Feasibility Study of Solar Photovoltaics on Landfills in Puerto Rico

A Study sponsored by the U.S. Department of Energy Weatherization and Intergovernmental Program Technical Assistance Project on behalf of the Puerto Rico Environmental Quality Board

James Salasovich and Gail Mosey

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Technical Report
NREL/TP-6A20-52181
August 2011

Contract No. DE-AC36-08GO28308

NATIONAL RENEWABLE ENERGY LABORATORY

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Prepared under Task No. IGST.0020

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Executive Summary

The U.S. Environmental Protection Agency (EPA), in accordance with the RE-Powering America's Land initiative, selected the Commonwealth of Puerto Rico for a feasibility study of renewables on several sites that are targeted for closure under the Resource Conservation and Recovery Act (RCRA).[1] The RCRA regulates the disposal of solid and hazardous waste. Citizens of Puerto Rico, city planners, and site managers are interested in redevelopment uses for landfills in Puerto Rico that are particularly well suited for solar photovoltaic (PV) installation. The purpose of this report is to assess the landfills with the highest potential for possible solar PV installation and estimate cost, performance, and site impacts of three different PV options: crystalline silicon (fixed tilt), crystalline silicon (single-axis tracking), and thin film (fixed tilt). Each option represents a standalone system that can be sized to use an entire available site area. In addition, the report outlines financing options that could assist in the implementation of a system. Landfill gas is another possible renewable energy option for the landfills in Puerto Rico. Landfill gas is briefly addressed in this feasibility study, but PV is the main focus.

The feasibility of PV systems installed on landfills is highly impacted by the available area for an array, solar resource, operating status, landfill cap status, distance to transmission lines, and distance to major roads. All of the landfills in Puerto Rico were screened according to these criteria in order to determine the sites with the greatest potential. Eight landfills were chosen for the first site visit, and a report is published at http://www.nrel.gov/docs/fy11osti/49237.pdf describing the analysis. Additional funding was received to conduct two additional site visits to landfills in Puerto Rico through the Department of Energy's Technical Assistance Program (TAP). Five landfills were chosen for the second site visit based on the screening criteria and location. Because of time constraints and the fact that Puerto Rico is a relatively large island, the five landfills chosen for this visit were all located in the same region—the western half of the island. Six landfills and one landing strip were chosen for the third site visit. The landfills for the third site visit were all located on the eastern half of the island. The findings from this report can also be applied to landfills throughout the island. The following lists the five landfills from the second site visit and the six landfills from the third site visit in alphabetical order:

Second site visit:

1. Aguadilla
2. Añasco
3. Isabela
4. Mayagüez
5. Moca.

Third site visit:

1. Carolina
2. Cayey

[1] EPA. "RCRA Online." http://www.epa.gov/epawaste/inforesources/online/index.htm. Accessed January 10, 2011.

3. Fajardo
4. Humacao
5. Juncos
6. Vega Baja.

After returning from the third site visit, it was determined that four sites on the Puerto Rican island of Vieques have potential areas for PV systems. Even though the sites were not visited, the following sites on Vieques are also included in this report as a viable option for PV:

Additional Site:

1. Former Vieques Landing Strip
2. Former Vieques Naval Training Range
3. Old Camp Garcia Landfill
4. Old Vieques Municipal Landfill.

The electric utility serving Puerto Rico is the Puerto Rico Electric Power Authority (PREPA). According to the most recent annual report[2] published by PREPA in June 2009, average residential electric rates were $0.2158/kWh, average commercial rates were $0.2232/kWh, and average industrial rates were $0.1831/kWh. These electric rates are similar to those found in the Hawaiian Islands, and they are roughly double the average electric rate in the Unites States. The net-metering laws in Puerto Rico state that whatever the PV electric output above the customer use, PREPA will buy 75% of that at either the avoided fuel cost or $0.10/kWh, whichever is greater. The avoided fuel cost is in the range of $0.10/kWh or lower, so $0.10/kWh was assumed. The PV system size limit for net metering is 25 kW for residential and 1 MW for commercial.

There is little to no electricity use at a closed landfill, and all of the electricity generated by a proposed PV system is assumed to be sold back to the utility. From an economic standpoint, the current net-metering laws in Puerto Rico are not advantageous for PV systems that generate large amounts of excess energy because of the relatively low buyback rate of 75% of $0.10/kWh. Setting up a power purchase agreement (PPA) where PREPA agrees to buy back the power at a higher rate would be much more beneficial. There are currently two large-scale PV projects in Puerto Rico that were both started in 2010 that use a PPA. The first project[3] is a 20 MW PV system in Guayama where AES Ilumina entered a PPA with PREPA; PREPA agreed to buy the electricity at a rate of $0.13/kWh. The second project[4] is a 63 MW PV system in Salinas where CIRO One Group entered a PPA with PREPA, but the buyback rate has yet to be established.

[2] URS. "Thirty-Sixth Annual Report on the Electricity Property of the Puerto Rico Electric Power Authority." http://www.aeepr.com/INVESTORS/Financial%20Information/Annual%20Reports/ConsEng_36th_Rpt_2009%20Annual%20Report%20Final.pdf. Accessed December 8, 2010.

[3] All Business. "Solar Power Project." http://www.allbusiness.com/energy-utilities/utilities-industry-electric-power-power/14753424-1.html. Accessed December 8, 2010.

[4] Marino, J. "Work to Start on 63 MW Solar Plant in Salinas." *Caribbean Business*. http://www.caribbeanbusinesspr.com/news03.php?nt_id=49337&ct_id=1. Accessed December 8, 2010.

The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at a rate of $0.13/kWh. Incentives offered by the federal government, the Commonwealth of Puerto Rico, and PREPA were assumed in this analysis. The federal tax credit is currently 30%. State incentives are currently offered for commercial solar power systems in Puerto Rico for $4/DC-Watt for up to 50% of the project costs or $100,000, whichever is lower. State incentives of $8/DC-Watt for up to $100,000 are offered for governmental systems. State incentives of $4/DC-Watt for up to $15,000 are offered for residential systems. PREPA currently offers no incentives for PV systems. Not all sites need to be developed; beginning with a smaller demonstration system and increasing capacity as funds become available may be a better approach. The economics of a potential PV system on landfills in Puerto Rico depend greatly on the buyback electric rate. Recently, PREPA has entered into PPAs with a buyback rate of $0.13/kWh. Based on past electric rate increases in Puerto Rico and other islands in the Caribbean, this buyback rate could increase to $0.15/kWh or higher in a relatively short amount of time.

Table of Contents

List of Figures

List of Tables

1 Background and Introduction

The Commonwealth of Puerto Rico is an island located in the northeastern Caribbean Sea and, as of 2010, has a population of approximately 4 million people. The area of Puerto Rico is 3,515 mi^2, and the approximate dimensions are 100 mi east to west and 35 mi north to south. The climate is a tropical marine climate with very little temperature variation throughout the year. The main utility company is the Puerto Rico Electric Power Authority (PREPA).

The U.S. Environmental Protection Agency (EPA), in accordance with the RE-Powering America's Land initiative, selected Puerto Rico for a feasibility study of solar photovoltaic (PV) feasibility on several landfill sites. Puerto Rico is particularly well suited for solar PV installation because of the solar resource availability. Due to the presence of suspected or known contaminants, landfills have limited redevelopment potential, and solar PV installations are a viable reuse. The purpose of this report is to present the results of a feasibility study conducted by the National Renewable Energy Laboratory (NREL) to assess several landfill sites in Puerto Rico with the highest potential for possible solar PV installation and estimate cost, performance, and site impacts of three different PV options: crystalline silicon (fixed tilt), crystalline silicon (single-axis tracking), and thin film (fixed tilt). Each option represents a standalone system that can be sized to use an entire available site area. In addition, the report outlines financing options that could assist in the implementation of a system.

One very promising and innovative use of closed landfills is to install solar PV systems. PV systems can be ground-mounted, and these types of systems work well on landfill sites where there are commonly large unshaded areas. In some cases, PV can be used to form the cap of the landfill. PV may generate revenue on a landfill site that may otherwise go unused. A majority of the landfills in Puerto Rico are municipally owned and operated, and these municipalities are interested in potential revenue flows from PV systems on landfills. PV systems on landfills may give the municipalities a reason to close the landfills in a timely manner and to maintain the landfill cap once it is in place.

The focus of this report is on PV systems, but another use of closed landfills is to install a landfill gas plant. The landfill gas could be used in a heating application or used to operate a generator in order to make electricity. The key points that need to be investigated to determine whether landfill gas capture is feasible are the age of the landfill, the size, and the types of gases generated by the landfill. For landfill gas capture, it is best to have a newly capped landfill because the landfill gas production greatly declines after 20–30 years. The types of gases that are generated by the landfill can be determined by doing a sample test. This involves drilling a hole into the landfill, putting a vacuum on the landfill, and sampling the rate and types of gases being generated. A detailed landfill gas study should be done in order to determine the feasibility of landfill gas capture and use at all relatively newly capped larger landfills in Puerto Rico.

Like most islands, Puerto Rico relies heavily on foreign sources of petroleum to operate its power plants. There are many compelling reasons to consider moving toward renewable energy sources for power generation instead of fossil fuels, including:

- Using oil to produce power may not be sustainable.

- Burning fossil fuels can have negative effects on human health and the environment.
- Extracting and transporting oil can lead to accidental spills, which can be devastating to the environment and communities.
- Depending on foreign oil can be a threat to national security.
- High and increasing electric rates are associated with oil-based power plants.
- Fluctuating electric costs are associated with oil-based power plants.
- Burning fossil fuels may contribute to climate change. Being an island, Puerto Rico is even more sensitive to climate change and the associated rising sea levels and increased frequency and severity of hurricanes.
- Generating energy without harmful emissions or waste products can be accomplished through renewable energy sources.
- Abundant renewable resources are available in Puerto Rico.

2 PV Systems

Solar photovoltaics (PV) are semiconductor devices that convert sunlight directly into electricity. They do so without any moving parts and without generating any noise or pollution. They must be mounted in an unshaded location; rooftops, carports, and ground-mounted arrays are common mounting locations. PV systems work very well in Puerto Rico, where the average global horizontal annual solar resource is 5.5 kWh/m^2/day. This number, however, is not the amount of energy that can be produced by a PV panel. The amount of energy produced by a panel depends on several factors. These factors include the type of collector, the tilt and azimuth of the collector, the temperature, the level of sunlight, and weather conditions. An inverter is required to convert the direct current (DC) to alternating current (AC) of the desired voltage compatible with building and utility power systems. The balance of the system consists of conductors/conduit, switches, disconnects, and fuses. Grid-connected PV systems feed power into the facility's electrical system and do not include batteries.

Figure 1 shows the major components of a grid-connected PV system and illustrates how these components are interconnected.

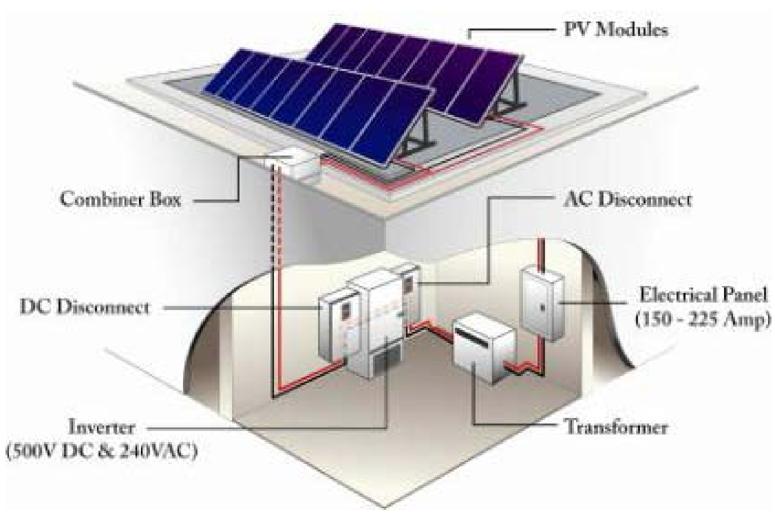

Figure 1. Major components of grid-connected PV system

Credit: NREL

PV panels are made up of many individual cells that all produce a small amount of current and voltage. These individual cells are connected in series to produce a larger current. PV panels are very sensitive to shading. When shade falls on a panel, the shaded portion of the panel cannot collect the high-energy beam radiation from the sun. If an individual cell is shaded, it will act as a resistance to the whole series circuit, impeding current flow and dissipating power rather than producing it. By determining solar access—the unimpeded ability of sunlight to reach a solar collector—one can determine whether an area is appropriate for solar panels.

For this assessment, the NREL team used a solar path calculator to assess shading at particular locations by analyzing the sky view where the solar panels will be located. The solar path calculator is equipped with a fisheye lens that takes a 360^o photo of the sky and plots out the shading obstructions throughout the year on a spherical axis. Shading analysis is typically done at locations where shading will most likely be an issue (e.g., close to a stand of trees or a hill on the perimeter of a landfill).

If a site is found to have good solar access for a PV system, then the next step is to determine the size of that system, which highly depends on the average energy use of the on-site facilities. Providing more power than a site would use is dependent on the economics of most net-metering agreements. In the case of the assessed sites, all of the electricity generated at the site would be sold to the serving utility, PREPA, because there is little or no electrical load. The system size would thus be determined by the amount of electricity the electric company would be willing to purchase or by how much land area is available. For the purpose of this report, the NREL assessment team assumed PREPA would purchase any electricity that the site can generate. The systems will be broken down by site so the system size can be adjusted based on what the utility requests.

2.1 Types of PV Systems

2.1.1 Ground-Mounted Systems

On a $/DC-Watt basis, ground-mounted PV systems are usually the lowest cost option to install. Several PV panel and mounting options are available, each having different benefits for different ground conditions. Table 1 outlines the energy density values that can be expected from each type of system.

Table 1. Energy Density by Panel and System for Ground-Mounted PV

System Type	Fixed-Tilt Energy Density ($DC-Watts/ft^2$)	Single-Axis Tracking Energy Density ($DC-Watts/ft^2$)
Crystalline Silicon	4.0	3.3
Thin Film	1.7	1.4
Hybrid HE[a]	4.8	3.9

[a] Because hybrid high efficiency (HE) panels do not represent a significant portion of the commercial market, they were not included in the analysis. Installing panel types that do not hold a significant portion of the commercial market would not be feasible for a large-scale solar generation plant.

For the purpose of this analysis, all fixed-tilt systems were assumed to be mounted at latitude with a tilt of 18.4 degrees. To get the most out of the available ground area, considering whether a site layout can be improved to better incorporate a solar energy system is important. If unused structures, fences, or electrical poles can be removed, the unshaded area can be increased to incorporate more PV panels. When considering a ground-mounted system, an electrical tie-in location should be identified to determine how the energy would be fed back into the grid. For this report, only fixed-tilt ground-mounted systems and single-axis tracking systems were considered.

Fixed-tilt systems are installed at a specified tilt and are fixed at that tilt for the life of the system. Single-axis tracking systems have a fixed tilt on one axis and a variable tilt on the other axis; the system is designed to follow the sun in its path through the sky. This allows the solar radiation to strike the panel at an optimum angle for a larger part of the day than can be achieved with a fixed-tilt system. A single-axis tracking system can collect nearly 30% more electricity per capacity than can a fixed-tilt system. The drawbacks include increased operation and maintenance (O&M) costs, less capacity per unit area (DC-Watt/ft^2), and greater installed cost ($/DC-Watt).

2.1.2 Roof-Mounted Systems

In many cases, a roof is the best location for a PV system. Roof-mounted PV systems are usually more expensive than ground-mounted systems, but a roof is a convenient location because it is out of the way and usually unshaded. Large areas with minimal rooftop equipment are preferred, but equipment can sometimes be worked around if necessary. If a building has a sloped roof, a typical flush-mounted crystalline silicon panel can achieve power densities on the order of 10 DC-Watt/ft^2. For buildings with flat roofs, rack-mounted systems can achieve power densities on the order of 8 DC-Watt/ft^2 with a crystalline silicon panel. Table 2 lists the energy density by panel type for roof-mounted PV.

Table 2. Energy Density by Panel Type for Roof-Mounted PV

System Type	Fixed-Tilt Energy Density (DC-Watts/ft^2)
Crystalline Silicon	10.0
Thin Film	4.3

Typically, PV systems are installed on roofs that either are less than 5 years old or have over 30 years left before replacement. The only roof area analyzed was the Recycling Center at the Guaynabo Landfill.

2.2 PV System Components

The PV system considered here has these components:

- PV arrays, which convert light energy to DC electricity
- Inverters, which convert DC to AC and provide important safety, monitoring, and control functions
- Various wiring, mounting hardware, and combiner boxes
- Monitoring equipment.

2.2.1 PV Array

The primary component of a PV system, the PV array, converts sunlight to electrical energy; all other components simply condition or control energy use. Most PV arrays consist of interconnected PV modules that range in size from 50 peak DC-Watts to 300 peak DC-Watts. Peak watts are the rated output of PV modules at standard operating conditions of 25°C (77°F) and insolation of 1,000 W/m^2. Because these standard operating conditions are nearly ideal, the actual output will be less under typical environmental conditions. PV modules are the most reliable components in any PV system. They have been engineered to withstand extreme temperatures, severe winds, and impacts. ASTM E1038-05[5] subjects modules to impacts from one-inch hail balls at terminal velocity (55 mph) at various parts of the module. PV modules have a life expectancy of 20–30 years, and manufacturers warranty them against power degradation for 25 years. The array is usually the most expensive component of a PV system; it accounts for approximately two-thirds the cost of a grid-connected system. Many PV manufacturers are available.[6]

2.2.2 Inverters

PV arrays provide DC power at a voltage that depends on the configuration of the array. This power is converted to AC at the required voltage and number of phases by the inverter. Inverters enable the operation of commonly used equipment such as appliances, computers, office equipment, and motors. Current inverter technology provides true sine wave power at a quality often better than that of the serving utility. The locations of both the inverter and the balance-of-system equipment are important. Inverters are available that include most or all of the control systems required for operation, including some metering and data-logging capability. Inverters must provide several operational and safety functions for interconnection with the utility system. The Institute of Electrical and Electronic Engineers, Inc. (IEEE) maintains standard *"P929 Recommended Practice for Utility Interface of Photovoltaic (PV) Systems,*"[7] which allows manufacturers to write "Utility-Interactive" on the listing label if an inverter meets the requirements of frequency and voltage limits, power quality, and non-islanding inverter testing. Underwriters Laboratory maintains "*UL Standard 1741, Standard for Static Inverters and Charge Controllers for Use in Photovoltaic Power Systems,"*[8] which incorporates the testing required by IEEE 929 and includes design (type) testing and production testing. A large choice of inverter manufacturers is available.[9]

2.3 Operation and Maintenance

The PV panels come with a 25-year performance warranty. The inverters, which come standard with a 5- or 10-year warranty (extended warranties available), would be expected to last 10–15 years. System performance should be verified on a vendor-provided website. Wire and rack connections should be checked. For this economic analysis, an annual O&M cost of 0.17% of total installed cost is used based on O&M costs of other fixed-tilt grid-tied PV systems. For the case of single-axis tracking, an annual O&M cost of 0.35% of the total installed cost is used based on O&M costs of existing single-axis tracking systems.

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[5] ASTM Standard E1038. "Standard Test Method for Determining Resistance of Photovoltaic Modules to Hail by Impact with Propelled Ice Balls." West Conshohocken, PA: ASTM International, 2005, DOI: 10.1520/E1038-05. http://www.astm.org/Standards/E1038.htm. Accessed September 2010.

[6] Go Solar California, a joint effort of the California Energy Commission and the California Public Utilities Commission, provides consumer information for solar energy systems. See http://www.gosolarcalifornia.org/equipment/pv_modules.php. Accessed March 2011.

