the battery can discharge.

Analysis. Based on the statistics around the charging and costs of each type of battery, it would be most beneficial to only consider using a battery that can power the lights, refrigerator and air conditioning for no more than 8 hours at the housing complex. By doing this it will give the Coast Guard the most cost efficient scenario as well as the best backup electricity availability.

Finding #2. 12 and 48 Volt batteries are the best options for storing electricity generated from the PV system at RBH.

Summary of Evidence. Our team researched implementing batteries in the PV system for renewable energy storage purposes. We investigated the PV system at RBH to understand the specifics of the system in order to find a battery bank that satisfied all of the system needs. We investigated different types of batteries purely based on matching the PV systems voltage output. We researched common types of battery voltages and the amount of batteries needed to handle the system's voltage output. Finally, we calculated the most cost efficient scenario for adding a battery bank to the PV system at RBH.

Explanation. During our teams' battery research, we discovered that rewiring the system to add a battery component was possible. We found that the PV system at RBH was wired in series. This discovery allowed our team to calculate the total voltage the system outputs. We calculated that the system outputs on average 330 Volts of electricity. From this information, we researched batteries that could be used in a battery bank that could handle 330 Volts of electricity. We created a spreadsheet of different voltage batteries and considered the price of a single battery as well as the number of batteries needed to match the 330 Volts the PV system requires.

Analysis. We found that in comparison, 12 and 48 Volt batteries were the best electricity storage option for the Coast Guard at RBH. During our research for batteries to satisfy a large voltage system, 12 and 48 Volt batteries were frequently marketed. Because these batteries were well marketed, we were able to compare many different types of 12 and 48 volt batteries to find an option that was economically beneficial as well as feasible. We found that twenty-eight 12 Volt batteries and seven 48 Volt batteries were cheaper options than other voltage batteries. From this we continued our battery research only considering 12 and 48 Volt batteries.

Finding #3. Flooded lead acid batteries aren't a viable option for the PV system at RBH.

Summary of Evidence. Our team investigated installing lead acid batteries to store the electricity produced by the PV system. We researched different categories of lead acid batteries to find the best option for the system. We investigated the benefits of each type of battery as well as the limitations of the batteries. We also considered the environmental impact of the batteries and the maintenance and labor factors that would occur with each type of battery. We finally researched the price of each battery so that we could create the best recommendation for the Coast Guard.

Explanation. Our team explored different types of batteries that could be implemented into the Coast Guard's PV system. We found that one of the most common types of batteries on the market was lead acid batteries. After more research, we found that there were different types of lead acid batteries that could be used within the PV system. The two types of batteries we based our analysis on were flooded lead acid batteries and sealed lead acid batteries.

Flooded and sealed lead acid batteries have many similarities, including a high temperature sensitivity. As a result, flooded and sealed lead acid batteries require a temperature regulated containment system in order to perform optimally at the housing complex. The containment system is an added expense when considering possible installation of a lead acid battery in general. In addition to lead acid batteries needing a temperature regulated containment unit, flooded lead acid batteries, in particular, require a fair amount of maintenance to to their aqueous nature. The chemical reaction inside them requires water to occur, which is why the maintenance of flooded lead acid batteries consists of renewing the water supply.

Not only is the maintenance an added complication of using flooded lead acid batteries, but the chemical reaction that occurs inside of them causes a complication as well. The chemical reaction inside of a flooded lead acid battery, emits a gas, which then needs to exit the batteries casing through its ventilation system. This resulting gas does have a small environmental impact, and when considering a product of this scale there would be a fairly significant negative impact on the environment.

Analysis. The previously stated restrictions that flooded lead acid batteries present would be a large inconvenience to the Coast Guard, as it would be difficult to get to each individual battery once enclosed inside of a large containment unit. The cost is also increased when considering flooded lead acid batteries, as not only would containment systems need temperature regulation, but a ventilation system as well. In addition to required maintenance, the environmental impact caused by flooded lead acid batteries would negate the money being spent to implement a renewable backup energy source in order to benefit the environment.

Finding #4. Lithium ion batteries perform at a higher level than sealed lead acid for a longer period of time.

Summary of Evidence. We completed a performance analysis based on factors that affect the overall performance of each type of battery, if it were to be installed at RBH. This analysis included cycle life, temperature sensitivity and discharge efficiency. Using these different factors we were able to find the type of battery that would function the best according to the needs of the Coast Guard's housing complex.

Explanation. There are many factors that alter the performance of each type of battery, which differ largely when considering environmental factors. These factors are shown below in Table 4

Table 4

Breakdown of Battery Compatibility Factors

Battery Types	**Lithium Ion**	**Lead Acid**
Cycle Life	2,000 @ 100% DoD	1,000 @ 50+% DoD
Temperature Sensitivity	Degrades @ > 115F	Degrades @ > 77F
Discharge Efficiency	100% @ 20hr rate 99% @ 4hr rate	100% @20hr rate 80% @ 4hr rate

Natural Self-Discharge	8% in 24hrs, then 1.5% per month	5% per month

Source: (Albright, Edie & Al-Hallaj, 2012)

As shown in the previous Table 4, lithium ion batteries are made to have a much longer cycle life when maintaining a 100% depth of discharge (DoD). DoD is a very important aspect to note when considering backup battery systems. In a backup battery situation, the battery system must have a DoD of 100%, or close to it to be effective. Lithium ion batteries have a lower temperature sensitivity than that of lead acid batteries. The difference before degradation of the two battery types is almost 40 degrees fahrenheit. Based on that difference lithium ion is better suited for a warmer climate.

Discharge efficiency of a battery is a critical attribute to acknowledge when considering the implementation of a backup battery system. We based the performance analysis on a 4-hour discharge efficiency to simulate the given scenario of a weekly power outage lasting roughly 4 hours in the case of RBH. When investigating the 4-hour discharge efficiencies, lithium ion has a 19% better efficiency rate than sealed lead acid batteries.