[7] "ANSI/IEEE Std 929-1988 IEEE Recommended Practice for Utility Interface of Residential and Intermediate Photovoltaic (PV) Systems." http://standards.ieee.org/reading/ieee/std_public/description/powergen/929-1988_desc.html. Accessed September 2010.

[8] "Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources: UL 1741." http://ulstandardsinfonet.ul.com/scopes/1741.html. Accessed September 2010.

[9] Go Solar California approves inverters.

2.4 PV Size and Performance

PV arrays must be installed in unshaded locations on the ground or on building roofs that have an expected life of at least 25 years. The predicted array performance was found using a combination of PVWATTS, a performance calculator for grid-connected PV systems created by NREL's Renewable Resource Data Center,[10] and SolOpt, a solar performance tool currently being developed at NREL. The performance data was used to calculate the amount of revenue that could be expected each year. The project economics were based on this analysis, and the calculations can be found in Appendix A.

[10] NREL. "PVWatts." http://www.nrel.gov/rredc/pvwatts/. Accessed September 2010.

3 PV Site Locations

This section summarizes the findings of the second and third NREL solar assessment site visits on October 26–29, 2010, and January 31–February 2, 2011, respectively. This section also summarizes the findings from a study performed on four sites on the island of Vieques. None of the sites on the island of Vieques were visited, but an EPA team on site provided the necessary information to carry out a solar PV feasibility study.

3.1 Pre-Site Visit Feasibility Screening

Puerto Rico has over 30 landfills throughout the island; see Figure 2 for a representation of the landfills plus roads and transmission lines. Some of these landfills are better suited to solar PV system placement than others. To narrow down the list of landfills and identify those sites with the most potential for solar PV systems, screening criteria was applied to each of the landfills.

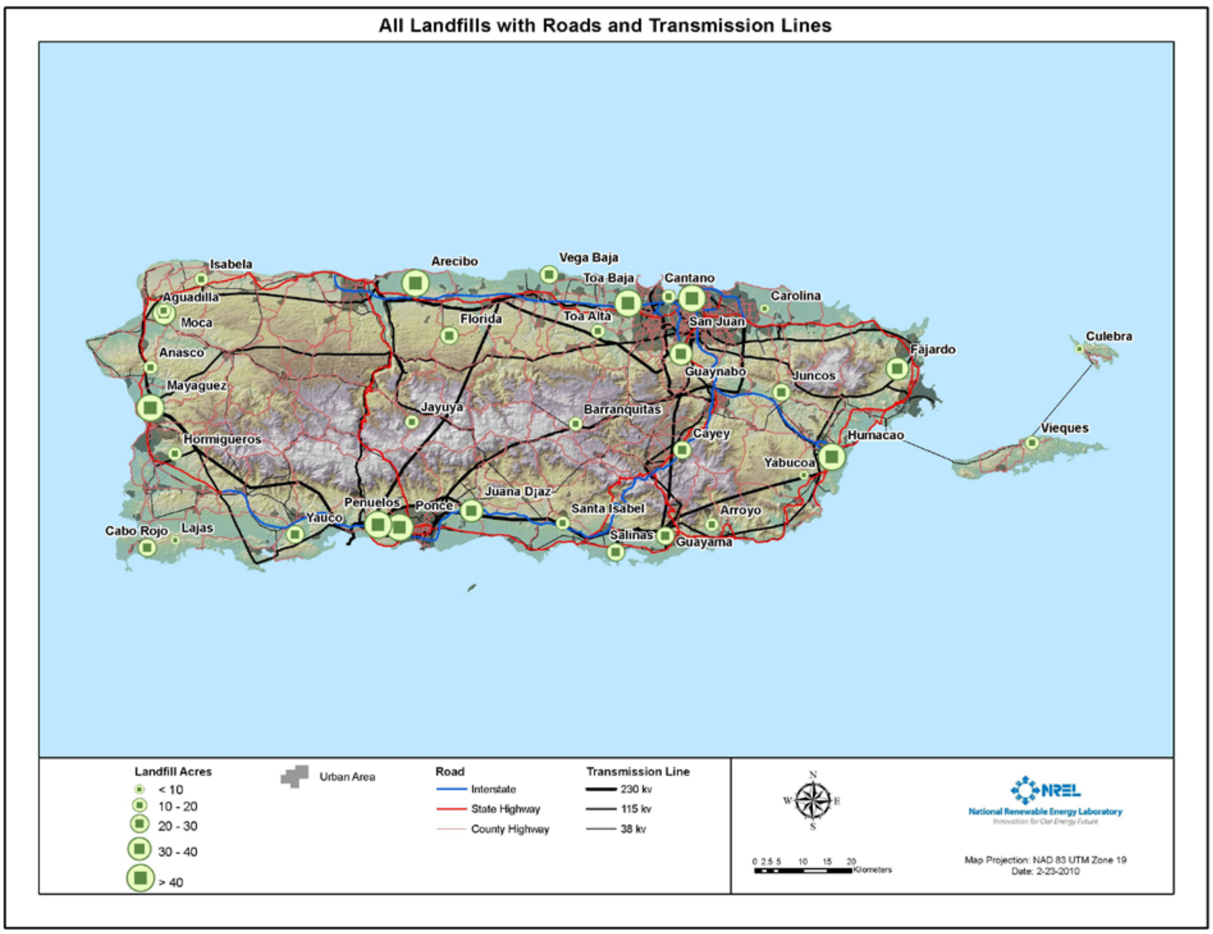

Figure 2. All landfills with roads and transmission lines

Credit: Anthony Lopez, NREL

The screening criteria consider aspects of the site that make it amenable to solar PV system placement and also consider infrastructure around the site, such as distance to roads and transmission lines, which make the system more feasible and economical. The screening criteria are as follows:

- Solar resource availability
- Acreage of the site
- Distance to graded road
- Distance to transmission lines
- Slope of the site.

All of the landfills in Puerto Rico have adequate solar resource availability for a solar PV system; see Figure 3 for a representation of the solar resource in Puerto Rico super-imposed on the landfill locations.

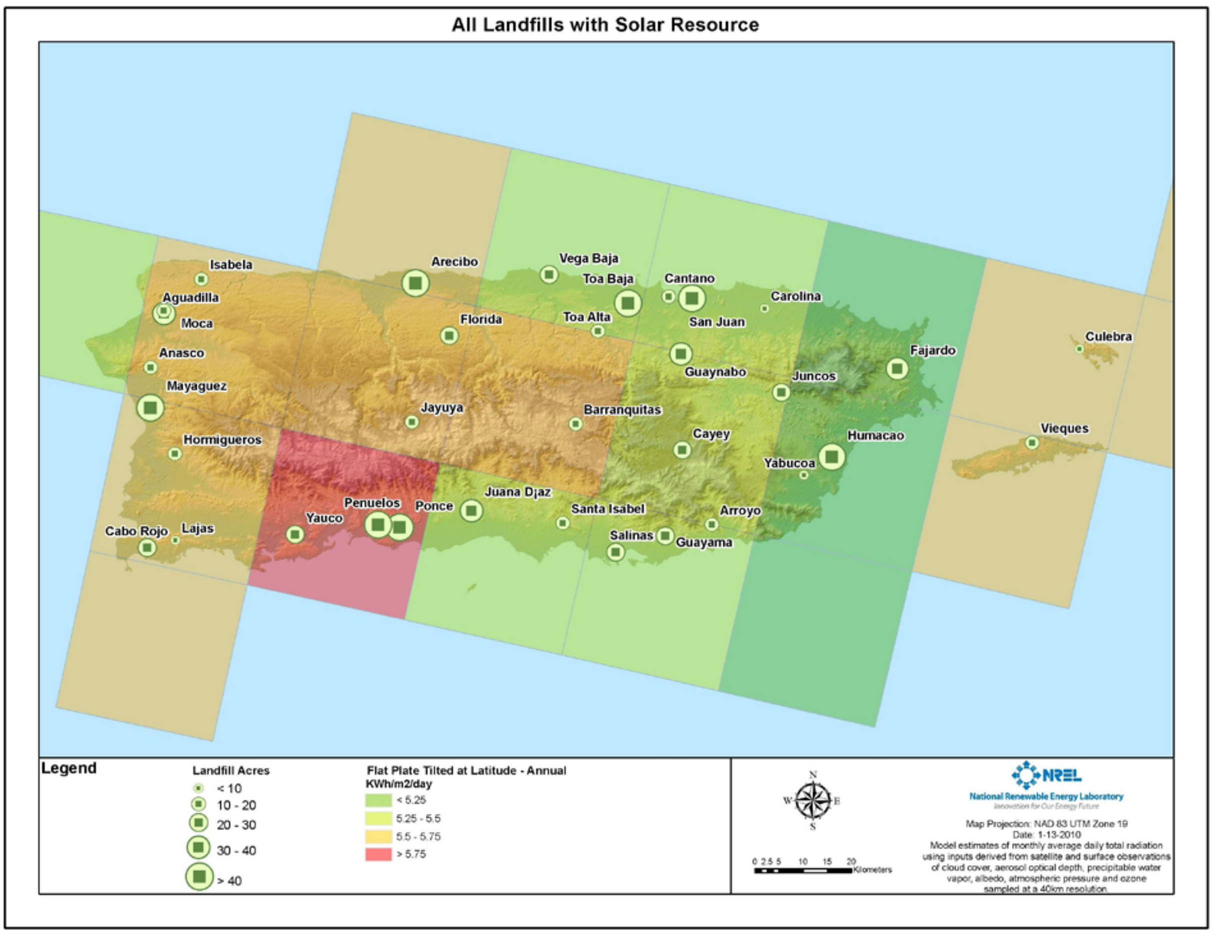

Figure 3. Solar resource availability and landfills in Puerto Rico

Credit: Anthony Lopez, NREL

The minimum acreage for a site to be considered high potential is 14 acres. This is an adequate size for a solar PV system to be feasible[11] and is reasonably inclusive of the landfills in Puerto Rico. Maximum distance to a graded road for solar PV is a loose criterion because PV systems can be transported on secondary roads, and most landfills in Puerto Rico have reasonable road access due to the nature of the former or ongoing landfill operation. Distance to transmission is another matter because of the expense associated with installing adequate transmission lines. Most, but not all, of the landfills in Puerto Rico are close to transmission of 38 kV, so a maximum distance of 1 mi to transmission was applied. The slope of the site should be no greater than 20% to allow for successful installation of the PV system. After applying the above criteria, 16 landfills were deemed as very high potential sites for solar PV, as seen in Figure 4.

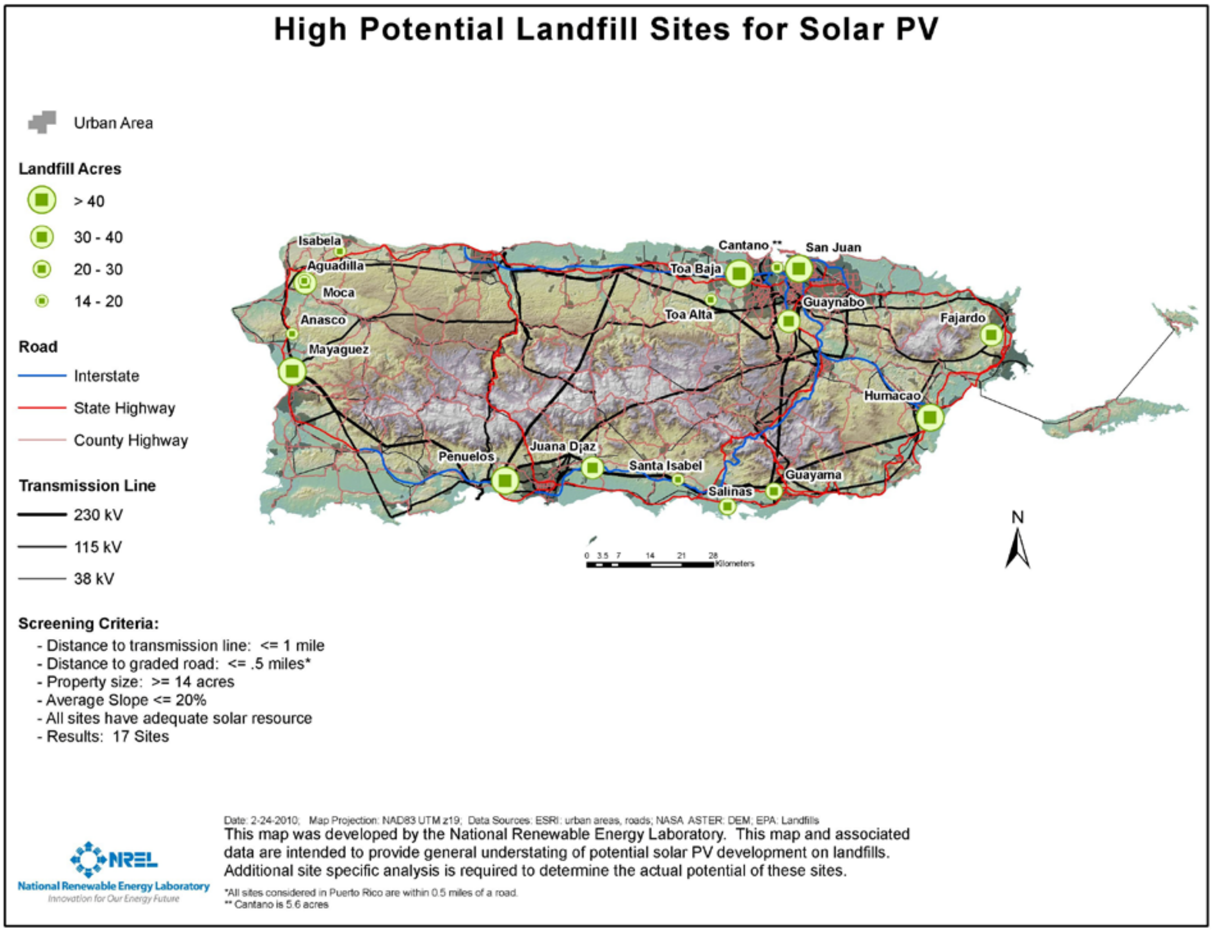

Figure 4. High potential landfill sites for solar PV in Puerto Rico

Credit: Anthony Lopez, NREL

[11] As a rule of thumb, NREL assumes 65 W/m^2 or 263 kW/acre for ground-mounted fixed tilt, 48 W/m^2 or 194 kW/acre for single-axis tracking, and 20 W/m^2 or 81 kW/acre for two-axis tracking. Denholm, P.; Margolis, R.M. (2008). "Land Use Requirements and the Per-Capita Solar Footprint for Photovoltaic Generation in the United States." *Energy Policy* (36); pp. 3531–3543.

Once the landfills with the highest potential for PV were determined, a plan for a second site visit could be mapped out. Because of time constraints and the fact that Puerto Rico is a relatively large island, it was determined that only four to six landfills could be assessed during the scheduled two-day site visit. Furthermore, the four to six landfills would have to be located in generally the same region of the island. At the start of the second site visit, the high potential sites were reviewed, and five landfill sites for solar PV were chosen for site visits, as listed below in alphabetical order.

1. Aguadilla
2. Añasco
3. Isabela
4. Mayagüez
5. Moca.

A third site visit was made to Puerto Rico and a total of six landfills were assessed during the two-day site visit. The sites from the third site visit are listed in alphabetical order below.

1. Carolina
2. Cayey
3. Fajardo
4. Humacao
5. Juncos
6. Vega Baja.

After returning from the third site visit it was determined that the island of Vieques to the east of Puerto Rico has four potential sites for installing PV. A site visit was not made to Vieques. However, the feasibility of installing PV on these four sites on Vieques was determined by collaborating with an EPA team on Vieques. The sites that were considered on Vieques are listed in alphabetical order below.

1. Former Vieques Landing Strip
2. Former Vieques Navel Training Range
3. Old Camp Garcia Landfill
4. Old Municipal Landfill.

The method for screening the sites and the findings from this report can generally be applied to other landfills throughout the island that were not visited due to similar climate and environmental conditions. The following sections summarize the findings of the NREL solar assessment.

There are currently two large-scale PV projects in Puerto Rico that were both started in 2010 that use a power purchase agreement (PPA). The first project[12] is a 20 MW PV system in Guayama where AES Ilumina entered a PPA with PREPA; PREPA agreed to buy the electricity at a rate of $0.13/kWh. The second project[13] is a 63 MW PV system in Salinas where the CIRO One Group entered a PPA with PREPA, but the buyback rate has yet to be established. The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric rate of $0.13/kWh. Incentives offered by the federal government, the Commonwealth of Puerto Rico, and by PREPA were assumed in this analysis.[14]

The cost of PV systems in Puerto Rico varies and therefore two cost estimates were used. The first estimate is in the low range of current installed costs of PV systems and is based on costs of the 20 MW system that is currently being installed in Guayama by AES Ilumina. The second estimate is in the higher range of current installed costs of PV systems and is based on past costs of smaller scale systems. Further discussion regarding assumptions and input data for analysis can be found in Section 4.

3.2 Second Site Visit

3.2.1 Aguadilla Landfill

Aguadilla is located on the northwest shore of Puerto Rico west of Isabela and north of Moca and Aguada. The approximate population is currently 65,000. The Aguadilla Landfill is located to the east of Aguadilla's city center and is to the east of highway PR-2. The Aguadilla Landfill is directly to the north of Moca Landfill. The Aguadilla Landfill is not a highly visible site as it is surrounded by trees. Figure 5 shows various views of the Aguadilla Landfill.

[12] All Business. "Solar Power Project." http://www.allbusiness.com/energy-utilities/utilities-industry-electric-power-power/14753424-1.html. Accessed December 8, 2010.
[13] Marino, J. "Work to Start on 63 MW Solar Plant in Salinas." *Caribbean Business*. http://www.caribbeanbusinesspr.com/news03.php?nt_id=49337&ct_id=1. Accessed December 8, 2010.
[14] Calculations for this analysis assume the 30% federal tax credit incentive would be captured for the system.

Figure 5. Views of the feasible area for PV at the Aguadilla Landfill

Credits: Jimmy Salasovich, NREL

As shown in Figure 5, there are large expanses of flat, unshaded land, and the landfill is closed and capped, which makes it a great candidate for a PV system. There is good storm water control, which creates more stable ground conditions that are less likely to have settling issues. This is important for PV systems since settling could damage or destroy parts of the PV system. There are electrical points around the site where a PV system could tie into. Construction could potentially be started on this site immediately. This site would need to have a ballast-mounted system implemented, as ground disturbances are not permitted. The site was relatively well kept and mowed at the time of the site visit.

The total feasible area for PV is 21,249 m^2. Figure 6 shows the Aguadilla Landfill taken from Google Earth; the feasible area for PV is shaded in orange. As shown, there is one relatively large area at the Aguadilla Landfill that is feasible for PV. See Table 3 for the ground-mounted PV system possibilities at the Aguadilla Landfill. The three options outline the types of solar technology that could potentially be used. The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric rate of $0.13/kWh. The cost of PV systems in Puerto Rico varies and therefore two cost estimates and associated simple paybacks are given.