The final performance factor that we considered in the analysis was the natural self-discharge rate of each battery type. This factor is often important when considering a backup situation, as backup batteries need to hold electricity for a longer period of time than a non-backup battery scenario.

The Coast Guard's backup system would only need the batteries to store their electricity for roughly one week. Based on this situation a lithium ion battery would actually lose 7% more of its total charge than the lead acid option.

After all of these calculations were taken into account, based on the situation at RBH a lithium ion battery would perform at roughly 90.5% efficiency, while lead acid would perform at roughly 78.5% efficiency. This means that when the environmental factors and situational requirements were taken into account lithium ion batteries performed much closer to their theoretical performance than lead acid batteries.

Analysis. The factors considered in our performance analysis showed both types of batteries having advantages in certain areas based on the given scenarios, however overall the performance shows lithium ion as a better option. When taking into account every factor of the performance analysis lithium ion was overall the best choice.

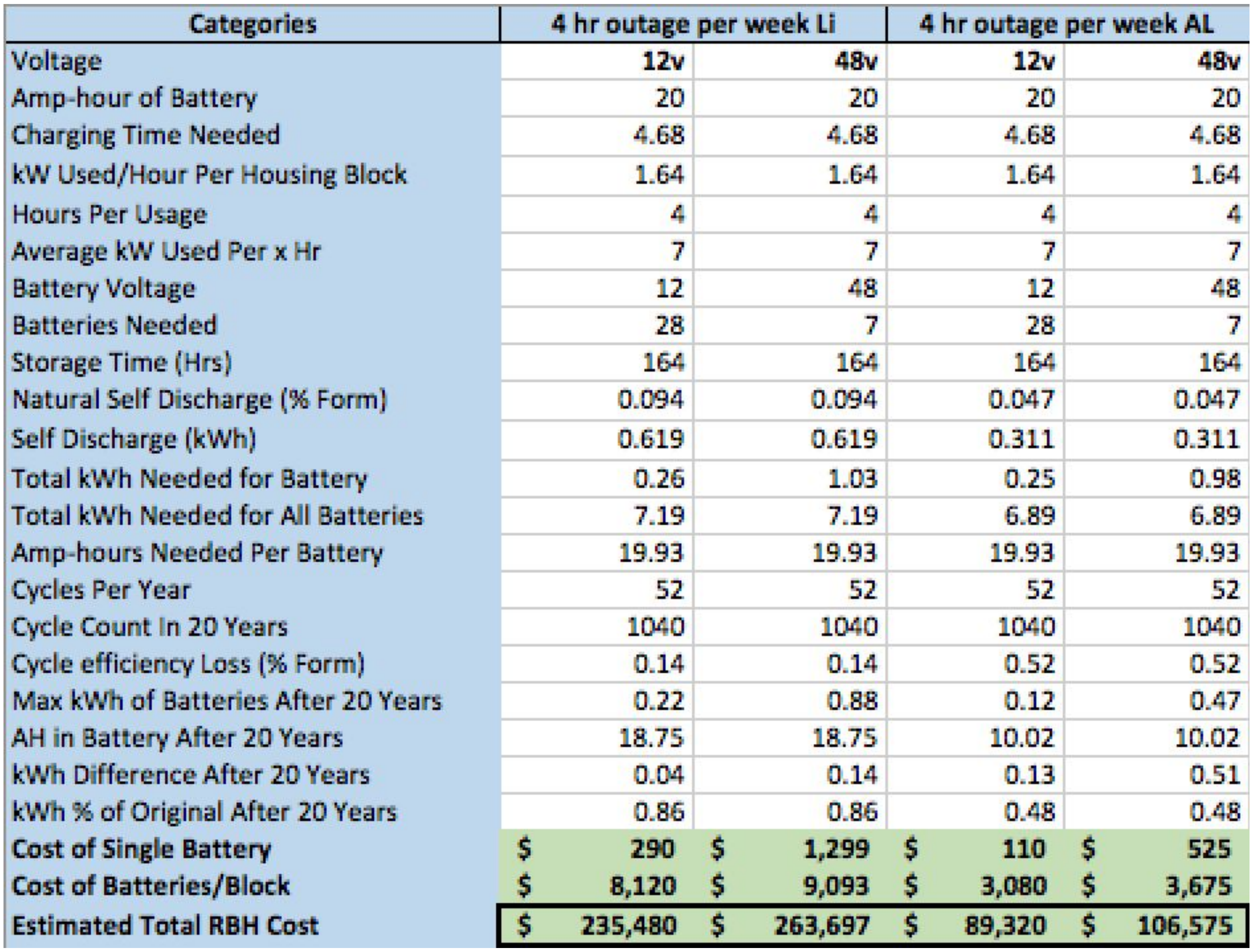
Finding #5. The cost of lithium ion batteries outweighed its performance advantages over sealed lead acid batteries.

Summary of Evidence. Throughout our battery analysis we compared different factors of lithium ion batteries to those of sealed lead acid batteries, within different scenarios. We compared any information relevant to the Coast Guard's situation that would affect battery performance, from temperature sensitivity, to cycle life, to maintenance needs. We combined the performance analysis with a cost analysis of the battery types to see which option would be the best overall choice when considering all elements and requirements involved in the given scenario.

Explanation. Lithium ion batteries outperform lead acid batteries, as shown in the performance analysis in Table 4. The other large advantage that lithium ion batteries have over lead acid is that all lithium ion cells are deep cycle, whereas only certain more expensive types of sealed lead acid batteries are. However, even when taking deep cycle into account sealed lead acid batteries are considerably less expensive than lithium ion batteries. A very important aspect to consider is the cost compared to performance over a large period of time of the two types of batteries. By comparing these batteries over a span of 20 years it is clear to see the difference in cost of each battery, after taking into account the performance inefficiencies based on RBH requirements. We chose 20 years as an appropriate time span because that is the calculated lifespan for lead acid batteries in the given scenario. In Table 5 below, it is clear that the best option for lithium ion batteries is significantly more expensive than the best option of lead acid battery, even when taking performance inefficiencies into account.

Table 5

Lithium Ion vs AGM Lead Acid Cost Analysis for Lighting and Refrigeration



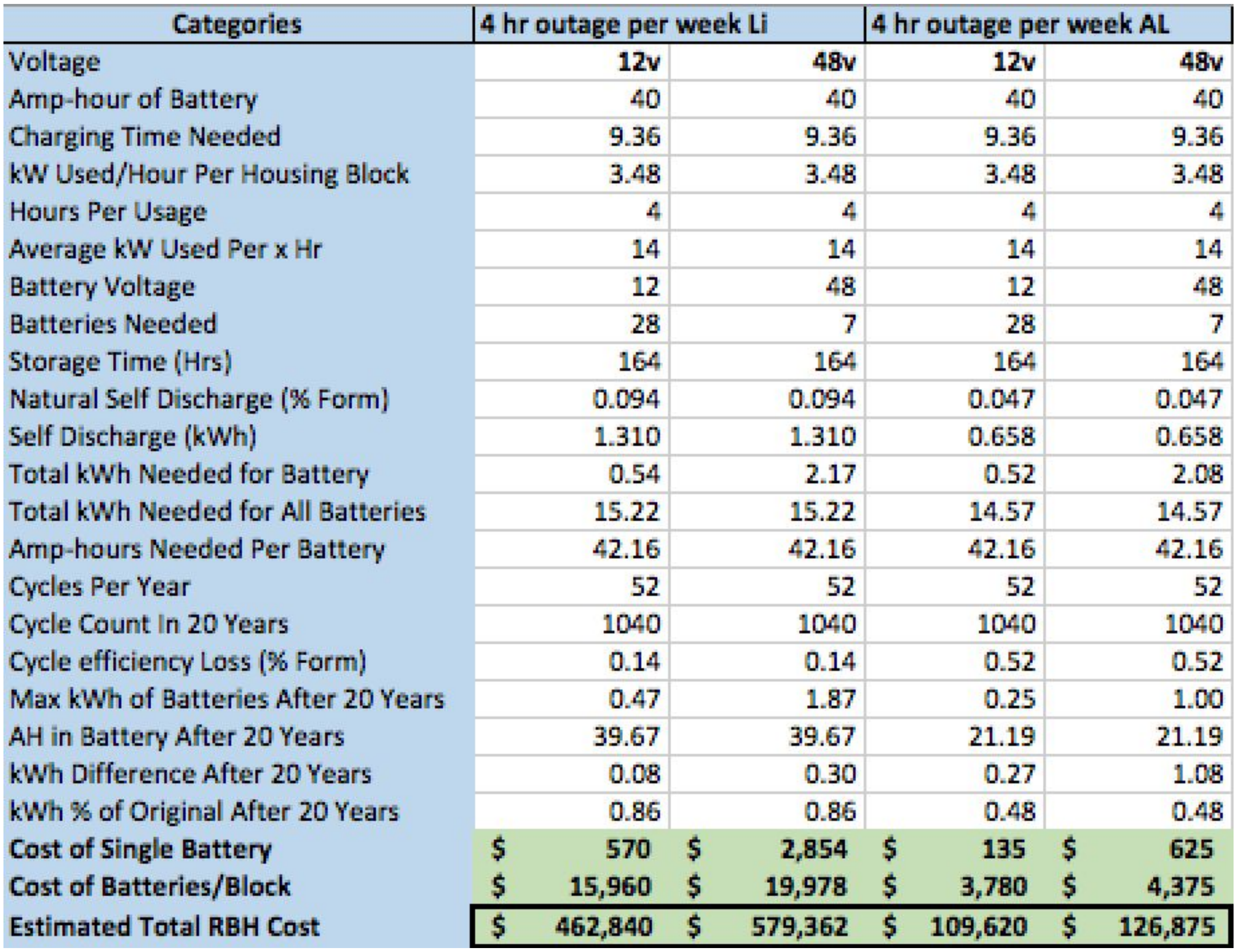
Categories	4 hr outage per week Li		4 hr outage per week AL	
Voltage	12v	48v	12v	48v
Amp-hour of Battery	20	20	20	20
Charging Time Needed	4.68	4.68	4.68	4.68
kW Used/Hour Per Housing Block	1.64	1.64	1.64	1.64
Hours Per Usage	4	4	4	4
Average kW Used Per x Hr	7	7	7	7
Battery Voltage	12	48	12	48
Batteries Needed	28	7	28	7
Storage Time (Hrs)	164	164	164	164
Natural Self Discharge (% Form)	0.094	0.094	0.047	0.047
Self Discharge (kWh)	0.619	0.619	0.311	0.311
Total kWh Needed for Battery	0.26	1.03	0.25	0.98
Total kWh Needed for All Batteries	7.19	7.19	6.89	6.89
Amp-hours Needed Per Battery	19.93	19.93	19.93	19.93
Cycles Per Year	52	52	52	52
Cycle Count In 20 Years	1040	1040	1040	1040
Cycle efficiency Loss (% Form)	0.14	0.14	0.52	0.52
Max kWh of Batteries After 20 Years	0.22	0.88	0.12	0.47
AH in Battery After 20 Years	18.75	18.75	10.02	10.02
kWh Difference After 20 Years	0.04	0.14	0.13	0.51
kWh % of Original After 20 Years	0.86	0.86	0.48	0.48
Cost of Single Battery	**$ 290**	**$ 1,299**	**$ 110**	**$ 525**
Cost of Batteries/Block	**$ 8,120**	**$ 9,093**	**$ 3,080**	**$ 3,675**
Estimated Total RBH Cost	**$ 235,480**	**$ 263,697**	**$ 89,320**	**$ 106,575**

Source: (Batteries, 2016; Energy Matters, 2007; Albring, Edie & Al-Hallaj, 2012; Retriev, 2016; Brouwer, Gupta, Honda, Zargarian, 2011; Consumer Power Incorporated, 2016; Rapid Tables, 2016; Wholesale Solar, 2016; Stark Power, 2016; Civic Solar, 2016; The Lithium Battery Company, 2016; Battery Stuff, 2016).