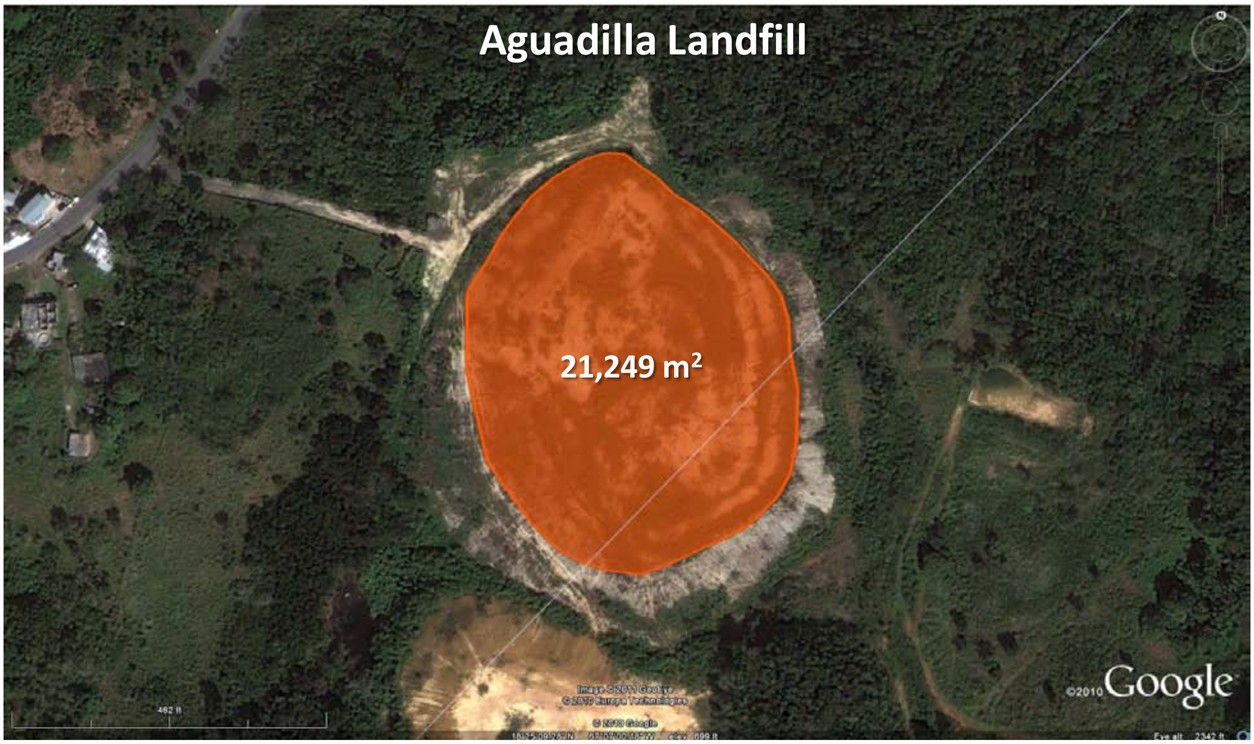

Figure 6. Aerial view of the feasible area for PV at the Aguadilla Landfill

Credit: Google Earth

Table 3. Aguadilla Landfill Site PV System Options

					System Cost Estimates with Incentives ($)		Simple Payback Estimates (years)	
System Type	**Potential System Size (kW)**	**Annual Energy Output (kWh)**	**Annual Cost Savings ($)**	**Annual O&M[a] ($/year)**	**Assuming Lower Cost[b]**	**Assuming Higher Cost[c]**	**Assuming Lower Cost[b]**	**Assuming Higher Cost[c]**
Crystalline Silicon—Fixed Tilt	800	1,281,600	$166,608	$9,520	$1,860,000	$3,820,000	11	24
Crystalline Silicon—Single-Axis Tracking	650	1,296,419	$168,534	$22,750	$2,175,000	$4,450,000	14	31
Thin Film—Fixed Tilt	350	560,700	$72,891	$3,808	$684,000	$1,468,000	10	21

[a] Annual O&M is based on the higher cost assumptions.
[b] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W and thin-film system costs are assumed to be $3.20/W.
[c] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W and thin-film system costs are assumed to be $6.40/W.

3.2.2 Añasco Landfill

The city of Añasco is located slightly inland off the west coast of Puerto Rico in a relatively mountainous region. The approximate population is currently 28,000. The Añasco Landfill is located to the north of the Añasco city center and just east of interstate PR-2 and is currently operating. The Añasco Landfill is not highly visible from interstate PR-2. Figure 7 shows various views of the Añasco Landfill.

Figure 7. Views of the feasible area for PV at the Añasco Landfill

Credits: Jimmy Salasovich, NREL

As shown in Figure 7, there are large expanses of flat, unshaded land. However, the Añasco Landfill is still active and is scheduled to be closed in 2011,[15] but this closure date is highly unlikely. There are electrical points a relatively short distance away that a PV system could tie into. Construction could potentially be started on this site once the landfill is closed and capped. This site would need to have a ballast-mounted system implemented on the landfill, as ground disturbances are not permitted.

The total feasible area for PV is 24,168 m^2. Figure 8 shows the Añasco Landfill taken from Google Earth; the feasible area for PV is shaded in orange. As shown, there is one relatively large area at the Añasco Landfill that is feasible for PV. See Table 4 for the ground-mounted PV system possibilities at the Añasco Landfill. The three options outline the types of solar technology that could potentially be used. The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the

[15] The projected closure date is based upon a study done in 2004 by Malcolm Pirnie Assoc. for the Puerto Rico Solid Waste Management Authority.

electricity at an electric rate of $0.13/kWh. The cost of PV systems in Puerto Rico varies and therefore two cost estimates and associated simple paybacks are given.

Figure 8. Aerial view of the feasible area for PV at the Añasco Landfill

Credit: Google Earth

Table 4. Añasco Landfill Site PV System Options

System Type	Potential System Size (kW)	Annual Energy Output (kWh)	Annual Cost Savings ($)	Annual O&M[a] ($/year)	System Cost Estimates with Incentives ($): Assuming Lower Cost[b]	System Cost Estimates with Incentives ($): Assuming Higher Cost[c]	Simple Payback Estimates (years): Assuming Lower Cost[b]	Simple Payback Estimates (years): Assuming Higher Cost[c]
Crystalline Silicon—Fixed Tilt	900	1,441,800	$187,434	$10,710	$2,105,000	$4,310,000	12	24
Crystalline Silicon—Single-Axis Tracking	750	1,495,868	$194,463	$26,250	$2,525,000	$5,150,000	14	31
Thin Film—Fixed Tilt	400	640,800	$83,304	$4,352	$796,000	$1,692,000	10	21

[a] Annual O&M is based on the higher cost assumptions.
[b] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[c] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.

3.2.3 Isabela Landfill

Isabela is located on the northwest shore of Puerto Rico to the east of Aguadilla. The current population of Isabela is approximately 44,000. The Isabela Landfill is located to the southwest of the city center and is currently operating. The landfill is not highly visible from the city or from surrounding highways, including Interstate PR-2. Figure 9 shows various views of the northern region of the Isabela Landfill, and Figure 10 shows various views of the southern region of the Isabela Landfill.

Figure 9. Views of the northern feasible area for PV at the Isabela Landfill

Credit: Jimmy Salasovich, NREL

Figure 10. Views of the southern feasible area for PV at the Isabela Landfill

Credit: Jimmy Salasovich, NREL

As shown in Figure 9 and Figure 10, there are large expanses of flat, unshaded land. However, the Isabela Landfill is still active even though it was scheduled to be closed originally in 2008.[16] At the present time, the landfill continues to receive waste and the municipality has approached the EPA regarding a possible lateral expansion. There are electrical lines on the site where a PV system could tie into. This site would need to have a ballast-mounted system implemented, as ground disturbances are not permitted. The site was relatively well kept at the time of the site visit.

The total feasible area for PV is 21,832 m^2. Figure 11 shows the Isabela Landfill taken from Google Earth; the feasible areas for PV are shaded in orange. As shown, there are three areas at the Isabela Landfill that are feasible for PV. The three regions are relatively closely spaced but are separated by slopes that are too steep for PV. See Table 5 for the ground-mounted PV system possibilities for the Isabela Landfill. The three options outline the types of solar technology that could potentially be used. The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric rate of $0.13/kWh. The cost of PV systems in Puerto Rico varies and therefore two cost estimates and associated simple paybacks are given.

[16] The projected closure date is based upon a study done in 2004 by Malcolm Pirnie Assoc. for the Puerto Rico Solid Waste Management Authority.

Figure 11. Aerial view of the feasible area for PV at the Isabela Landfill

Credit: Google Earth

Table 5. Isabela Landfill Site PV System Options

					System Cost Estimates with Incentives ($)		Simple Payback Estimates (years)	
System Type	**Potential System Size (kW)**	**Annual Energy Output (kWh)**	**Annual Cost Savings ($)**	**Annual O&M[a] ($/year)**	**Assuming Lower Cost[b]**	**Assuming Higher Cost[c]**	**Assuming Lower Cost[b]**	**Assuming Higher Cost[c]**
Crystalline Silicon—Fixed Tilt	850	1,361,700	$177,021	$10,115	$1,982,500	$4,065,000	12	24
Crystalline Silicon—Single-Axis Tracking	700	1,396,143	$181,499	$24,500	$2,350,000	$4,800,000	14	31
Thin Film—Fixed Tilt	350	560,700	$72,891	$3,808	$684,000	$1,468,000	10	21

[a] Annual O&M is based on the higher cost assumptions.
[b] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[c] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.

3.2.4 Mayagüez Landfill

The city of Mayagüez is located slightly inland off the west coast of Puerto Rico and is south of Añasco. The approximate population is currently 105,000. The Mayagüez Landfill is located to the north of the city center and just east of interstate PR-2. The Mayagüez Landfill is not highly visible from interstate PR-2. Figure 12 shows various views of the Mayagüez Landfill.

Figure 12. Views of the feasible area for PV at the Mayagüez Landfill

Credits: Jimmy Salasovich, NREL

As shown in Figure 12, there are large expanses of flat, unshaded land; however, the Mayagüez Landfill is still active. The projected closure date is 2011,[17] but this closure date is highly unlikely. There are electrical points a relatively short distance away that a PV system could tie into. Construction could potentially be started on this site once the landfill is closed and capped. This site would need to have a ballast-mounted system implemented on the landfill, as ground disturbances are not permitted.

The total feasible area for PV is 80,193 m^2. Figure 13 shows the Mayagüez Landfill taken from Google Earth; the feasible area for PV is shaded in orange. As shown, there is one relatively large area at the Mayagüez Landfill that is feasible for PV. See Table 6 for the ground-mounted PV system possibilities for the Mayagüez Landfill. The three options outline the types of solar technology that could potentially be used. The economics of the potential systems were

[17] The projected closure date is based upon a study done in 2004 by Malcolm Pirnie Assoc. for the Puerto Rico Solid Waste Management Authority.

analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric rate of $0.13/kWh. The cost of PV systems in Puerto Rico varies and therefore two cost estimates and associated simple paybacks are given.

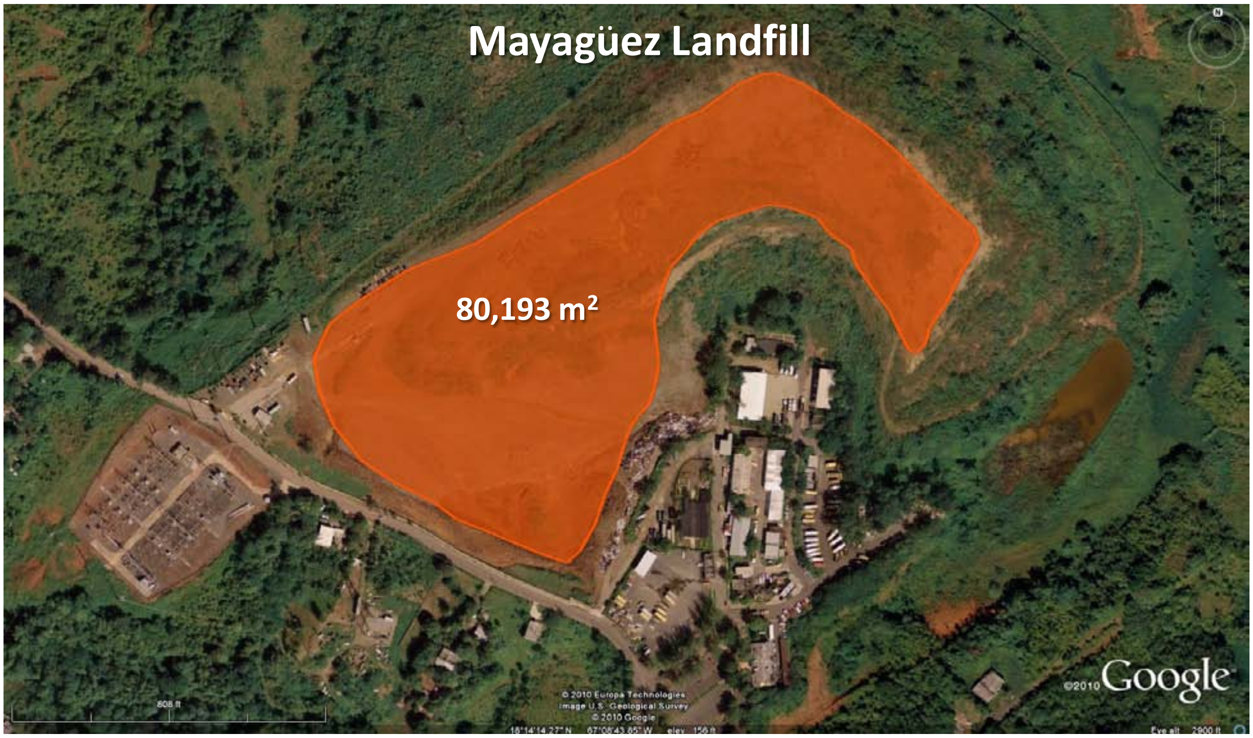

Figure 13. Aerial view of the feasible area for PV at the Mayagüez Landfill

Credit: Google Earth

Table 6. Mayagüez Landfill Site PV System Options

System Type	Potential System Size (kW)	Annual Energy Output (kWh)	Annual Cost Savings ($)	Annual O&M[a] ($/year)	System Cost Estimates with Incentives ($)		Simple Payback Estimates (years)	
					Assuming Lower Cost[b]	Assuming Higher Cost[c]	Assuming Lower Cost[b]	Assuming Higher Cost[c]
Crystalline Silicon—Fixed Tilt	3,100	4,966,200	$645,606	$36,890	$7,495,000	$15,090,000	12	25
Crystalline Silicon—Single-Axis Tracking	2,550	5,085,950	$661,173	$89,250	$8,825,000	$17,750,000	14	31
Thin Film—Fixed Tilt	1,300	2,082,600	$270,738	$14,144	$2,812,000	$5,724,000	11	22

[a] Annual O&M is based on the higher cost assumptions.
[b] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[c] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.

3.2.5 Moca Landfill PV System

The city of Moca is located slightly inland off the northwest coast of Puerto Rico and is located to the southeast of Aguadilla. The approximate population is currently 38,000. The Moca Landfill is located to the north of the city center and to the east of interstate PR-2. The Moca Landfill is directly to the south of the Aguadilla Landfill. The Moca Landfill is not a particularly visible site as it is nestled in the hills. Figure 14 shows various views of the Moca Landfill.

Figure 14. Views of the feasible area for PV at the Moca Landfill

Credits: Jimmy Salasovich, NREL

As shown in Figure 14, there are large expanses of flat, unshaded land. The Moca Landfill is scheduled to be closed in 2013,[18] but this closure date is highly unlikely. There are electrical points a relatively short distance away that a PV system could tie into. Construction could potentially be started on this site once the landfill is closed and capped. This site would need to have a ballast-mounted system implemented, as ground disturbances are not permitted.

The total feasible area for PV is 33,466 m^2. Figure 15 shows the Moca Landfill taken from Google Earth; the feasible area for PV is shaded in orange. As shown, there are two relatively large areas at the Moca Landfill that are feasible for PV. See Table 7 for the ground-mounted PV system possibilities for the Moca Landfill. The three options outline the types of solar technology that could potentially be used. The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric rate of $0.13/kWh. The cost of PV systems in Puerto Rico varies and therefore two cost estimates and associated simple paybacks are given.

[18] The projected closure date is based upon a study done in 2004 by Malcolm Pirnie Assoc. for the Puerto Rico Solid Waste Management Authority.

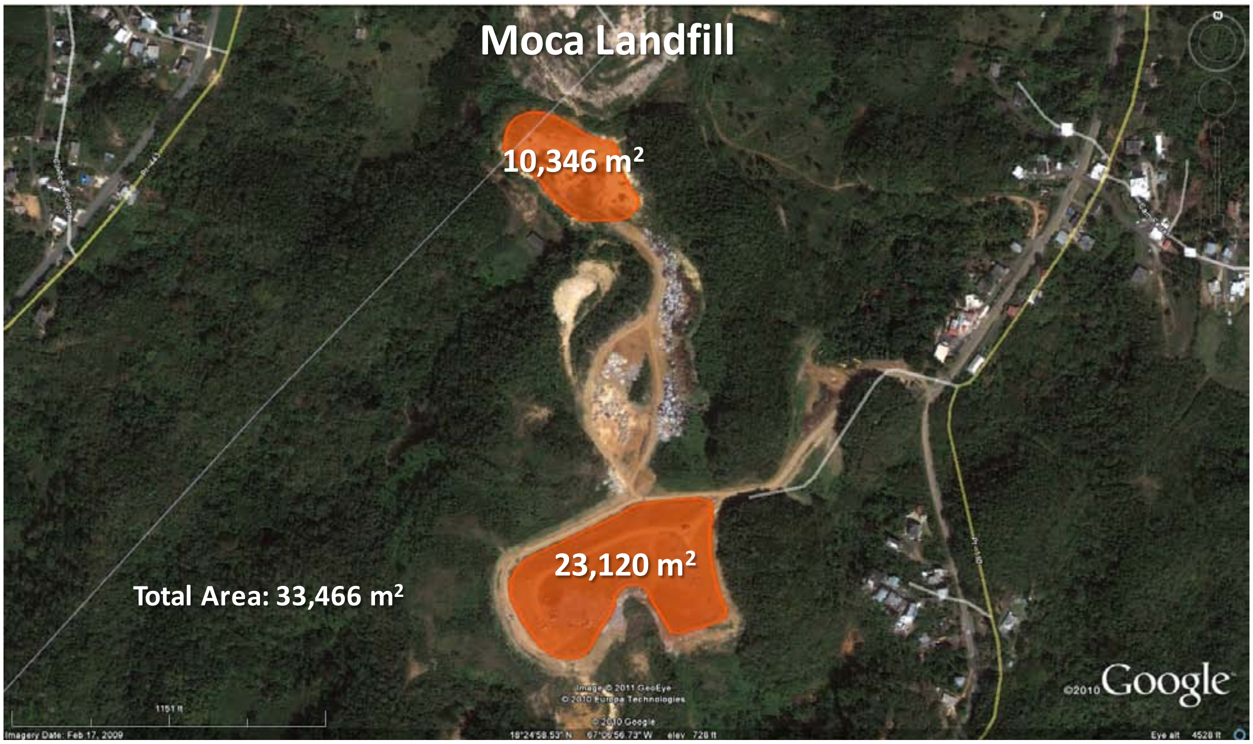

Figure 15. Aerial view of the feasible area for PV at the Moca Landfill

Credit: Google Earth

Table 7. Moca Landfill Site PV System Options

System Type	Potential System Size (kW)	Annual Energy Output (kWh)	Annual Cost Savings ($)	Annual O&M[a] ($/year)	System Cost Estimates with Incentives ($): Assuming Lower Cost[b]	System Cost Estimates with Incentives ($): Assuming Higher Cost[c]	Simple Payback Estimates (years): Assuming Lower Cost[b]	Simple Payback Estimates (years): Assuming Higher Cost[c]
Crystalline Silicon—Fixed Tilt	1,300	2,082,600	$270,738	$15,470	$3,085,000	$6,270,000	12	25
Crystalline Silicon—Single-Axis Tracking	1,050	2,094,215	$272,248	$36,750	$3,575,000	$7,250,000	14	31
Thin Film—Fixed Tilt	550	881,100	$114,543	$5,984	$1,132,000	$2,364,000	10	22

[a] Annual O&M is based on the higher cost assumptions.
[b] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[c] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.

3.3 Third Site Visit

3.3.1 Carolina Landfill

Carolina is located on the northeast shore of Puerto Rico east of San Juan. The approximate population is currently 189,000. The Carolina Landfill is located to the northwest of Carolina's city center. Figure 16 shows various views of the Carolina Landfill.

Figure 16. Views of the feasible area for PV at the Carolina Landfill

Credits: Jimmy Salasovich, NREL

As shown in Figure 16, there are large expanses of flat, unshaded land, and the landfill is closed and capped, which makes it a great candidate for a PV system. There are electrical points around the site where a PV system could tie into. Construction could potentially be started on this site immediately. This site would need to have a ballast-mounted system implemented, as ground disturbances are not permitted. The site was relatively well kept and mowed at the time of the site visit.

The total feasible area for PV is 17,712 m^2. Figure 17 shows the Carolina Landfill taken from Google Earth; the feasible area for PV is shaded in orange. As shown, there is one relatively large area at the Carolina Landfill that is feasible for PV. See Table 8 for the ground-mounted PV system possibilities at the Carolina Landfill. The three options outline the types of solar technology that could potentially be used. The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric rate of $0.13/kWh. The cost of PV systems in Puerto Rico varies and therefore two cost estimates and associated simple paybacks are given.

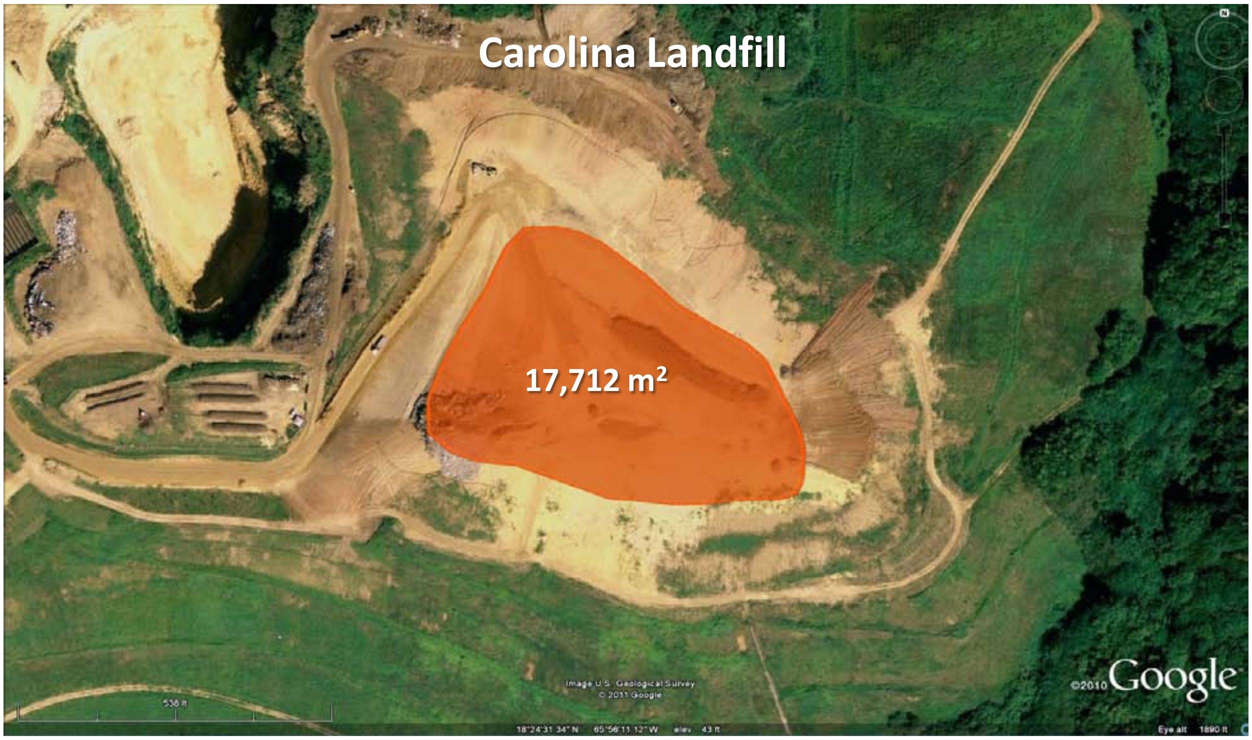

Figure 17. Aerial view of the feasible area for PV at the Carolina Landfill

Credit: Google Earth

Table 8. Carolina Landfill Site PV System Options

System Type	Potential System Size (kW)	Annual Energy Output (kWh)	Annual Cost Savings ($)	Annual O&M[a] ($/year)	System Cost Estimates with Incentives ($): Assuming Lower Cost[b]	System Cost Estimates with Incentives ($): Assuming Higher Cost[c]	Simple Payback Estimates (years): Assuming Lower Cost[b]	Simple Payback Estimates (years): Assuming Higher Cost[c]
Crystalline Silicon—Fixed Tilt	650	1,041,300	$135,369	$7,735	$1,492,500	$3,085,000	11	24
Crystalline Silicon—Single-Axis Tracking	550	1,096,970	$142,606	$19,250	$1,825,000	$3,750,000	14	30
Thin Film—Fixed Tilt	300	480,600	$62,478	$3,264	$572,000	$1,244,000	9	21

[a] Annual O&M is based on the higher cost assumptions.
[b] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[c] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.

3.3.2 Cayey Landfill

The city of Cayey is located in the central eastern region of Puerto Rico in a relatively mountainous region. The approximate population is currently 47,000. The Cayey Landfill is located to the northeast of the Cayey city center and is currently operating. Figure 18 shows various views of the Cayey Landfill.

Figure 18. Views of the feasible area for PV at the Cayey Landfill

Credits: Jimmy Salasovich, NREL

As shown in Figure 18, there are large expanses of flat, unshaded land. However, the Cayey Landfill is still active even though it was scheduled to be closed originally in 2008.[19] There are electrical points a relatively short distance away that a PV system could tie into. Construction could potentially be started on this site once the landfill is closed and capped. This site would need to have a ballast-mounted system implemented on the landfill, as ground disturbances are not permitted.

The total feasible area for PV is 9,270 m^2. Figure 19 shows the Cayey Landfill taken from Google Earth; the feasible area for PV is shaded in orange. As shown, there is one relatively large area at the Cayey Landfill that is feasible for PV. See Table 9 for the ground-mounted PV system possibilities at the Cayey Landfill. The three options outline the types of solar technology that could potentially be used. The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric

[19] The projected closure date is based upon a study done in 2004 by Malcolm Pirnie Assoc. for the Puerto Rico Solid Waste Management Authority.

rate of $0.13/kWh. The cost of PV systems in Puerto Rico varies and therefore two cost estimates and associated simple paybacks are given.

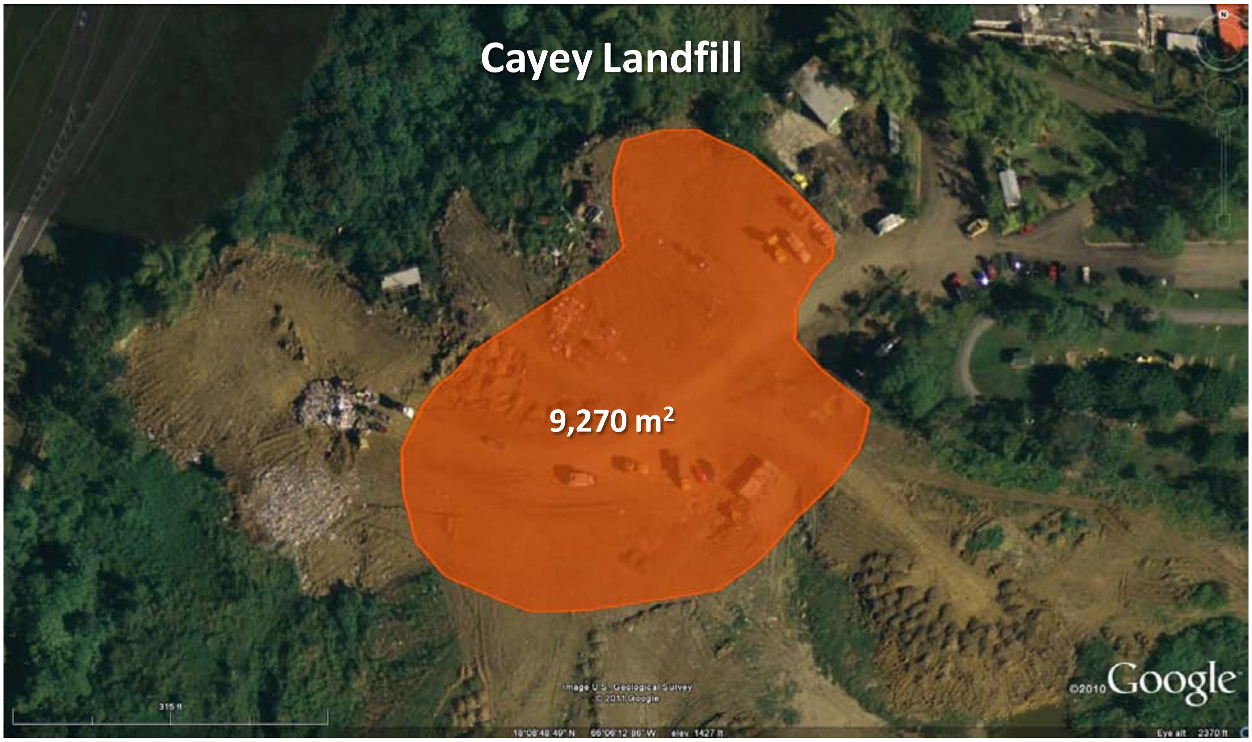

Figure 19. Aerial view of the feasible area for PV at the Cayey Landfill

Credit: Google Earth

Table 9. Cayay Landfill Site PV System Options

System Type	Potential System Size (kW)	Annual Energy Output (kWh)	Annual Cost Savings ($)	Annual O&M[a] ($/year)	System Cost Estimates with Incentives ($)		Simple Payback Estimates (years)	
					Assuming Lower Cost[b]	Assuming Higher Cost[c]	Assuming Lower Cost[b]	Assuming Higher Cost[c]
Crystalline Silicon—Fixed Tilt	350	560,700	$72,891	$4,165	$757,500	$1,615,000	11	23
Crystalline Silicon—Single-Axis Tracking	300	598,347	$77,785	$10,500	$950,000	$2,000,000	13	30
Thin Film—Fixed Tilt	150	240,300	$31,239	$1,632	$236,000	$572,000	9	19

[a] Annual O&M is based on the higher cost assumptions.
[b] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[c] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.

3.3.3 Fajardo Landfill

Fajardo is located on the east shore of Puerto Rico to the east of San Juan. The current population of Fajardo is approximately 41,000. The Fajardo Landfill is located to the southwest of the city center and is currently operating. Figure 20 shows various views of the Fajardo Landfill.

Figure 20. Views of the feasible area for PV at the Fajardo Landfill

Credit: Jimmy Salasovich, NREL

As shown in Figure 20, there are relatively large expanses of flat, unshaded land. However, the Fajardo Landfill is still active even though it was scheduled to be closed originally in 2008.[20] There are electrical lines on the site where a PV system could tie into. This site would need to have a ballast-mounted system implemented, as ground disturbances are not permitted.

The total feasible area for PV is 5,348 m^2. Figure 21 shows the Fajardo Landfill taken from Google Earth; the feasible areas for PV are shaded in orange. As shown, there is one area at the Fajardo Landfill that is feasible for PV. See Table 10 for the ground-mounted PV system possibilities for the Fajardo Landfill. The three options outline the types of solar technology that could potentially be used. The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric rate of $0.13/kWh. The cost of PV systems in Puerto Rico varies and therefore two cost estimates and associated simple paybacks are given.

[20] The projected closure date is based upon a study done in 2004 by Malcolm Pirnie Assoc. for the Puerto Rico Solid Waste Management Authority.

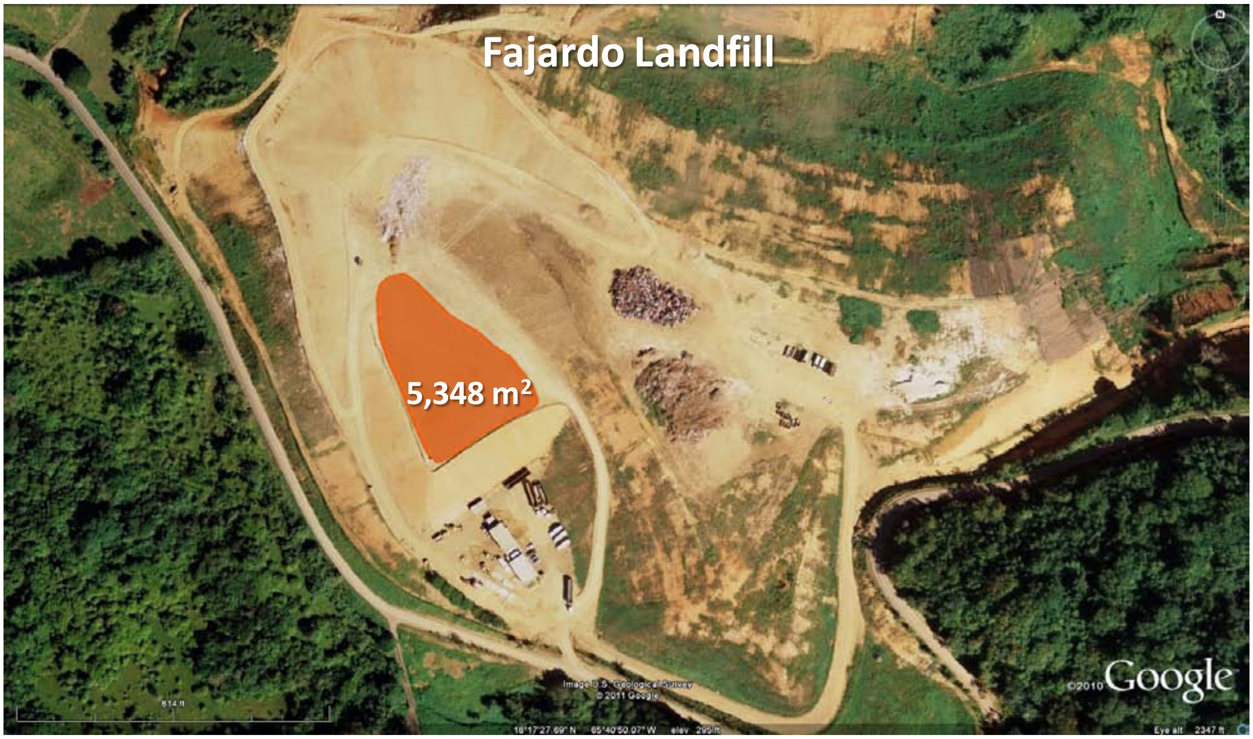

Figure 21. Aerial view of the feasible area for PV at the Fajardo Landfill

Credit: Google Earth

Table 10. Fajardo Landfill Site PV System Options

System Type	Potential System Size (kW)	Annual Energy Output (kWh)	Annual Cost Savings ($)	Annual O&M[a] ($/year)	System Cost Estimates with Incentives ($): Assuming Lower Cost[b]	System Cost Estimates with Incentives ($): Assuming Higher Cost[c]	Simple Payback Estimates (years): Assuming Lower Cost[b]	Simple Payback Estimates (years): Assuming Higher Cost[c]
Crystalline Silicon—Fixed Tilt	200	320,400	$41,652	$2,380	$390,000	$880,000	11	22
Crystalline Silicon—Single-Axis Tracking	150	299,174	$38,893	$5,250	$425,000	$950,000	12	28
Thin Film—Fixed Tilt	100	160,200	$20,826	$1,088	$124,000	$348,000	6	18

[a] Annual O&M is based on the higher cost assumptions.
[b] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[c] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.

3.3.4 Humacao Landfill

The city of Humacao is located on the east coast of Puerto Rico. The approximate population is currently 62,000. The Humacao Landfill is located to the southeast of the city center. Figure 22 shows various views of the Humacao Landfill.

Figure 22. Views of the feasible area for PV at the Humacao Landfill

Credits: Jimmy Salasovich, NREL

As shown in Figure 22, there are large expanses of flat, unshaded land; however, the Humacao Landfill is still active. The projected closure date is 2011,[21] but this closure date is highly unlikely. There are electrical points a relatively short distance away that a PV system could tie into. Construction could potentially be started on this site once the landfill is closed and capped. This site would need to have a ballast-mounted system implemented on the landfill, as ground disturbances are not permitted.

The total feasible area for PV is 95,912 m^2. Figure 23 shows the Humacao Landfill taken from Google Earth; the feasible area for PV is shaded in orange. As shown, there is one relatively large area at the Humacao Landfill that is feasible for PV. See Table 11 for the ground-mounted PV system possibilities for the Humacao Landfill. The three options outline the types of solar technology that could potentially be used. The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric rate of \$0.13/kWh. The cost of PV systems in Puerto Rico varies and therefore two cost estimates and associated simple paybacks are given.

[21] The projected closure date is based upon a study done in 2004 by Malcolm Pirnie Assoc. for the Puerto Rico Solid Waste Management Authority.

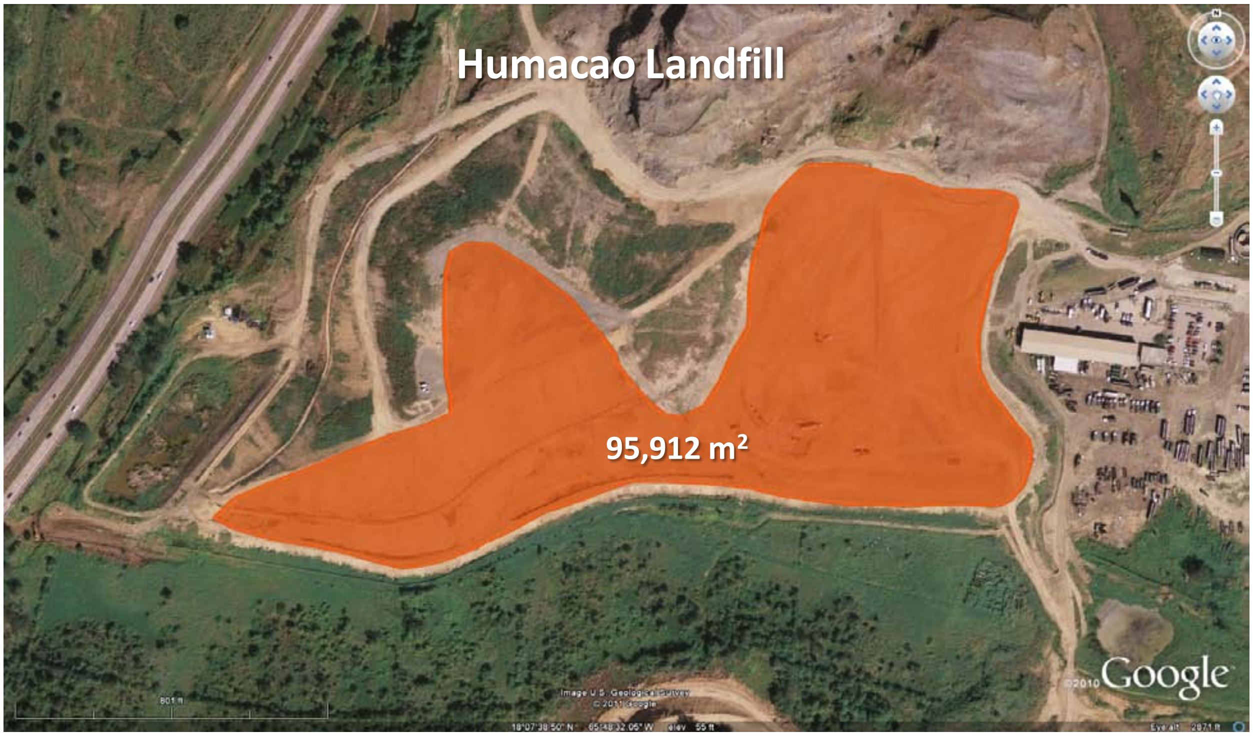

Figure 23. Aerial view of the feasible area for PV at the Humacao Landfill

Credit: Google Earth

Table 11. Humacao Landfill Site PV System Options

System Type	Potential System Size (kW)	Annual Energy Output (kWh)	Annual Cost Savings ($)	Annual O&M[a] ($/year)	System Cost Estimates with Incentives ($)		Simple Payback Estimates (years)	
					Assuming Lower Cost[b]	Assuming Higher Cost[c]	Assuming Lower Cost[b]	Assuming Higher Cost[c]
Crystalline Silicon—Fixed Tilt	3,700	5,927,400	$770,562	$44,030	$8,965,000	$18,030,000	12	25
Crystalline Silicon—Single-Axis Tracking	3,000	5,983,470	$777,851	$105,000	$10,400,000	$20,900,000	14	31
Thin Film—Fixed Tilt	1,550	2,483,100	$322,803	$16,864	$3,372,000	$6,844,000	11	22

[a] Annual O&M is based on the higher cost assumptions.
[b] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[c] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.