The same statement holds true even when analyzing the scenario of powering refrigeration, lighting and air conditioning for a four hour period on a weekly basis. The analysis and pricing for this scenario can be seen in Table 6 below.

Table 6

Lithium Ion vs AGM Lead Acid Cost Analysis for Air Conditioning, Lighting and Refrigeration



Categories	4 hr outage per week Li		4 hr outage per week AL	
Voltage	**12v**	**48v**	**12v**	**48v**
Amp-hour of Battery	40	40	40	40
Charging Time Needed	9.36	9.36	9.36	9.36
kW Used/Hour Per Housing Block	3.48	3.48	3.48	3.48
Hours Per Usage	4	4	4	4
Average kW Used Per x Hr	14	14	14	14
Battery Voltage	12	48	12	48
Batteries Needed	28	7	28	7
Storage Time (Hrs)	164	164	164	164
Natural Self Discharge (% Form)	0.094	0.094	0.047	0.047
Self Discharge (kWh)	1.310	1.310	0.658	0.658
Total kWh Needed for Battery	0.54	2.17	0.52	2.08
Total kWh Needed for All Batteries	15.22	15.22	14.57	14.57
Amp-hours Needed Per Battery	42.16	42.16	42.16	42.16
Cycles Per Year	52	52	52	52
Cycle Count In 20 Years	1040	1040	1040	1040
Cycle efficiency Loss (% Form)	0.14	0.14	0.52	0.52
Max kWh of Batteries After 20 Years	0.47	1.87	0.25	1.00
AH in Battery After 20 Years	39.67	39.67	21.19	21.19
kWh Difference After 20 Years	0.08	0.30	0.27	1.08
kWh % of Original After 20 Years	0.86	0.86	0.48	0.48
Cost of Single Battery	**$ 570**	**$ 2,854**	**$ 135**	**$ 625**
Cost of Batteries/Block	**$ 15,960**	**$ 19,978**	**$ 3,780**	**$ 4,375**
Estimated Total RBH Cost	**$ 462,840**	**$ 579,362**	**$ 109,620**	**$ 126,875**

Source: (Batteries, 2016; Energy Matters, 2007; Albring, Edie & Al-Hallaj, 2012; Retriev, 2016; Brouwer, Gupta, Honda, Zargarian, 2011; Consumer Power Incorporated, 2016; Rapid Tables, 2016; Wholesale Solar, 2016; Stark Power, 2016; The Lithium Battery Company, 2016).

Analysis. Based on the breakdown of pricing for each potential battery option, as shown in Table 6, it shows that although lithium ion batteries have better performance, lead acid batteries are the overall best option for RBH.

Finding #6. The most cost efficient battery to comprise the backup battery bank of is a 48V sealed lead acid battery.

Summary of Evidence. We created a spreadsheet that accounted for different power outage time lengths during a week to assess how much power would be needed to power the housing complex. We found multiple batteries to fit each scenario in order to get an estimation on the costs of each situation. Based on those cost we calculated the price of each battery bank, as well as the cost to have each battery installed throughout the entire housing complex. Using the information in the created spreadsheet, we were able to find what the most efficient battery would be.

Explanation. We created a number of different scenarios with varying lengths of power outage per week, as well as varying appliances that would need to be powered. In the calculations we also included any factors that would change over time, such as natural self discharge and loss of efficiency due to increased cycle life. In addition to this we made sure to make our calculations include the loss in efficiency as a result of having a constant depth of discharge at 100%, as that is how a backup battery would be used. For all of these calculations we used a 20 year basis, as this is roughly how long it would take the average lead acid battery to reach its full cycle life if it were to be used once a week, like we estimated in our calculations. After all of the calculations the total price of the 48V sealed lead acid battery was significantly cheaper than any of the lithium ion options, and even more cost efficient than other lead acid options when considering wiring. The 48V sealed lead acid battery for the recommended situation ends up costing roughly $106,000, whereas the cheapest lithium ion options is roughly $235,000.

Analysis. Based on the information we gathered, and calculations we made, we found that the most cost effective option was to use 48V sealed lead acid batteries. Even though the 12V sealed lead acid batteries are slightly cheaper when used in the same scenario, there are four times as many batteries, creating more labor, causing a need for more wiring and based on the average energy densities it would also require a larger storage container.

Finding #7. A backup battery would not be plausible based on the amount of batteries that would be needed to partially power RBH for four hours.

Summary of Evidence. We used the average dimensions and weight of an individual battery, as well as the amount of batteries needed for each housing block in order to calculate to total weight and size of all the batteries needed to power RBH. Each housing block would need a very large battery bank, which would result in several complications, as well as escalated costs.

Explanation. After doing battery research we selected the smallest bank of batteries to see if it would be plausible to implement in terms of size. We calculated the necessary battery bank composed of 48V 40AH lithium ion batteries, since lithium ion batteries are generally more compact than lead acid. A battery bank comprised of these batteries would provide enough electricity for the partial electricity scenario for 4 hours a week.

Using this battery, the smallest model we researched was 24.4” x 17.5” x 10” (inches) and weighing 120 lbs (Lithionics Battery, 2015). Based on the total of 7 batteries needed per bank, the total size of the battery bank, for each housing block with PV arrays, would be roughly 14.2’ x 10.2’ x 5.8’ (feet). In addition to the large size of the battery bank, the weight is an issue as well. Eventually these batteries will need to be removed and taken to a battery disposal plant in order to avoid a significant negative environmental impact. Based on the weight of each individual battery the weight of each battery bank would be approximately 840 lbs. Using the weight 840 lbs for each battery bank, the weight of all the battery banks needed to provide partial electricity for 4 hours a week would roughly 11.75 tons of batteries for the entire housing complex.

Based on the amount of batteries, as well as their size, finding a containment unit large enough to hold each battery bank and strong enough to withstand the climate would be very expensive. In addition to the cost of the containment units, they would also require significant electricity to keep the temperature regulation in order, which would pull electricity away from the batteries during an outage. This would defeat the purpose of having a battery at all, if a large amount of the electricity created goes towards powering the backup system itself.

As discussed in Section 2.7, although lithium ion and sealed lead acid batteries both have low environmental impact, the amount of environmental impact depends on the disposal process itself (Jinqi et al., 2008). When disposed of correctly both lithium ion and lead acid batteries are broken down chemically and each compound is returned back to its elemental form (Jinqi et al., 2008). It is more important to do this with lithium ion batteries, as they not only pose a potential environmental issue, but also major safety issues, if not disposed of properly (McKenna, McMannus, Cooper & Thompson, 2012). If a lithium ion battery's casing is broken open and water is allowed to seep inside, the chemicals responsible for charging and discharging the battery would react with the water causing a violent chemical reaction, resulting in an explosion (McKenna, McMannus, Cooper & Thompson, 2012). In order to properly take care of the disposal process without major environmental repercussions, the Coast Guard would have to pay a battery disposal company to carry out the process. This would likely get expensive, based on the amount of batteries that would be required to provide backup power to RBH.

In addition to the cost of battery disposal, when the time comes there will be significant labor required to remove, ship and dispose of 11.75 tons worth of batteries. In addition to the removal of the battery, both the shipping for the initial install and any shipping of batteries after removal of dead batteries would be very costly.

Analysis. Based on the calculations of size, it would not be plausible to have battery banks of these size and weight installed in the Río Bayamón housing complex. It would not only take up a large amount of space, but the cost and potential environmental impact of having battery banks of that size would potentially do more harm than good.

5. RECOMMENDATIONS

After analyzing the PV system, the contract around it, and the possibility of implementing a backup battery system we came up with the following recommendations:

1. Continue Using Generator Backup
2. Sign a net metering agreement with PREPA

CONTINUE USING GENERATOR BACKUP

Recommendation #1. The United States Coast Guard continues to use diesel generators in the case of a power outages, instead of implementing backup solar batteries.

Explanation. Diesel generators are more beneficial than implementing solar backup batteries for the following reasons:

1. High cost to install backup battery systems.
2. High disposal costs at end of battery life and potential environmental consequences.

Cost Issues of Battery Installation. Based on the total cost breakdown of the batteries, the balancing of systems, labor, and containment systems, it is not feasible to install backup batteries at the housing complex. The average generator produces up to 15 kWh. Based on this production, the generators are able to provide electricity for longer periods of time compared to the backup battery systems we considered. Generating electricity with a diesel generator would cost roughly $0.1613 per kWh based on the average US rate of $2.42/gallon for diesel (EIA, 2016b). The average inflation of diesel prices over the past 10 years which was 12.94% (EIA, 2016b). Given these estimations, if the Coast Guard were to use a generator to power refrigeration and lights for four hours a week for 20 years, it would cost approximately $23,506. Although the batteries would provide a renewable source of electricity, our calculations indicate that it is far more beneficial for both long and short term to continue to use generators for backup power in the case of an outage. Using generators is also more convenient as the infrastructure is already in place. The combination of these factors lead us to the recommend not implementing backup battery systems in the housing complex due to the high costs of the system outweighing the benefits backup battery systems would provide.

Cost and Potential Environmental Impact of Batteries. Since reducing environmental impact is one of the primary goals of the ESPC, we carefully considered the possible repercussions associated with implementing a backup battery system. Although the individual batteries that we considered for implementation pose few environmental concerns, issues arise when considering the scale required to power the housing complex. The chemicals within each battery are possibly harmful to the environment. When considering a small scale battery system, the benefits of a renewable energy system would outweigh the risks associated with battery disposal. This does not remain true for large scale battery banks. A battery bank capable of providing power to the housing complex during power outages could exceed eleven tons. Disposing of this quantity of batteries could result in a large environmental impact, which we feel outweighs the benefit of providing a small amount of backup power.

Proper disposal of large quantities of battery would require substantial costs. The combination of disconnecting batteries, shipping truckloads of batteries to disposal facilities, and paying fees associated with the disposal adds another expense to the system. Based on all of the potential complications with a backup battery system of this scale, we recommend not considering batteries for backup power purposes.

SIGN A NET METERING AGREEMENT WITH PREPA

Recommendation #2. The United States Coast Guard should sign a net metering agreement with PREPA to reduce financial losses.

Explanation. The Coast Guard has not signed a net metering agreement. Without a net metering agreement, the Coast Guard is faced with greater financial losses. These losses are due to the fact that the Coast Guard is not rewarded with energy credits for the energy the PV system produces.