3.3.5 Juncos Landfill

The city of Juncos is located slightly inland off the east coast of Puerto Rico. The approximate population is currently 36,000. The Juncos Landfill is located to the north of the city center. Figure 24 shows various views of the Juncos Landfill.

Figure 24. Views of the feasible area for PV at the Juncos Landfill

Credits: Jimmy Salasovich, NREL

As shown in Figure 24, there are large expanses of flat, unshaded land. The Juncso Landfill is scheduled to be closed in 2013,[22] but this closure date is highly unlikely. There are electrical points a relatively short distance away that a PV system could tie into. Construction could potentially be started on this site once the landfill is closed and capped. This site would need to have a ballast-mounted system implemented, as ground disturbances are not permitted.

The total feasible area for PV is 14,599 m^2. Figure 25 shows the Juncos Landfill taken from Google Earth; the feasible area for PV is shaded in orange. As shown, there is one relatively large area at the Juncos Landfill that is feasible for PV. See Table 12 for the ground-mounted PV system possibilities for the Juncos Landfill. The three options outline the types of solar technology that could potentially be used. The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric rate of $0.13/kWh. The cost of PV systems in Puerto Rico varies and therefore two cost estimates and associated simple paybacks are given.

[22] The projected closure date is based upon a study done in 2004 by Malcolm Pirnie Assoc. for the Puerto Rico Solid Waste Management Authority.

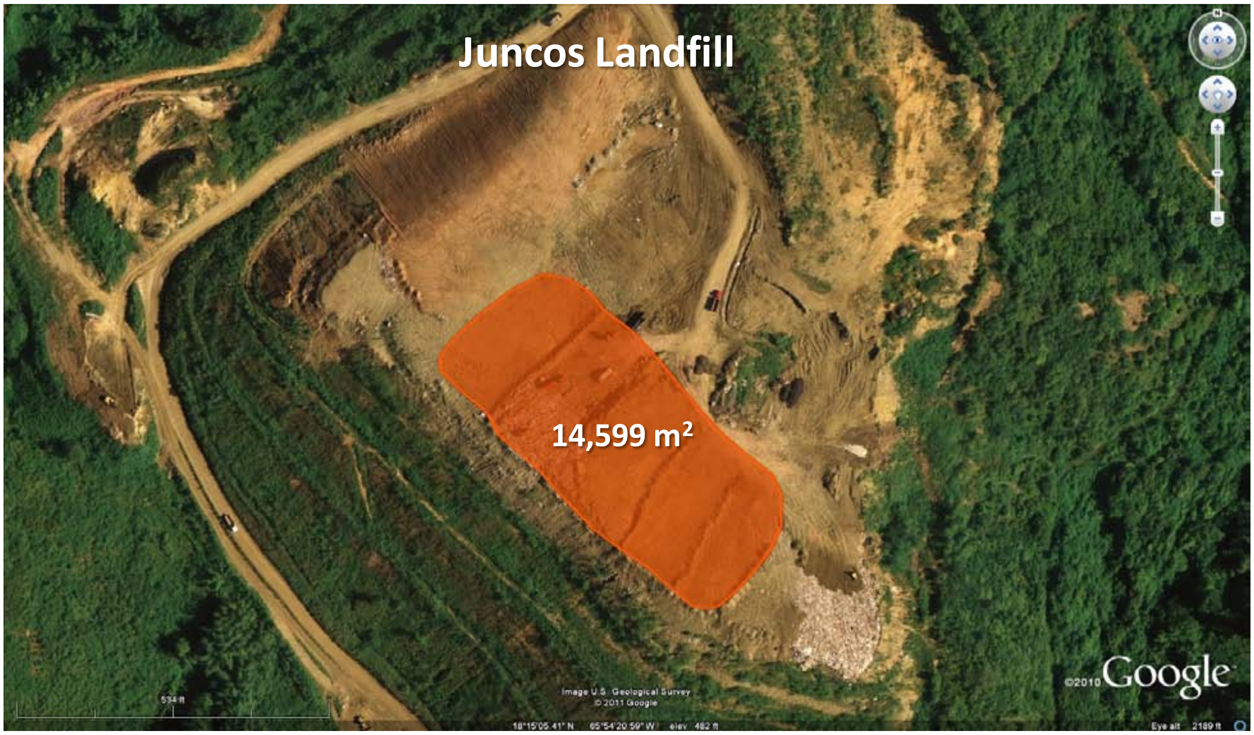

Figure 25. Aerial view of the feasible area for PV at the Juncos Landfill

Credit: Google Earth

Table 12. Juncos Landfill Site PV System Options

					System Cost Estimates with Incentives ($)		Simple Payback Estimates (years)	
System Type	**Potential System Size (kW)**	**Annual Energy Output (kWh)**	**Annual Cost Savings ($)**	**Annual O&M[a] ($/year)**	**Assuming Lower Cost[b]**	**Assuming Higher Cost[c]**	**Assuming Lower Cost[b]**	**Assuming Higher Cost[c]**
Crystalline Silicon—Fixed Tilt	550	881,100	$114,543	$6,545	$1,247,500	$2,595,000	11	24
Crystalline Silicon—Single-Axis Tracking	450	897,521	$116,678	$15,750	$1,475,000	$3,050,000	14	30
Thin Film—Fixed Tilt	200	320,400	$41,652	$2,176	$348,000	$796,000	9	20

[a] Annual O&M is based on the higher cost assumptions.
[b] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[c] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.

3.3.6 Vega Baja Landfill

The city of Vega Baja is located in the center of the north coast in of Puerto Rico. The approximate population is currently 63,000. The Vega Baja Landfill is located to the northeast of the city center. Figure 26 shows various views of the Vega Baja Landfill.

Figure 26. Views of the feasible area for PV at the Vega Baja Landfill

Credits: Jimmy Salasovich, NREL

As shown in Figure 26, there are large expanses of flat, unshaded land. The Vega Baja Landfill is scheduled to be closed in 2013,[23] but this closure date is highly unlikely. There are electrical points a relatively short distance away that a PV system could tie into. Construction could potentially be started on this site once the landfill is closed and capped. This site would need to have a ballast-mounted system implemented, as ground disturbances are not permitted.

The total feasible area for PV is 15,462 m^2. Figure 27 shows the Vega Baja Landfill taken from Google Earth; the feasible area for PV is shaded in orange. As shown, there is one relatively large area at the Vega Baja Landfill that is feasible for PV. See Table 13 for the ground-mounted PV system possibilities for the Vega Baja Landfill. The three options outline the types of solar technology that could potentially be used. The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric rate of $0.13/kWh. The cost of PV systems in Puerto Rico varies and therefore two cost estimates and associated simple paybacks are given.

[23] The projected closure date is based upon a study done in 2004 by Malcolm Pirnie Assoc. for the Puerto Rico Solid Waste Management Authority.

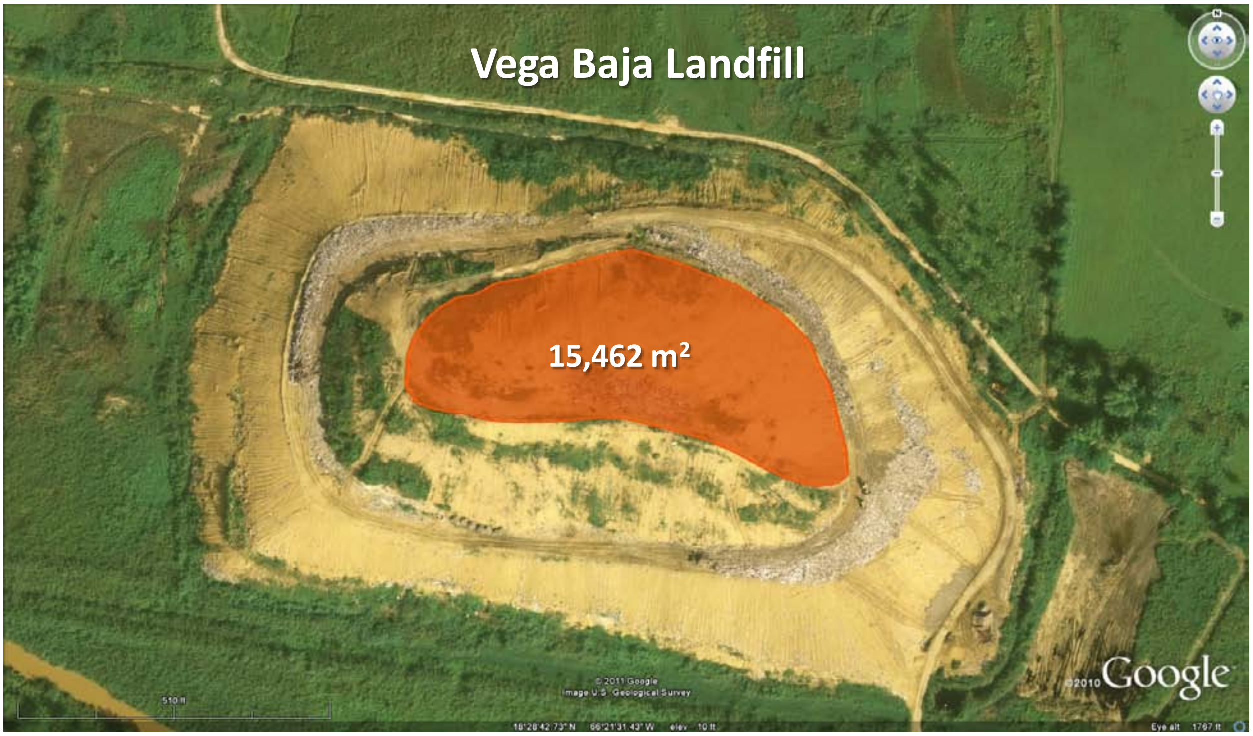

Figure 27. Aerial view of the feasible area for PV at the Vega Baja Landfill

Credit: Google Earth

Table 13. Vega Baja Landfill Site PV System Options

System Type	Potential System Size (kW)	Annual Energy Output (kWh)	Annual Cost Savings ($)	Annual O&M[a] ($/year)	System Cost Estimates with Incentives ($): Assuming Lower Cost[b]	System Cost Estimates with Incentives ($): Assuming Higher Cost[c]	Simple Payback Estimates (years): Assuming Lower Cost[b]	Simple Payback Estimates (years): Assuming Higher Cost[c]
Crystalline Silicon—Fixed Tilt	600	961,200	$124,956	$7,140	$1,370,000	$2,840,000	11	24
Crystalline Silicon—Single-Axis Tracking	500	997,245	$129,642	$17,500	$1,650,000	$3,400,000	14	30
Thin Film—Fixed Tilt	250	400,500	$52,065	$2,992	$460,000	$1,020,000	9	21

[a] Annual O&M is based on the higher cost assumptions.
[b] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[c] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.

3.4 Vieques Study

Vieques is a Puerto Rican island and is located to the east of Puerto Rico. The current population of Vieques is approximately 9,000.

3.4.1 Former Viequs Landing Strip

The Former Vieques Landing Strip is located in the south-center of the island and to the southwest of the Former Vieques Navel Training Range. The feasibility of a PV system at the Former Vieques Landing Strip was determined without visiting the site. An EPA team on site at Vieques provided the required information to perform the feasibility study, but there are no photos of the site.

There are large expanses of flat, unshaded land at the Former Vieques Landing Strip. The landing strip is no longer functional and therefore construction of a PV system could begin immediately. There are electrical lines close to the site where a PV system could tie into. Unlike at landfills, ground disturbances are permitted and therefore this site would not require a ballast-mounted system to be implemented, as ground disturbances are not permitted.

The total feasible area for PV at the Former Vieques Landing Strip is 233,279 m^2. Figure 28 shows the Former Vieques Landing Strip taken from Google Earth; the feasible areas for PV are shaded in orange. As shown, there is one large area at the Former Vieques Landing Strip that is feasible for PV. See Table 14 for the ground-mounted PV system possibilities for the Former Vieques Landing Strip. The three options outline the types of solar technology that could potentially be used. The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric rate of $0.13/kWh. The cost of PV systems in Puerto Rico varies and therefore two cost estimates and associated simple paybacks are given.

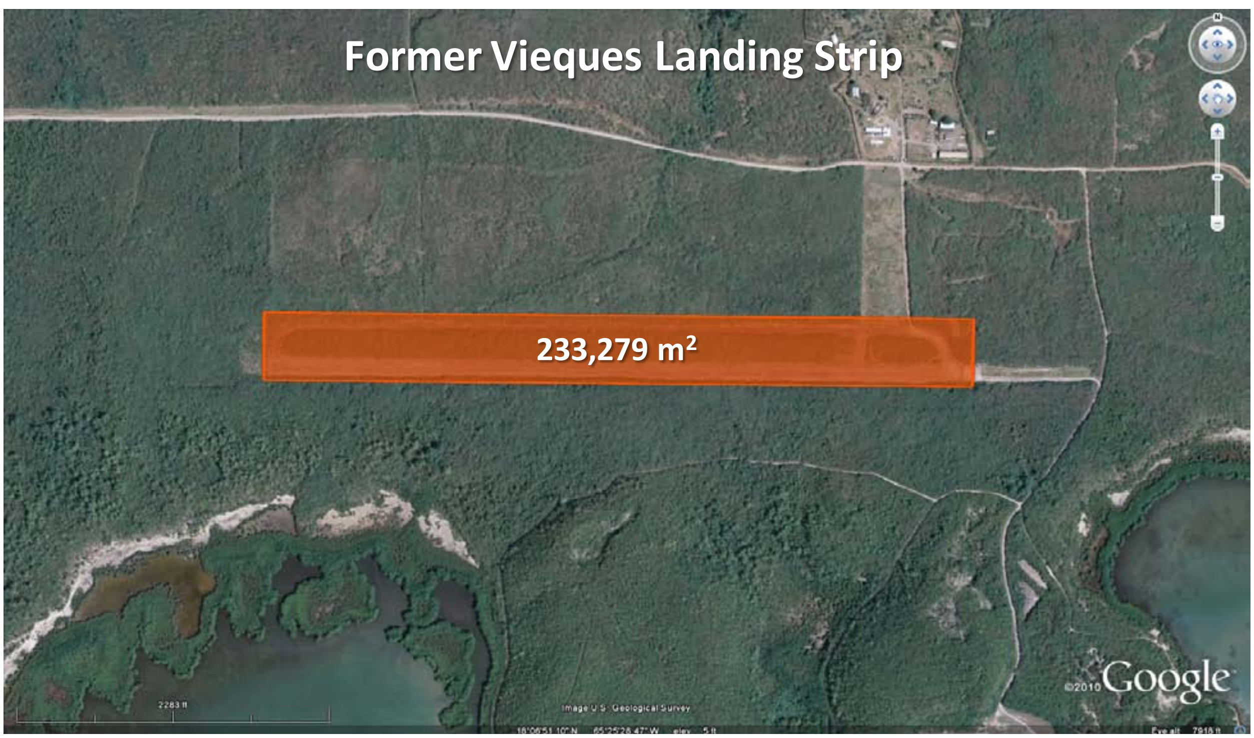

Figure 28. Aerial view of the feasible area for PV at the Former Vieques Landing Strip

Credit: Google Earth

Table 14. Former Vieques Landing Strip Site PV System Options

System Type	Potential System Size (kW)	Annual Energy Output (kWh)	Annual Cost Savings ($)	Annual O&M[a] ($/year)	System Cost Estimates with Incentives ($)		Simple Payback Estimates (years)	
					Assuming Lower Cost[b]	Assuming Higher Cost[c]	Assuming Lower Cost[b]	Assuming Higher Cost[c]
Crystalline Silicon—Fixed Tilt	9,000	14,418,000	$1,874,340	$107,100	$21,950,000	$44,000,000	12	25
Crystalline Silicon—Single-Axis Tracking	7,400	14,759,226	$1,918,699	$259,000	$25,800,000	$51,700,000	14	31
Thin Film—Fixed Tilt	3,800	6,087,600	$791,388	$41,344	$8,412,000	$16,924,000	11	23

[a] Annual O&M is based on the higher cost assumptions.
[b] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[c] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.

3.4.2 Former Vieques Naval Training Range

The Former Vieques Naval Training Range is located in the south-center of the island and directly to the northeast of the Former Vieques Landing Strip. The feasibility of a PV system at the Former Vieques Naval Training Range was determined without visiting the site. An EPA team on site at Vieques provided the required information to perform the feasibility study, but there are no photos of the site.

There are large expanses of flat, unshaded land at the Former Vieques Naval Training Range. The training range is no longer functional and therefore construction of a PV system could begin immediately. There are electrical lines close to the site where a PV system could tie into. Unlike at landfills, ground disturbances are permitted and therefore this site would not require a ballast-mounted system to be implemented.

The total feasible area for PV at the Former Vieques Naval Training Range is 116,643 m^2. Figure 29 shows the Former Vieques Naval Training Range taken from Google Earth; the feasible areas for PV are shaded in orange. As shown, there is one large area at the Former Vieques Naval Training Range that is feasible for PV. See Table 15 for the ground-mounted PV system possibilities for the Former Vieques Naval Training Range. The three options outline the types of solar technology that could potentially be used. The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric rate of $0.13/kWh. The cost of PV systems in Puerto Rico varies and therefore two cost estimates and associated simple paybacks are given.