In accordance with the contract between the Coast Guard and Schneider Electric, the Coast Guard pays Schneider Electric for every kWh the PV system produces and all production adjustments, at an agreed upon rate. The caveat is that the electricity produced by the PV system is not actually used by the Coast Guard. The energy the PV system produces is fed to the PREPA grid, and without a net metering agreement, the Coast Guard is provided nothing in return. Under the current agreement, the Coast Guard pays for the energy the PV system produces, in addition to the electricity the Coast Guard consumes from PREPA. With a net metering agreement the Coast Guard would continue to pay Schneider Electric for the electricity produced by the PV system. However, with a net metering agreement, the Coast Guard would pay PREPA only the difference between their consumption and the amount of electricity the PV system generates. An agreement of this nature would significantly reduce the Coast Guard's financial losses during future contract years.

6. Project Extensions

This section is comprised of important topics, which our team did not have time to investigate, but feel may be of value to the Coast Guard in the future. This section addresses the following topics:

1. Use of batteries for regular off-grid use under normal circumstance, rather than using batteries exclusively for backup purposes.
2. Mass communication tools to notify residents during system outages.

Extension 1. After researching the potential addition of a backup battery system, we performed an in-depth battery analysis considering the different types of batteries and their properties in a variety of situations. The situations we considered varied in period of use, however, our research and analysis focused exclusively on batteries for use in a backup battery system. Our entire cost-benefit analysis was based on deep cycle batteries that were specifically designed to store electricity for a large amount of time and release the electricity at a very high depth of discharge (DoD), when needed.

We did not investigate the potential use of a battery system as an alternative to net metering. Using a battery in lieu of a net metering contract would consist of incorporating batteries into the existing system, and wiring the system so power could be provided to the housing units directly from the battery system. Currently the electricity produced by the PV system is fed directly to the utility grid. This type of battery system would not require a deep cycle battery, as the requirements for cycle life and depth of discharge would vary significantly from that of a backup type system. Adding batteries to the existing PV system would be beneficial if a net metering agreement was not completed because the housing complex could utilize the electricity produced by the PV system instead of giving it away without compensation. Due to time constraints, we were unable to perform a cost benefit analysis for this type of battery system, which would effectively shift the entire PV system from a grid tied system to a off-grid, or hybrid PV system.

Extension 2. To address reliability concerns, we recommended that the Coast Guard continue to use the generators currently in place rather than installing backup battery systems. We did not look into simplifying the current process the Coast Guard undergoes to start the backup generators during a power outage. Currently, the Coast Guard has to add fuel to the generators, physically connect the generators to the housing blocks, and finally, inform all the residents to reduce their electricity use. Informing the residents is critical to regulate fuel usage.

Based on this current process, we believe it could be beneficial for the Coast Guard to utilize a form of automated mass communication. An automated message could be sent via email or text message in the case of a power outage. Implementing this type of system could potentially save the Coast Guard time save time and distribute the message faster.

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APPENDICES

Appendix A:

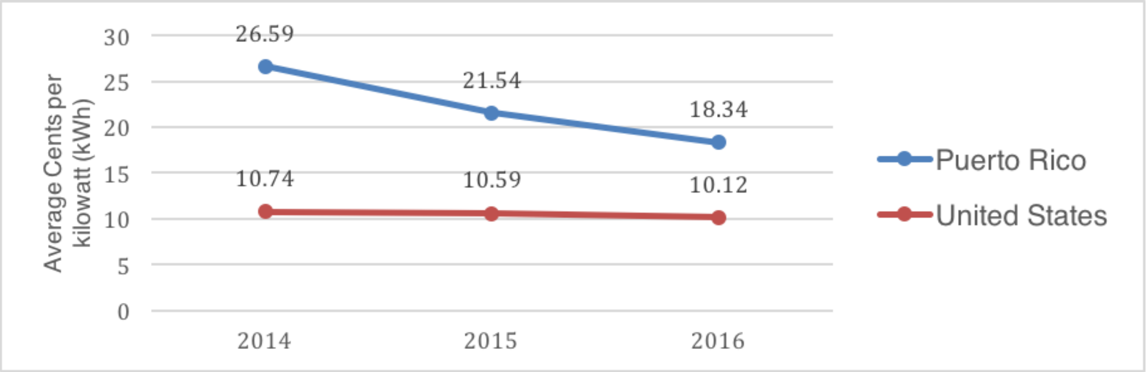

Figure A1. Average commercial electricity prices (in cents) in Puerto Rico versus the United States from 2014 to May 2016. Source: Data obtained from U.S. Energy Information Administration (EIA,2016c)

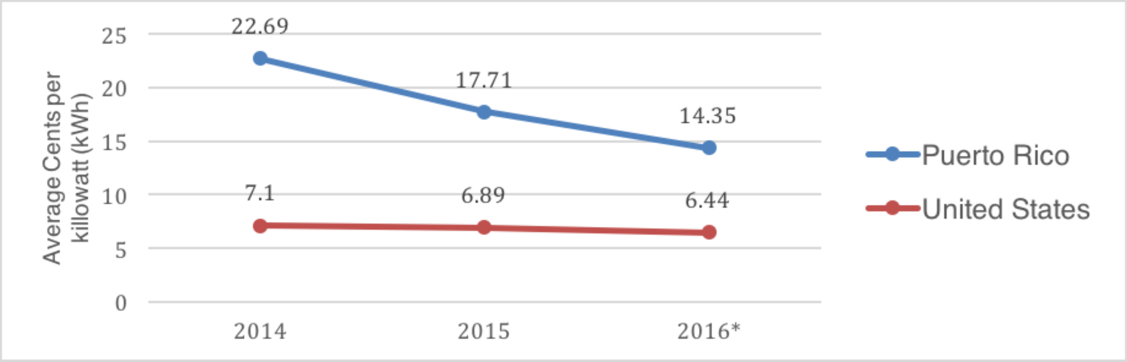

Figure A2. Average industrial electricity prices (in cents) in Puerto Rico versus the United States from 2014 to May 2016. Source: Data obtained from U.S. Energy Information Administration (EIA,2016c)

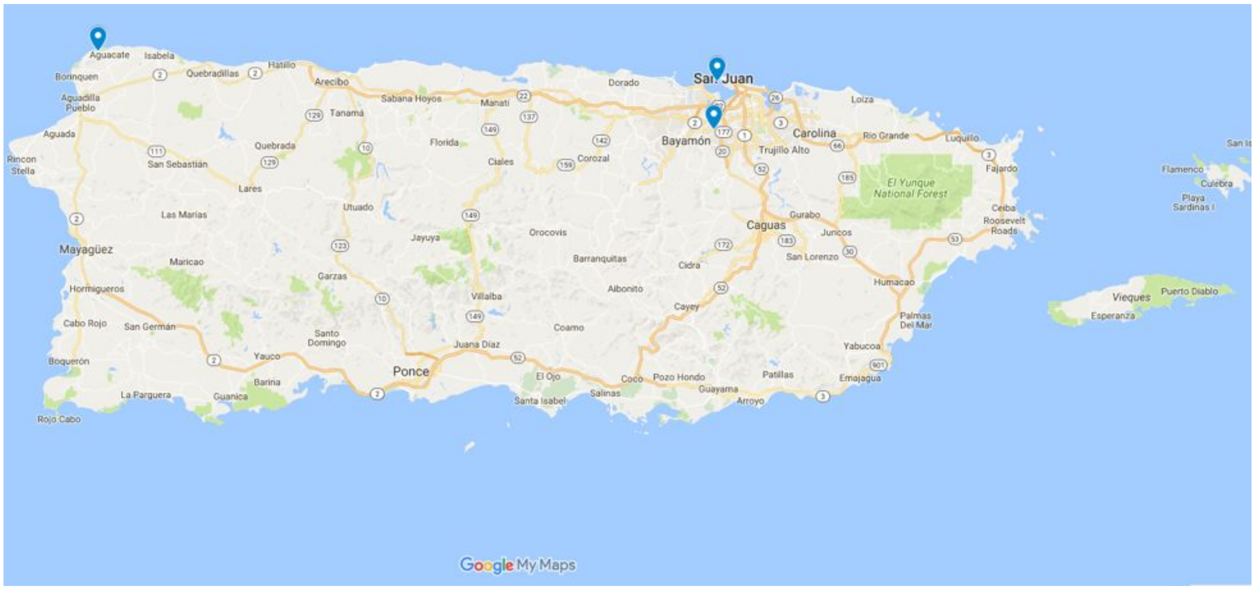

Figure A3. United States Coast Guard Puerto Rico ESPC locations with EMCs within Puerto Rico. Pinned locations include Air Station Borinquen, Sector San Juan Headquarters, Río Bayamón Housing Source: Map constructed with Google MyMaps

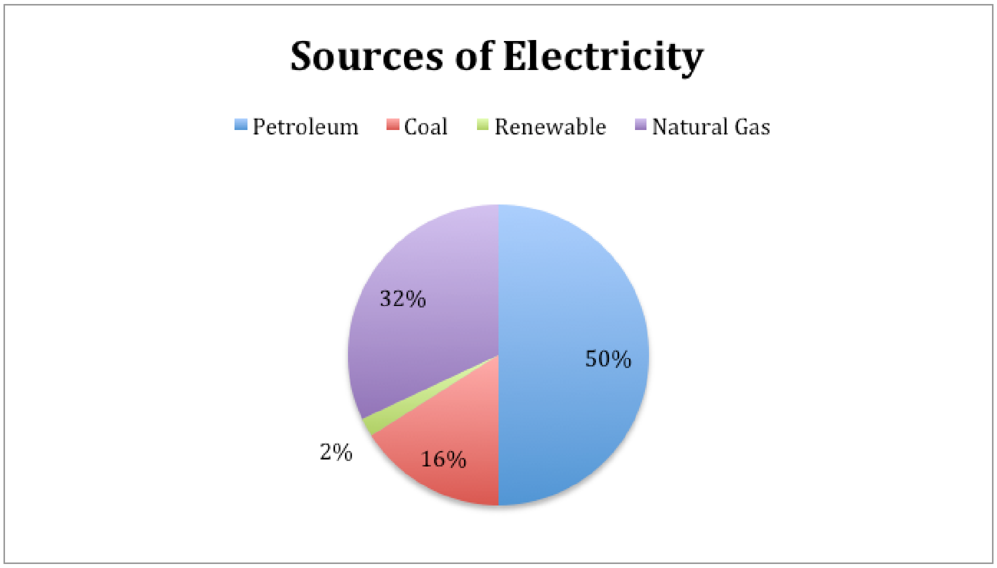

Figure A4. Electricity produced from imported resources (percentage of total electricity produced) in Puerto Rico in 2015. Source: Data obtained from U.S. Energy Information Administration (EIA, 2016c)

Appendix B:

Table B1

Inverters used by photovoltaic systems at Río Bayamón.

Array Location	Inverter Manufacturer	Inverter Model
Building B1-B3 Building C-K Building M Building O-Z	Schneider Electric Xantrex	GT 5.0 (240 V)
Building L Building N	Satcon	PowerGate Plus 50 kW (240 V)
Community Center	PVPowered	PVP-30kW-LV (208 V)
Carport Ground Mount	Satcon	PowerGate Plus 50 kW (208 V)

Source: (Vaughn 2010b)