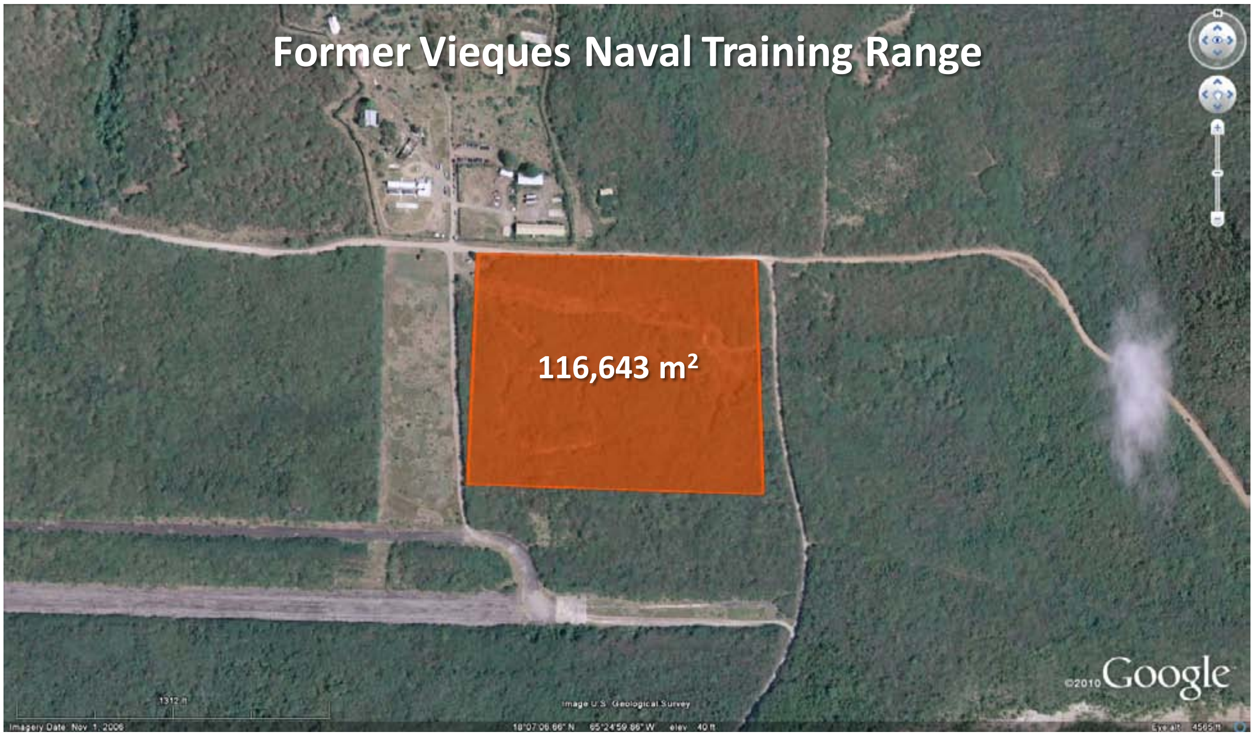

Figure 29. Aerial view of the feasible area for PV at the Former Vieques Naval Training Range

Credit: Google Earth

Table 15. Former Vieques Naval Training Range Site PV System Options

					System Cost Estimates with Incentives ($)		Simple Payback Estimates (years)	
System Type	**Potential System Size (kW)**	**Annual Energy Output (kWh)**	**Annual Cost Savings ($)**	**Annual O&M[a] ($/year)**	**Assuming Lower Cost[b]**	**Assuming Higher Cost[c]**	**Assuming Lower Cost[b]**	**Assuming Higher Cost[c]**
Crystalline Silicon—Fixed Tilt	4,500	7,209,000	$937,170	$53,550	$10,925,000	$21,950,000	12	25
Crystalline Silicon—Single-Axis Tracking	3,700	7,379,613	$959,350	$129,500	$12,850,000	$25,800,000	14	31
Thin Film—Fixed Tilt	1,900	3,043,800	$395,694	$20,672	$4,156,000	8,412,000	11	22

[a] Annual O&M is based on the higher cost assumptions.
[b] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[c] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.

3.4.3 Old Camp Garcia Landfill on Vieques

The Old Camp Garcia Landfill on Vieques is located in the south-center of the island and to the east of the Former Vieques Landing Strip and Naval Training Range. The feasibility of a PV system at the Old Camp Garcia Landfill on Vieques was determined without visiting the site. An

EPA team on site at Vieques provided the required information to perform the feasibility study, but there are no photos of the site.

There are large expanses of flat, unshaded land at the Old Camp Garcia Landfill on Vieques. The landfill is no longer operational and therefore construction of a PV system could begin immediately. There are electrical lines close to the site where a PV system could tie into. This site would need to have a ballast-mounted system implemented, as ground disturbances are not permitted.

The total feasible area for PV at the Old Camp Garcia Landfill on Vieques is 257,795 m^2. Figure 30 shows the Old Camp Garcia Landfill on Vieques taken from Google Earth; the feasible areas for PV are shaded in orange. As shown, there is one large area at the Old Camp Garcia Landfill on Vieques that is feasible for PV. See Table 16 for the ground-mounted PV system possibilities for the Old Camp Garcia Landfill on Vieques. The three options outline the types of solar technology that could potentially be used. The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric rate of $0.13/kWh. The cost of PV systems in Puerto Rico varies and therefore two cost estimates and associated simple paybacks are given.

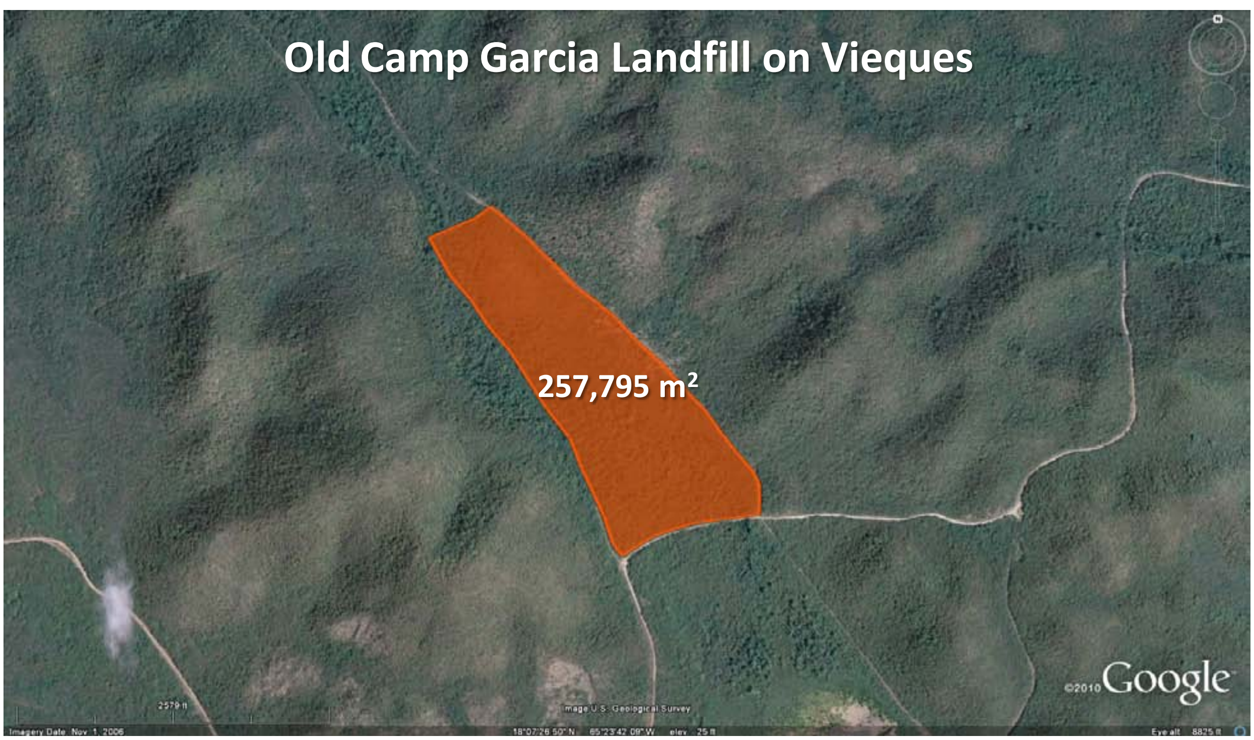

Figure 30. Aerial view of the feasible area for PV at the Old Camp Garcia Landfill on Vieques

Credit: Google Earth

Table 16. Old Camp Garcia Landfill on Vieques Site PV System Options

System Type	Potential System Size (kW)	Annual Energy Output (kWh)	Annual Cost Savings ($)	Annual O&M[a] ($/year)	System Cost Estimates with Incentives ($) Assuming Lower Cost[b]	Assuming Higher Cost[c]	Simple Payback Estimates (years) Assuming Lower Cost[b]	Assuming Higher Cost[c]
Crystalline Silicon—Fixed Tilt	10,000	16,020,000	$2,082,600	$119,000	$24,400,000	$48,900,000	12	25
Crystalline Silicon—Single-Axis Tracking	8,200	16,354,818	$2,126,126	$287,000	$28,600,000	$57,300,000	14	31
Thin Film—Fixed Tilt	4,200	6,728,400	$874,692	$45,696	$9,308,000	$18,716,000	11	23

[a] Annual O&M is based on the higher cost assumptions.
[b] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[c] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.

3.4.4 Old Vieques Municipal Landfill

The Old Vieques Municipal Landfill is located in the center of the island on the north shore. The feasibility of a PV system at the Old Vieques Municipal Landfill was determined without visiting the site. An EPA team on site at Vieques provided the required information to perform the feasibility study, but there are no photos of the site.

There are relatively large expanses of flat, unshaded land at the Old Vieques Municipal Landfill. The landfill is no longer functional and therefore construction of a PV system could begin immediately. There are electrical lines close to the site where a PV system could tie into. This site would need to have a ballast-mounted system implemented, as ground disturbances are not permitted.

The total feasible area for PV at the Old Vieques Municipal Landfill is 26,738 m^2. Figure 31 shows the Old Vieques Municipal Landfill taken from Google Earth; the feasible areas for PV are shaded in orange. As shown, there is one large area at the Old Vieques Municipal Landfill that is feasible for PV. See Table 17 for the ground-mounted PV system possibilities for the Old Vieques Municipal Landfill. The three options outline the types of solar technology that could potentially be used. The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric rate of $0.13/kWh. The cost of PV systems in Puerto Rico varies and therefore two cost estimates and associated simple paybacks are given.

Figure 31. Aerial view of the feasible area for PV at the Old Vieques Municipal Landfill

Credit: Google Earth

Table 17. Old Vieques Municipal Landfill Site PV System Options

System Type	Potential System Size (kW)	Annual Energy Output (kWh)	Annual Cost Savings ($)	Annual O&M[a] ($/year)	System Cost Estimates with Incentives ($): Assuming Lower Cost[b]	System Cost Estimates with Incentives ($): Assuming Higher Cost[c]	Simple Payback Estimates (years): Assuming Lower Cost[b]	Simple Payback Estimates (years): Assuming Higher Cost[c]
Crystalline Silicon—Fixed Tilt	1,000	1,602,000	$208,260	$11,900	$2,350,000	$4,800,000	12	24
Crystalline Silicon—Single-Axis Tracking	850	1,695,317	$220,391	$29,750	$2,875,000	$5,850,000	14	31
Thin Film—Fixed Tilt	400	640,800	$83,304	$4,352	$796,000	$1,692,000	10	21

[a] Annual O&M is based on the higher cost assumptions.
[b] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[c] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.

3.5 Summary of All Sites from Second Site Visit

Five landfills in Puerto Rico were considered for the second site visit, and all five landfills were found to be suitable for PV systems. Figure 32 shows a comparison of the landfills in Puerto Rico that were visited. The landfills are all at the same scale so that the relative size can be visualized. The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric rate of $0.13/kWh.

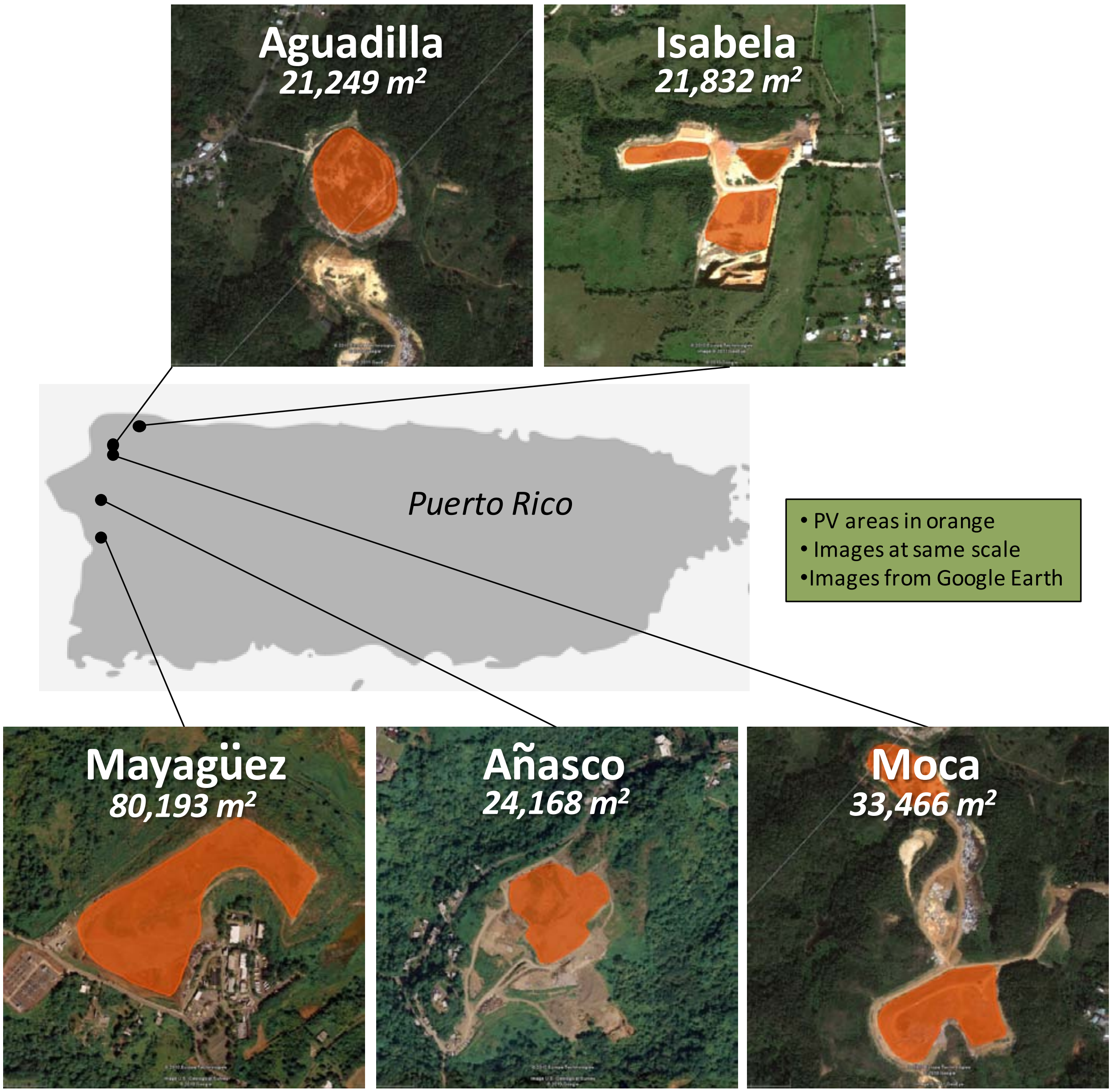

Figure 32. Second site visit—Comparison of the feasible areas for PV at landfills in Puerto Rico

Credits: Google Earth

Table 18 summarizes the system performance and economics of a potential system that would use all feasible landfill areas from the second site visit that were surveyed in Puerto Rico. All sites do not need to be developed in one project; beginning with a smaller demonstration system and increasing capacity as funds become available could be a better approach. Calculations for this analysis assume the 30% federal tax credit incentive would be captured for the system.

Table 18. Second Site Visit—PV System Performance and Economics by System Type[a]

					System Cost Estimates with Incentives ($)		Simple Payback Estimates (years)	
PV System Size (kW)	Annual Output (kWh/year)	Number of Houses Powered[b]	Annual Cost Savings ($/year)	Annual O&M[c] ($/year)	Assuming Lower Cost[d]	Assuming Higher Cost[e]	Assuming Lower Cost[d]	Assuming Higher Cost[e]
Crystalline Silicon (Fixed Tilt 18.4°)								
6,950	11,133,900	1,009	$1,447,407	$82,705	$16,527,500	$33,555,000	12	25
Crystalline Silicon (Single-Axis Tracking)								
5,700	11,368,593	1,030	$1,477,917	$199,500	$19,450,000	$39,400,000	14	31
Thin Film (Fixed Tilt 18.4°)								
2,950	4,725,900	428	$614,367	$32,096	$6,108,000	$12,716,000	10	22

[a] Data assume a maximum usable area of all feasible landfills of 180,908 m^2.
[b] Number of average American households that could hypothetically be powered by the PV system assuming 11,040 kWh/year/household.[24]
[c] Annual O&M is based on the higher cost assumptions.[d] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[e] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.

3.6 Summary of All Sites from Third Site Visit

Six landfills in Puerto Rico were considered for the third site visit, and all six landfills were found to be suitable for PV systems. Figure 33 shows a comparison of the landfills in Puerto Rico that were visited. The landfills are all at the same scale so that the relative size can be visualized. The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric rate of $0.13/kWh.

[24] U.S. Energy Information Administration. http://www.eia.doe.gov/ask/electricity_faqs.asp#electricity_use_home. Accessed October 22, 2010.

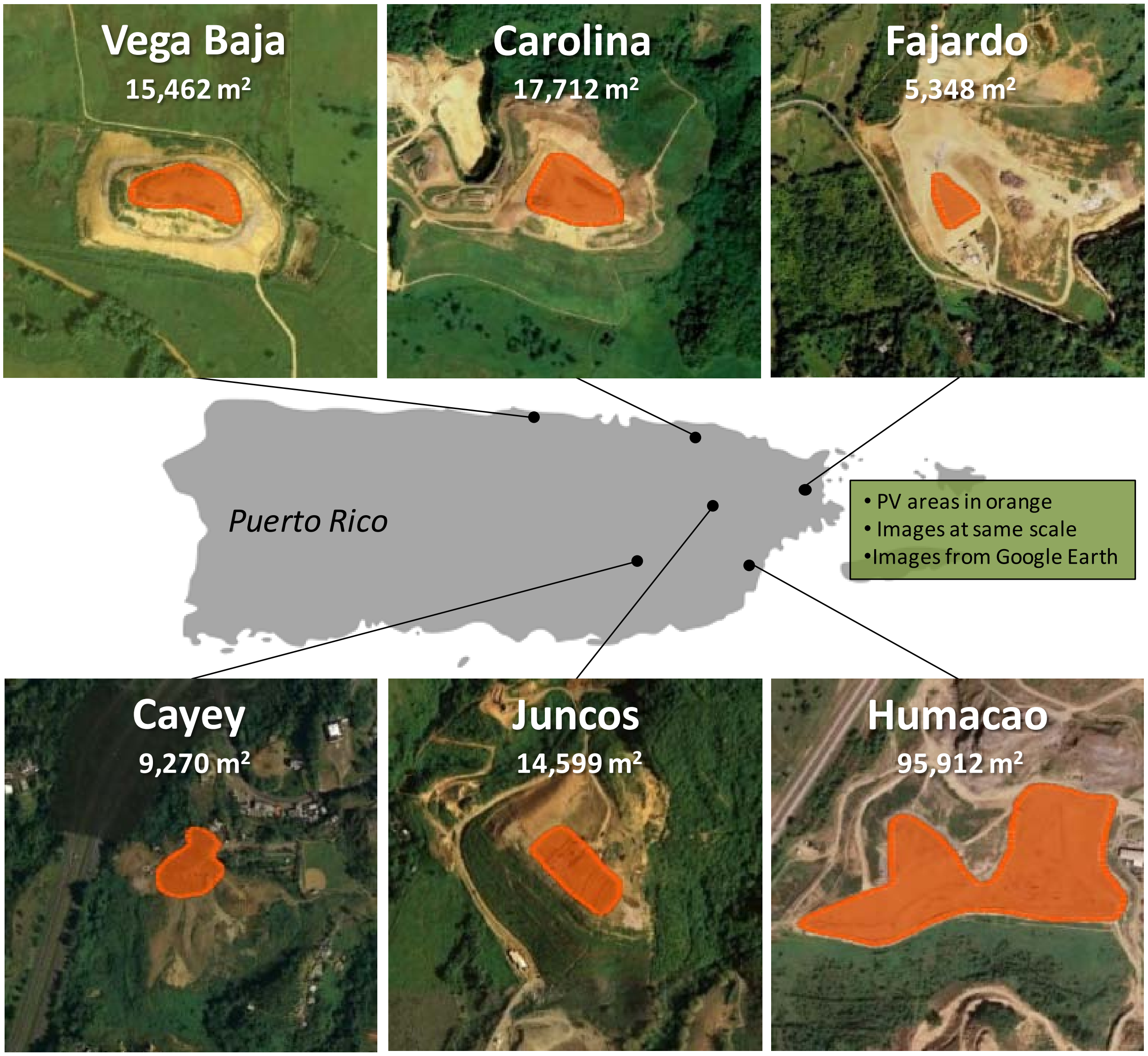

Figure 33. Third site visit—Comparison of the feasible areas for PV at landfills in Puerto Rico

Credits: Google Earth

Table 19 summarizes the system performance and economics of a potential system that would use all feasible landfill areas from the third site visit that were surveyed in Puerto Rico. All sites do not need to be developed in one project; beginning with a smaller demonstration system and increasing capacity as funds become available could be a better approach. Calculations for this analysis assume the 30% federal tax credit incentive would be captured for the system.