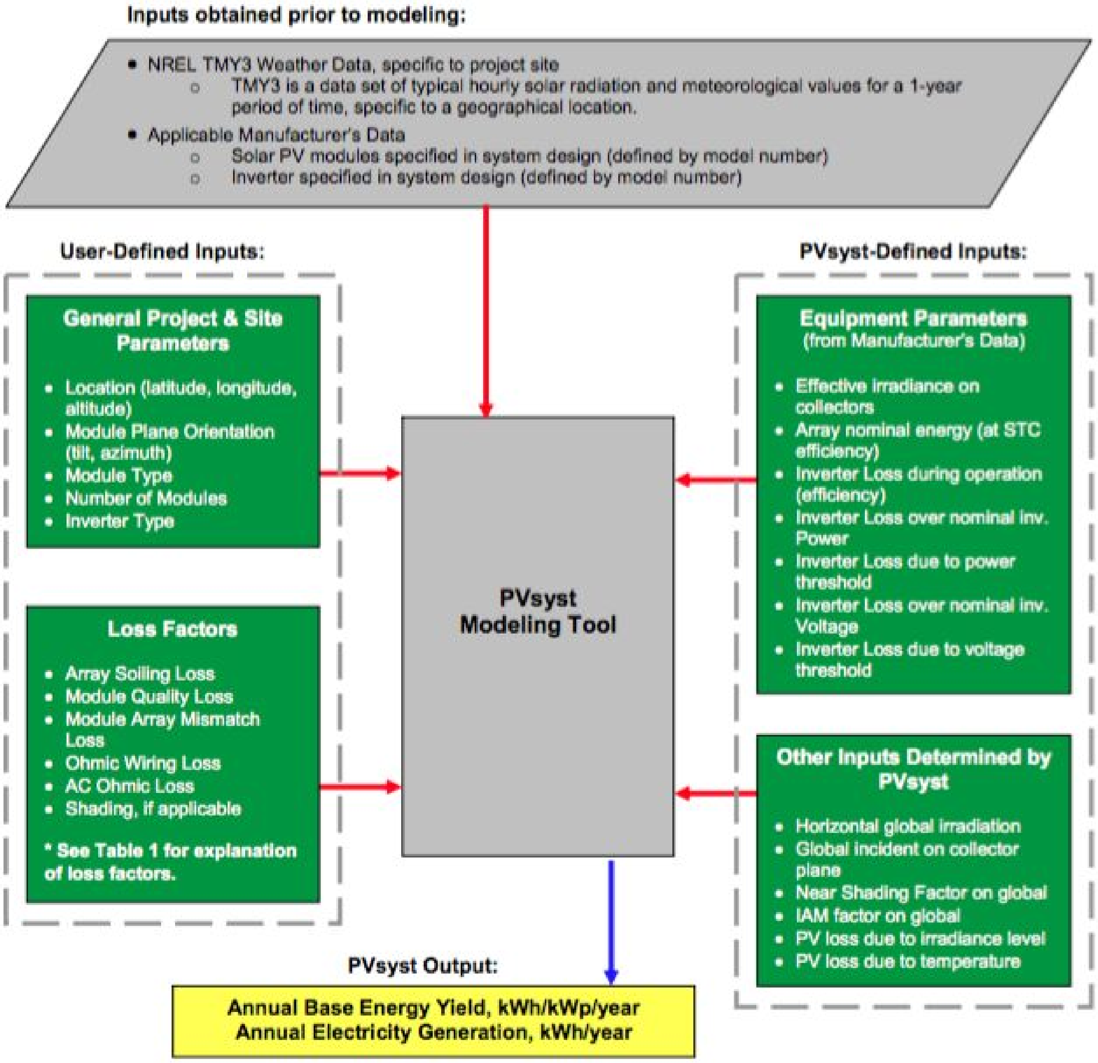

Figure B1. Schneider Electric Solar PV Energy Model Methodology. Source: (Vaughn 2010b)

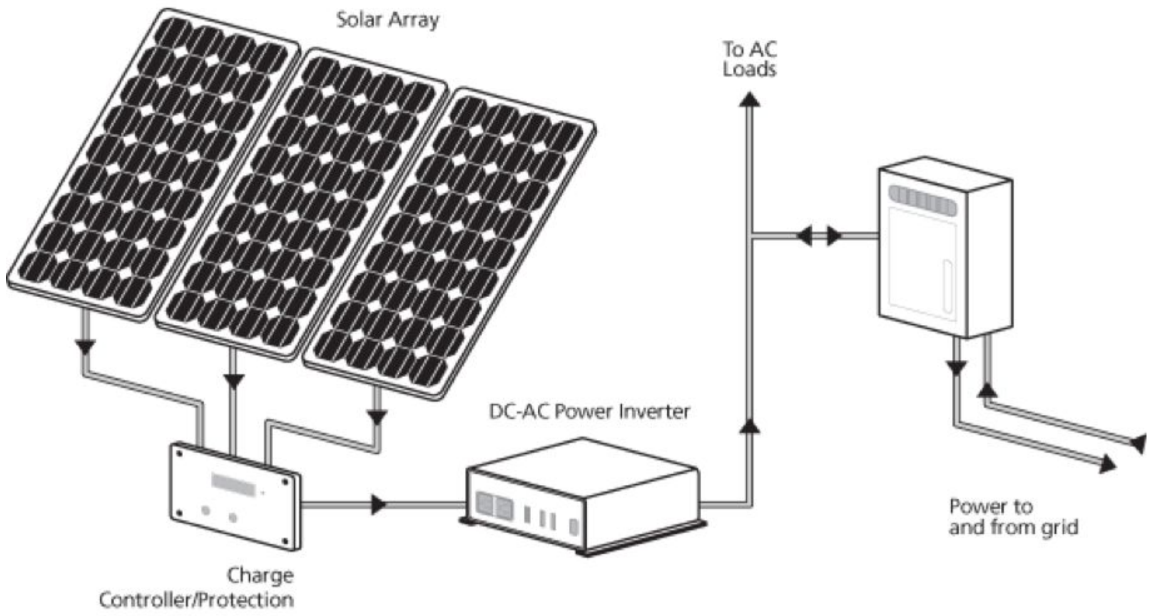

Figure B2. Photovoltaic System Components Overview. Source: (Samlex Solar, 2016)