Table 19. Third Site Visit—PV System Performance and Economics by System Type[a]

PV System Size (kW)	Annual Output (kWh/year)	Number of Houses Powered[b]	Annual Cost Savings ($/year)	Annual O&M[c] ($/year)	System Cost Estimates with Incentives ($): Assuming Lower Cost[d]	System Cost Estimates with Incentives ($): Assuming Higher Cost[e]	Simple Payback Estimates (years): Assuming Lower Cost[d]	Simple Payback Estimates (years): Assuming Higher Cost[e]
Crystalline Silicon (Fixed Tilt 18.4°)								
6,050	9,692,100	878	$1,259,973	$71,995	$14,222,500	$29,045,000	12	24
Crystalline Silicon (Single-Axis Tracking)								
4,950	9,872,726	894	$1,283,454	$173,250	$16,725,000	$34,050,000	14	31
Thin Film (Fixed Tilt 18.4°)								
2,550	4,085,100	370	$531,063	$27,744	$5,112,000	$10,824,000	10	22

[a] Data assume a maximum usable area of all feasible landfills of 158,303 m^2.
[b] Number of average American households that could hypothetically be powered by the PV system assuming 11,040 kWh/year/household.[25]
[c] Annual O&M is based on the higher cost assumptions.
[d] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[e] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.

3.7 Summary of All Sites from Vieques

Four sites on the Puerto Rican island of Vieques were considered, and all four sites were found to be suitable for PV systems. Figure 34 shows a comparison of the sites in Vieques that were visited. The sites are all at the same scale so that the relative size can be visualized. The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric rate of $0.13/kWh.

[25] U.S. Energy Information Administration. http://www.eia.doe.gov/ask/electricity_faqs.asp#electricity_use_home. Accessed October 22, 2010.

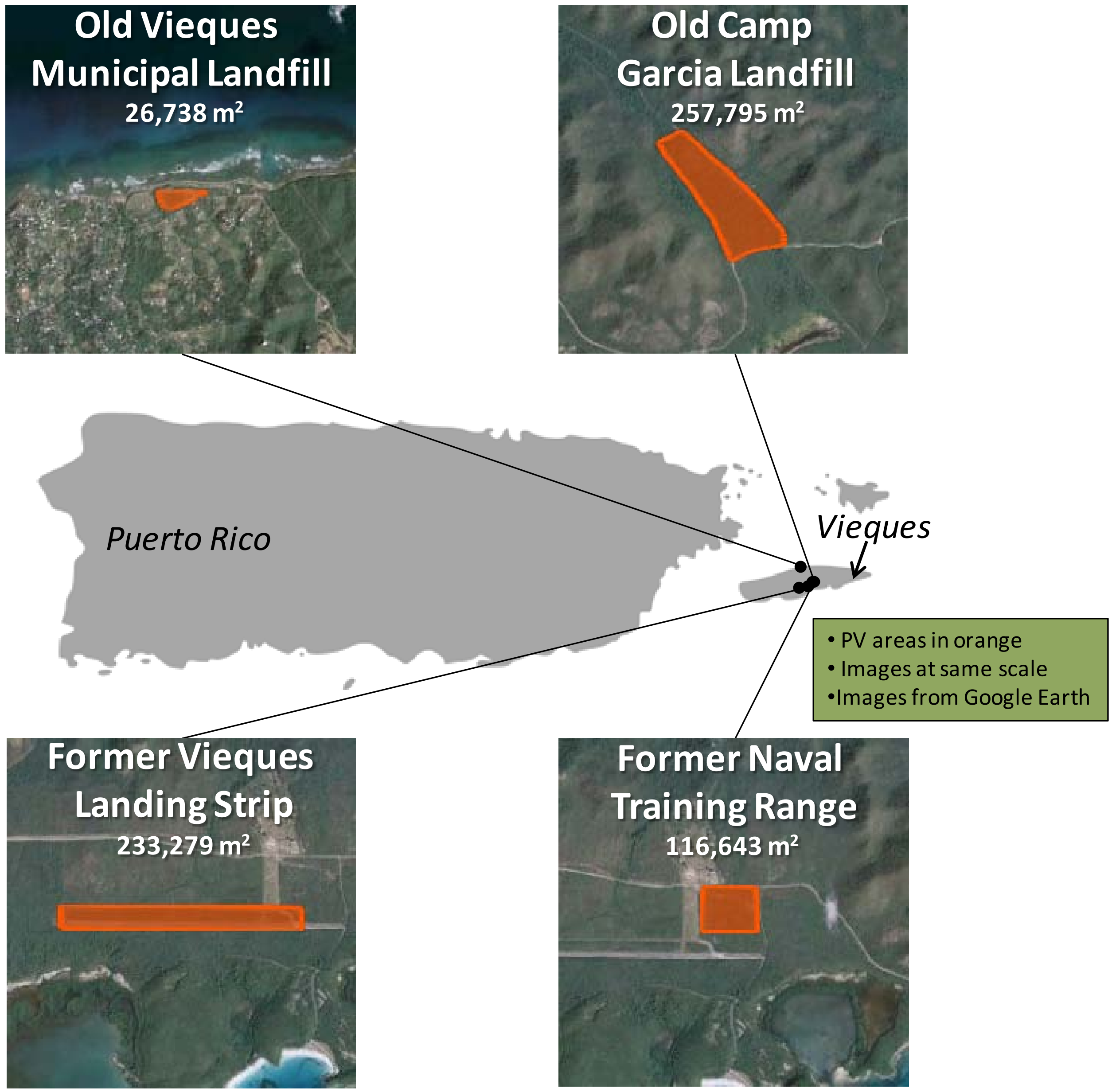

Figure 34. Comparison of the feasible areas for PV at sites on Vieques

Credits: Google Earth

Table 20 summarizes the system performance and economics of a potential system that would use all feasible sites that were surveyed in Vieques. All sites do not need to be developed in one project; beginning with a smaller demonstration system and increasing capacity as funds become available may be a better approach. Calculations for this analysis assume the 30% federal tax credit incentive would be captured for the system.

Table 20. Vieques—PV System Performance and Economics by System Type[a]

					System Cost Estimates with Incentives ($)		Simple Payback Estimates (years)	
PV System Size (kW)	Annual Output (kWh/year)	Number of Houses Powered[b]	Annual Cost Savings ($/year)	Annual O&M[c] ($/year)	Assuming Lower Cost[d]	Assuming Higher Cost[e]	Assuming Lower Cost[d]	Assuming Higher Cost[e]
Crystalline Silicon (Fixed Tilt 18.4°)								
24,500	39,249,000	3,555	$5,102,370	$291,550	$59,625,000	$119,650,000	12	25
Crystalline Silicon (Single-Axis Tracking)								
20,150	40,188,974	3,640	$5,224,567	$705,250	$70,125,000	$140,650,000	14	31
Thin Film (Fixed Tilt 18.4°)								
10,300	16,500,600	1,495	$2,145,078	$112,064	$22,672,000	$45,744,000	11	23

[a] Data assume a maximum usable area of all feasible sites of 634,455 m^2.
[b] Number of average American households that could hypothetically be powered by the PV system assuming 11,040 kWh/year/household.[26]
[c] Annual O&M is based on the higher cost assumptions.
[d] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[e] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.

[26] U.S. Energy Information Administration. http://www.eia.doe.gov/ask/electricity_faqs.asp#electricity_use_home. Accessed October 22, 2010.

4 Economics and Performance

4.1 Assumptions and Input Data for Analysis

The viability of PV depends greatly on the local electricity rate. According to the most recent annual report,[27] published in June 2009 by PREPA, average residential electric rates were $0.2158/kWh, average commercial rates were $0.2232/kWh, and average industrial rates were $0.1831/kWh. These electric rates are similar to those found in the Hawaiian Islands, and they are roughly double the average electric rate in the Unites States. The net-metering laws in Puerto Rico state that whatever the PV electric output above the customer use, PREPA will buy 75% of that at either the avoided fuel cost or $0.10/kWh, whichever is greater. The avoided fuel cost is in the range of $0.10/kWh or lower so $0.10/kWh was assumed. The PV system size limit for net metering is 25 kW for residential and 1 MW for commercial.

There is little to no electricity use at a closed landfill and all of the electricity generated by a proposed PV system is assumed to be sold back to the utility. From an economic standpoint, the current net-metering laws in Puerto Rico are not advantageous for PV systems that generate large amounts of excess energy because of the relatively low buyback rate of 75% of $0.10/kWh. Setting up a PPA where PREPA would agree to buy back the power at a higher rate would be much more beneficial. There are currently two large-scale PV projects in Puerto Rico that were both started in 2010 that use a PPA. The first project[28] is a 20 MW PV system in Guayama where AES Ilumina entered a PPA with PREPA where PREPA agreed to buy the electricity at a rate of $0.13/kWh. The second project[29] is a 63 MW PV system in Salinas where the CIRO One Group entered a PPA with PREPA, but the buyback rate has yet to be established.

The economics of the potential systems were analyzed assuming that a PPA with PREPA would be used and PREPA would buy back the electricity at an electric rate of $0.13/kWh. Incentives offered by the federal government, the Commonwealth of Puerto Rico, and PREPA were assumed in this analysis.

The cost of PV systems in Puerto Rico varies and therefore two cost estimates were used. The first estimate is in the low range of current installed costs of PV systems and is based on costs of the 20 MW system that is currently being installed in Guayama by AES Ilumina. The second estimate is in the higher range of current installed costs of PV systems and is based on past costs of smaller scale systems. The low-range installed cost for fixed-tilt ground-mounted systems was assumed to be $3.50/W for crystalline silicon and $3.20/W for thin film. The low-range installed cost for single-axis tracking systems was assumed to be $5.00/W for crystalline silicon. It was assumed that the low-range installed cost of fixed-tilt roof-mounted systems would be $6.00/W for crystalline silicon and $5.40/W for thin film. The high-range installed cost for fixed-tilt ground-mounted systems was assumed to be $7.00/W for crystalline silicon and $6.40/W for thin film. The high-range installed cost for single-axis tracking systems was assumed to be

[27] Thirty-Sixth Annual Report on the Electricity Property of the Puerto Rico Electric Power Authority. http://www.aeepr.com/INVESTORS/Financial%20Information/Annual%20Reports/ConsEng_36th_Rpt_2009%20Annual%20Report%20Final.pdf. Accessed December 8, 2010.
[28] All Business. "Solar Power Project." http://www.allbusiness.com/energy-utilities/utilities-industry-electric-power-power/14753424-1.html. Accessed December 8, 2010.
[29] Marino, J. "Work to Start on 63 MW Solar Plant in Salinas." *Caribbean Business*. http://www.caribbeanbusinesspr.com/news03.php?nt_id=49337&ct_id=1. Accessed December 8, 2010.

$10.00/W for crystalline silicon. It was assumed that the high-range installed cost of fixed-tilt roof-mounted systems would be $9.33/W for crystalline silicon and $8.73/W for thin film. These prices include the PV array and the balance-of-system components for each system, including the inverter, electrical equipment, and installation. The economics of grid-tied PV depend on incentives, the cost of electricity, and the solar resource including panel tilt and orientation.

A system DC to AC conversion of 77% was assumed. This includes losses in the inverter, wire losses, PV module losses, and losses due to temperature effects. PVWATTS[30] was used to calculate energy performance.

It was assumed for this analysis that federal and state incentives are received. Identifying and leveraging state incentives and grants is an important part of making PV systems cost effective. A private, tax-paying entity that owns PV systems can qualify for a 30% federal business energy investment tax credit (ITC) and accelerated depreciation on the PV system, which are worth about 15%. The total potential tax benefits to the tax-paying entity are about 45% of the system cost. Alternatively, the tax-paying entity can opt to receive a cash payment of up to 30% of eligible project costs from the U.S. Department of Treasury Section 1603 program[31] once the eligible system is in service. The American Reinvestment and Recovery Act of 2009 (Recovery Act) allows for this cash payment in lieu of the ITC. To receive the payment from the Treasury, construction of the property must begin no later than December 31, 2010. Because the federal government does not pay taxes, private ownership of the PV system is required to capture tax incentives or Section 1603 grant payments.[32] Municipalities are not tax-paying entities and therefore would have to pursue a PPA in order to get the 30% federal tax credit, which is described in Section 4.2.

4.2 Incentives and Financing Opportunities

The Database of State Incentives for Renewables and Efficiency (DSIRE) provides a summary of net metering, interconnection rules, and other incentives available to Puerto Rico utility customers.[33] The power from these systems could be sold to PREPA.

Renewable energy systems, including commercial solar PV, are subject to interconnection rules promulgated at the state level. Interconnection rules for Puerto Rico were found on the DSIRE website. PREPA adopted interconnection standards in 2007 that are based on the interconnections standards established in the federal Energy Policy Act of 2005.[34] This requires all interconnected systems to comply with the safety and performance requirements put forth in the IEEE Standard 1547 as well as local construction and safety standards.[35]

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[30] PVWATTS, http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/, Accessed July, 2011.

[31] This program was codified in Section 1603 of the American Recovery and Reinvestment Act of 2009.

[32] DSIRE. "Puerto Rico." http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=PR14F&re=1&ee=1. Accessed September 2010.

[33] DSIRE. "Puerto Rico." http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=PR14F&re=1&ee=1. Accessed September 2010.

[34] Energy Policy Act of 2005, http://doi.net/iepa/EnergyPolicyActof2005.pdf, Accessed July, 2011.

[35] DSIRE. "Puerto Rico." http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=PR14F&re=1&ee=1. Accessed September 2010.

State incentives are currently offered for commercial solar power systems in Puerto Rico for $4/DC-Watt for up to 50% of the project costs or $100,000, whichever is lower. State incentives of $8/DC-Watt up to $100,000 are offered for governmental systems. State incentives of $4/DC-Watt up to $15,000 are offered for residential systems. The 30% tax credit federal incentive can be captured if the system is owned by a tax-paying entity.

The system facilitator could potentially pursue an agreement with PREPA that would negotiate both a higher price for the electricity produced by the potential system and the potential to sell renewable energy certificates (RECs). Any power that is produced by a solar PV system will help the state reach its renewable portfolio standard (RPS) and be a major opportunity for PREPA to accelerate the diversification of their energy mix with clean energy. It has been demonstrated across the country that people are willing to pay a premium for certified clean energy,[36] and PREPA could start a voluntary green power purchase pilot program with energy from the landfills in Puerto Rico.[37]

Technical assistance to support project development is available through the U.S. Department of Energy (DOE) and the Office of Energy Efficiency and Renewable Energy (EERE). The activity provides technical assistance to commercial power developers, technology projects involving liquid fuels developed from biomass, and information to the public on renewable energy applications. The DOE Office of EERE can assist commercial wind and solar developers by providing detailed renewable resource maps, interfacing with Puerto Rico utilities, and contacting local economic developers.

There are several options for financing a solar PV system. However, obtaining investment from landowners with little on-site presence—such as is the case with the landfills in Puerto Rico—can be difficult. A potential alternative financing option is the third-party ownership PPA. The agreement works by having a solar contractor install, finance, and operate the system while the utility company purchases the electricity generated by the system. The system is financed by the solar contractor, and the payments are paid by the electricity and RECs that are sold to the utility. In this configuration, the land that the solar system is on would need to be leased to the owner of the system for the duration of the contract.

Another gap financing tool that may be available is tax increment financing (TIF). Connecticut, Iowa, Michigan, and Wisconsin have been leaders in structuring state-facilitated TIF as an effective and efficient means to enhance site reuse and redevelopment programs and to obtain successful cleanup and redevelopment results. Municipalities are good candidates for TIF because it is an incentive they can implement under their own control. A full list of incentives can be found in Appendix B.

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[36] Transmission & Distribution World. "NREL Highlights Utility Green Power Leaders." http://tdworld.com/customer_service/doe-nrel-utility-green-power-0409/. Accessed July 20, 2100.

[37] An example of such a program is Xcel Energy's Windsource program. For more information, see http://www.xcelenergy.com/Colorado/Company/Environment/Renewable%20Energy/Pages/Wind_Power.aspx. For detailed information about federal, state, and local incentives in Puerto Rico, see http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=PR14F&re=1&ee=1.

4.3 Job Creation

The implementation of this project would represent a large amount of money entering the clean energy industry of Puerto Rico. The Council of Economic Advisors (CEA) calculated the number of jobs (direct, indirect, and induced) created due to federal spending using economic models developed with real world data. CEA found that $92,000 in federal spending is equivalent to one job-year. This means that for every $92,000 of federal money that is spent, there is one job created that can be sustained for one year. This project represents a large amount of money that would create a significant number of jobs. A portion of these jobs, including the installation and system maintenance jobs, will be created within the community. The jobs created columns in Tables 21–26 refer to the number of job-years that would be created as a result of the one-time project capital investment. This means that the jobs will be created and sustained for one year. The jobs sustained columns refer to the number of jobs that would be sustained as a result of the O&M of the system. These jobs will be sustained for the life of the system, due to the annual cost to keep the system operating.

4.3.1 Second Site Visit

See Table 21 and Table 22 for an estimate of job creation by system type if all five landfills in Puerto Rico from the second site visit were used for solar PV.

Table 21. Second Site Visit—Estimated Job Creation by PV System Type Assuming Lower Installed Cost[a]

System Type	Jobs Created[b] (job years)	Jobs Sustained[c] (number of jobs)
Crystalline Silicon (Fixed Tilt)	180	0
Crystalline Silicon (Single-Axis Tracking)	211	1
Thin Film (Fixed Tilt)	66	0

[a] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[b] Job-years created as a result of project capital investment including direct, indirect, and induced jobs.
[c] Jobs (direct, indirect, and induced) sustained as a result of O&M of the system.

Table 22. Second Site Visit—Estimated Job Creation by PV System Type Assuming Higher Installed Cost[a]

System Type	Jobs Created[b] (job years)	Jobs Sustained[c] (number of jobs)
Crystalline Silicon (Fixed Tilt)	365	0
Crystalline Silicon (Single-Axis Tracking)	428	2
Thin Film (Fixed Tilt)	138	0

[a] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.
[b] Job-years created as a result of project capital investment including direct, indirect, and induced jobs.
[c] Jobs (direct, indirect, and induced) sustained as a result of O&M of the system.

4.3.2 Third Site Visit

See Table 23 and Table 24 for an estimate of job creation by system type if all six landfills in Puerto Rico from the third site visit were used for solar PV.

Table 23. Third Site Visit—Estimated Job Creation by PV System Type Assuming Lower Installed Cost[a]

System Type	Jobs Created[b] (job years)	Jobs Sustained[c] (number of jobs)
Crystalline Silicon (Fixed Tilt)	155	0
Crystalline Silicon (Single-Axis Tracking)	182	1
Thin Film (Fixed Tilt)	56	0

[a] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[b] Job-years created as a result of project capital investment including direct, indirect, and induced jobs.
[c] Jobs (direct, indirect, and induced) sustained as a result of O&M of the system.

Table 24. Third Site Visit—Estimated Job Creation by PV System Type Assuming Higher Installed Cost[a]

System Type	Jobs Created[b] (job years)	Jobs Sustained[c] (number of jobs)
Crystalline Silicon (Fixed Tilt)	316	1
Crystalline Silicon (Single-Axis Tracking)	370	2
Thin Film (Fixed Tilt)	118	0

[a] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.
[b] Job-years created as a result of project capital investment including direct, indirect, and induced jobs.
[c] Jobs (direct, indirect, and induced) sustained as a result of O&M of the system.

4.3.3 Vieques

See Table 25 and Table 26 for an estimate of job creation by system type if all four sites from the Vieques study were used for solar PV.

Table 25. Vieques—Estimated Job Creation by PV System Type Assuming Lower Installed Cost[a]

System Type	Jobs Created[b] (job years)	Jobs Sustained[c] (number of jobs)
Crystalline Silicon (Fixed Tilt)	648	2
Crystalline Silicon (Single-Axis Tracking)	762	4
Thin Film (Fixed Tilt)	246	1

[a] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[b] Job-years created as a result of project capital investment including direct, indirect, and induced jobs.
[c] Jobs (direct, indirect, and induced) sustained as a result of O&M of the system.

Table 26. Vieques—Estimated Job Creation by PV System Type Assuming Higher Installed Cost[a]

System Type	Jobs Created[b] (job years)	Jobs Sustained[c] (number of jobs)
Crystalline Silicon (Fixed Tilt)	1,301	3
Crystalline Silicon (Single-Axis Tracking)	1,529	8
Thin Film (Fixed Tilt)	497	1

[a] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.
[b] Job-years created as a result of project capital investment including direct, indirect, and induced jobs.
[c] Jobs (direct, indirect, and induced) sustained as a result of O&M of the system.

5 Hypothetical Electric Rate Increases

The economics of potential PV systems on landfills in Puerto Rico depend greatly on the cost of electricity and at what rate the utility will buy back the excess electricity. Currently, PREPA has entered a PPA where they agreed to buy back the electricity generated by a PV system at an electric rate of $0.13/kWh. This rate could hypothetically increase to $0.15/kWh or higher in a relatively short amount of time. A rate increase of this magnitude would further improve the economics of a solar PV generation plant.

5.1.1 Second Site Visit

See Table 27 and Table 28 for a summary of the system economics from the second site visit assuming a hypothetical buyback electric rate increase to $0.15/kWh.

Table 27. Second Site Visit—PV System Performance and Economics Assuming Lower Installed Cost[a] and with a Hypothetical Rate Increase to $0.15/kWh[b]

Array Tilt (Deg)	PV System Size (kW)	Annual Output (kWh/year)	Annual Cost Savings ($/year)	Annual O&M ($/year)	System Cost with Incentives ($)	Payback Period with Incentive (years)
Crystalline Silicon (Fixed Tilt)						
18.4	6,950	11,133,900	$1,670,085	$41,353	$16,527,500	10
Crystalline Silicon (Single-Axis Tracking)						
0	5,700	11,368,593	$1,705,289	$99,750	$19,450,000	12
Thin Film (Fixed Tilt)						
18.4	2,950	4,725,900	$708,885	$16,048	$6,108,000	9

[a] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[b] Data assume a maximum usable area of all feasible landfills of 180,908 m^2.

Table 28. Second Site Visit—PV System Performance and Economics Assuming Higher Installed Cost[a] and with a Hypothetical Rate Increase to $0.15/kWh[b]

Array Tilt (Deg)	PV System Size (kW)	Annual Output (kWh/year)	Annual Cost Savings ($/year)	Annual O&M ($/year)	System Cost with Incentives ($)	Payback Period with Incentive (years)
Crystalline Silicon (Fixed Tilt)						
18.4	6,950	11,133,900	$1,670,085	$82,705	$33,555,000	21
Crystalline Silicon (Single-Axis Tracking)						
0	5,700	11,368,593	$1,705,289	$199,500	$39,400,000	26
Thin Film (Fixed Tilt)						
18.4	2,950	4,725,900	$708,885	$32,096	$12,716,000	19

[a] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.
[b] Data assume a maximum usable area of all feasible landfills of 180,908 m^2.

5.1.2 Third Site Visit

See Table 29 and Table 30 for a summary of the system economics from the third site visit assuming a hypothetical buyback electric rate increase to $0.15/kWh.

Table 29. Third Site Visit—PV System Performance and Economics Assuming Lower Installed Costs[a] and with a Hypothetical Rate Increase to $0.15/kWh[b]

Array Tilt (Deg)	PV System Size (kW)	Annual Output (kWh/year)	Annual Cost Savings ($/year)	Annual O&M ($/year)	System Cost with Incentives ($)	Payback Period with Incentive (years)
Crystalline Silicon (Fixed Tilt)						
18.4	6,050	9,692,100	$1,453,815	$35,998	$14,222,500	10
Crystalline Silicon (Single-Axis Tracking)						
0	4,950	9,872,726	$1,480,909	$86,625	$16,725,000	12
Thin Film (Fixed Tilt)						
18.4	2,550	4,085,100	$612,765	$13,872	$5,112,000	9

[a] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[b] Data assume a maximum usable area of all feasible landfills of 158,303 m^2.

Table 30. Third Site Visit—PV System Performance and Economics Assuming Higher Installed Cost[a] and with a Hypothetical Rate Increase to $0.15/kWh[b]

Array Tilt (Deg)	PV System Size (kW)	Annual Output (kWh/year)	Annual Cost Savings ($/year)	Annual O&M ($/year)	System Cost with Incentives ($)	Payback Period with Incentive (years)
Crystalline Silicon (Fixed Tilt)						
18.4	6,050	9,692,100	$1,453,815	$71,995	$29,045,000	21
Crystalline Silicon (Single-Axis Tracking)						
0	4,950	9,872,726	$1,480,909	$173,250	$34,050,000	26
Thin Film (Fixed Tilt)						
18.4	2,550	4,085,100	$612,765	$27,744	$10,824,000	19

[a] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.
[b] Data assume a maximum usable area of all feasible landfills of 158,303 m^2.

5.1.3 Vieques

See Table 31 and Table 32 for a summary of the system economics from Vieques assuming a hypothetical buyback electric rate increase to $0.15/kWh.

Table 31. Vieques—PV System Performance and Economics Assuming Lower Installed Cost[a] and with a Hypothetical Rate Increase to $0.15/kWh[b]

Array Tilt (Deg)	PV System Size (kW)	Annual Output (kWh/year)	Annual Cost Savings ($/year)	Annual O&M ($/year)	System Cost with Incentives ($)	Payback Period with Incentive (years)
Crystalline Silicon (Fixed Tilt)						
18.4	24,500	39,249,000	$5,877,350	$145,775	$59,625,000	10
Crystalline Silicon (Single-Axis Tracking)						
0	20,150	40,188,974	$6,028,346	$352,625	$70,125,000	12
Thin Film (Fixed Tilt)						
18.4	10,300	16,500,600	$2,475,090	$56,032	$22,672,000	9

[a] $3.50/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $5.00/W, and thin-film system costs are assumed to be $3.20/W.
[b] Data assume a maximum usable area of all feasible landfills of 634,455 m^2.

Table 32. Vieques—PV System Performance and Economics Assuming Higher Installed Cost[a] and with a Hypothetical Rate Increase to $0.15/kWh[b]

Array Tilt (Deg)	PV System Size (kW)	Annual Output (kWh/year)	Annual Cost Savings ($/year)	Annual O&M ($/year)	System Cost with Incentives ($)	Payback Period with Incentive (years)
Crystalline Silicon (Fixed Tilt)						
18.4	24,500	39,249,000	$5,887,350	$291,550	$119,650,000	21
Crystalline Silicon (Single-Axis Tracking)						
0	20,150	40,188,974	$6,028,346	$705,250	$140,650,000	26
Thin Film (Fixed Tilt)						
18.4	10,300	16,500,600	$2,475,090	$112,064	$45,744,000	19

[a] $7.00/W is for a crystalline silicon fixed-tilt system. Single-axis tracking system costs are assumed to be $10.00/W, and thin-film system costs are assumed to be $6.40/W.
[b] Data assume a maximum usable area of all feasible landfills of 634,455 m^2.

6 Conclusions and Recommendations

The landfills and sites considered in this report are all feasible areas in which to implement solar PV systems. Using obtainable and accessible land that is unavailable for other purposes allows for reuse of land that would not otherwise contribute to productivity for Puerto Rico. Installing a solar generation plant and the associated facilities on landfills and former landing strips and naval ranges relieves “greenfields” of land-use impacts. Developing solar facilities on landfills and abandoned sites can provide an economically viable reuse option for these sites in Puerto Rico. The landfills and sites have existing transmission capacity, roads, industrial zoning, and all other critical infrastructure in place for PV systems. One obstacle to PV on landfills and the sites on Vieques is that sites require little to no electricity once they are capped and closed. Therefore, finding a use for the electricity generated by the PV system is a key element.

It is recommended that the party ultimately responsible for facilitating the implementation of PV systems contact PREPA and attempt to set up an agreement in which PREPA would purchase the electricity generated at the sites studied. According to the site production calculations, the most cost-effective system in terms of return on investment is the thin-film fixed-tilt technology. The lower cost of the system combined with the ample land available makes a thin-film system a good fit for these sites. Thin-film technology is a proven technology that can be successfully implemented with a ballasted-style mounting system. Crystalline silicon system styles—both fixed-tilt and single-axis tracking systems—could also be implemented, but the increased cost of the crystalline silicon panels may extend the payback period.

For this feasibility study, system calculations and sizes were based on site area; however, actual system installation should be based on the availability of funds or on the amount of power that can be sold. Installing a small demonstration system and adding capacity as funding becomes available might make sense. When the system goes out to bid, a design-build contract should be issued that requests the best performance (kWh/year) at the best price and that allows vendors to optimize system configuration, including slope. A third-party ownership PPA provides the most feasible way for a system to be financed on these sites. All payback calculations assumed that the 30% federal tax credit would be captured for the systems.

In the coming years, increasing electrical rates and increased necessity for clean power will continue to improve the feasibility of implementing solar PV systems at these sites.

Appendix A. Assumptions for Calculations for Second Site Visit[38]

Table A-1. Second Site Visit—Assumptions for Calculations for Ground-Mounted PV Systems Assuming $3.50/W for Crystalline Silicon Fixed-Tilt Systems, $5.00/W for Single-Axis Tracking Systems, and $3.20/W for Thin-Film Fixed-Tilt Systems

Location	Array Tilt (Deg)	Max Usable Area (ft^2)	Rounded PV System Size (kW)	Annual Output (kWh/year)	Annual Cost Savings ($/year)	Annual O&M ($/year)	System Cost with Incentives ($)	Payback Period (years)
Crystalline Silicon (Fixed Tilt)								
Aguadilla	18.4	205,853	800	1,281,600	$166,608	$4,760	$1,860,000	11
Añasco	18.4	234,132	900	1,441,800	$187,434	$5,355	$2,105,000	12
Isabela	18.4	211,502	850	1,361,700	$177,021	$5,058	$1,982,500	12
Maygüez	18.4	776,874	3,100	4,966,200	$645,606	$18,445	$7,495,000	12
Moca	18.4	324,200	1,300	2,082,600	$270,738	$7,735	$3,085,000	12
All Site Total	18.4	1,752,561	6,950	11,133,900	$1,447,407	$41,353	$16,527,500	12
Crystalline Silicon (Single-Axis Tracking)								
Aguadilla	0	205,853	650	1,296,419	$168,534	$11,375	$2,175,000	14
Añasco	0	234,132	750	1,495,868	$194,463	$13,125	$2,525,000	13
Isabela	0	211,502	700	1,396,143	$181,499	$12,250	$2,350,000	13
Maygüez	0	776,874	2,550	5,085,950	$661,173	$44,625	$8,825,000	14
Moca	0	324,200	1,050	2,094,215	$272,248	$18,375	$3,575,000	14
All Site Total	0	1,752,561	5,700	11,368,593	$1,477,917	$99,750	$19,450,000	14
Thin Film (Fixed Tilt)								
Aguadilla	18.4	205,853	350	560,700	$72,891	$1,904	$684,000	10
Añasco	18.4	234,132	400	640,800	$83,304	$2,176	$796,000	10
Isabela	18.4	211,502	350	560,700	$72,891	$1,904	$684,000	10
Maygüez	18.4	776,874	1,300	2,082,600	$270,738	$7,072	$2,812,000	11
Moca	18.4	324,200	550	881,100	$114,543	$2,992	$1,132,000	10
All Site Total	18.4	1,752,561	2,950	4,725,900	$614,367	$16,048	$6,108,000	10

[38] The calculations in Appendix A assume that the 30% federal tax credit is secured.

Table A-2. Second Site Visit—Assumptions for Calculations for Ground-Mounted PV Systems Assuming $7.00/W for Crystalline Silicon Fixed-Tilt Systems, $10.00/W for Single-Axis Tracking Systems, and $6.40/W for Thin-Film Fixed-Tilt Systems

Location	Array Tilt (Deg)	Max Usable Area (ft^2)	Rounded PV System Size (kW)	Annual Output (kWh/year)	Annual Cost Savings ($/year)	Annual O&M ($/year)	System Cost with Incentives ($)	Payback Period (years)
Crystalline Silicon (Fixed Tilt)								
Aguadilla	18.4	205,853	800	1,281,600	$166,608	$9,520	$3,820,000	24
Añasco	18.4	234,132	900	1,441,800	$187,434	$10,710	$4,310,000	24
Isabela	18.4	211,502	850	1,361,700	$177,021	$10,115	$4,065,000	24
Maygüez	18.4	776,874	3,100	4,966,200	$645,606	$36,890	$15,090,000	25
Moca	18.4	324,200	1,300	2,082,600	$270,738	$15,470	$6,270,000	25
All Site Total	18.4	1,752,561	6,950	11,133,900	$1,447,407	$82,705	$33,555,000	25
Crystalline Silicon (Single-Axis Tracking)								
Aguadilla	0	205,853	650	1,296,419	$168,534	$22,750	$4,450,000	31
Añasco	0	234,132	750	1,495,868	$194,463	$26,250	$5,150,000	31
Isabela	0	211,502	700	1,396,143	$181,499	$24,500	$4,800,000	31
Maygüez	0	776,874	2,550	5,085,950	$661,173	$89,250	$17,750,000	31
Moca	0	324,200	1,050	2,094,215	$272,248	$36,750	$7,250,000	31
All Site Total	0	1,752,561	5,700	11,368,593	$1,477,917	$199,500	$39,400,000	31
Thin Film (Fixed Tilt)								
Aguadilla	18.4	205,853	350	560,700	$72,891	$3,808	$1,468,000	21
Añasco	18.4	234,132	400	640,800	$83,304	$4,352	$1,692,000	21
Isabela	18.4	211,502	350	560,700	$72,891	$3,808	$1,468,000	21
Maygüez	18.4	776,874	1,300	2,082,600	$270,738	$14,144	$5,724,000	22
Moca	18.4	324,200	550	881,100	$114,543	$5,984	$2,364,000	22
All Site Total	18.4	1,752,561	2,950	4,725,900	$614,367	$32,096	$12,716,000	22

Table A-3. Second Site Visit—Other Assumptions, Including Assumptions for Costs and System Types

Cost Assumptions				
Variable	**Quantity of Variable**	**Unit of Variable**		
Buyback Electricity Rate	$0.13	$/kWh		
Annual O&M (Fixed)	0.17%	% of installed cost		
Annual O&M (Tracking)	0.35%	% of installed cost		
System Assumptions **System Type**	**Annual Energy (kWh/kW)**	**Low Installed Cost Assumption ($/W)**	**High Installed Cost Assumption ($/W)**	**Energy Density (W/ft^2)**
Ground Crystalline Fixed	1,602	$3.50	$7.00	4.0
Ground Single-Axis Tracking	1,994	$5.00	$10.00	3.3
Ground Thin-Film Fixed	1,602	$3.20	$6.40	1.7
Roof Crystalline Fixed	1,602	$6.00	$9.33	10.0
Roof Thin-Film Fixed	1,602	$5.40	$8.73	4.3
Other Assumptions	Ground Utilization	90% of available area		
	Incentives	Federal tax credit and state incentives		

Appendix B. Assumptions for Calculations for Third Site Visit[39]

Table B-1. Third Site Visit—Assumptions for Calculations for Ground-Mounted PV Systems Assuming $3.50/W for Crystalline Silicon Fixed-Tilt Systems, $5.00/W for Single-Axis Tracking Systems, and $3.20/W for Thin-Film Fixed-Tilt Systems

Location	Array Tilt (Deg)	Max Usable Area (ft^2)	Rounded PV System Size (kW)	Annual Output (kWh/year)	Annual Cost Savings ($/year)	Annual O&M ($/year)	System Cost with Incentives ($)	Payback Period (years)
Crystalline Silicon (Fixed Tilt)								
Carolina	18.4	171,580	650	1,041,300	$135,369	$3,868	$1,492,500	11
Cayey	18.4	89,806	350	560,700	$72,891	$2,083	$757,500	11
Fajardo	18.4	51,812	200	320,400	$41,652	$1,190	$390,000	10
Humacao	18.4	929,141	3,700	5,927,400	$770,562	$22,015	$8,965,000	12
Juncos	18.4	141,431	550	881,100	$114,543	$3,273	$1,247,500	11
Vega Baja	18.4	149,791	600	961,200	$124,956	$3,570	$1,370,000	11
All Site Total	18.4	1,533,563	6,950	9,692,100	$1,259,973	$35,998	$14,222,500	12
Crystalline Silicon (Single-Axis Tracking)								
Carolina	0	171,580	550	1,096,970	$142,606	$9,625	$1,825,000	14
Cayey	0	89,806	300	598,347	$77,785	$5,250	$950,000	13
Fajardo	0	51,812	150	299,174	$38,893	$2,625	$425,000	12
Humacao	0	929,141	3,000	5,983,470	$777,851	$52,500	$10,400,000	14
Juncos	0	141,431	450	897,521	$116,678	$7,875	$1,475,000	14
Vega Baja	0	149,791	500	997,245	$129,642	$8,750	$1,650,000	14
All Site Total	0	1,533,563	4,950	9,872,726	$1,283,454	$86,625	$16,725,000	14
Thin Film (Fixed Tilt)								
Carolina	18.4	171,580	300	480,600	$62,478	$1,632	$572,000	9
Cayey	18.4	89,806	150	240,300	$31,239	$816	$236,000	8
Fajardo	18.4	51,812	100	160,200	$20,826	$544	$124,000	6
Humacao	18.4	929,141	1,550	2,483,100	$322,803	$8,432	$3,372,000	11
Juncos	18.4	141,431	200	320,400	$41,652	$1,088	$348,000	9
Vega Baja	18.4	149,791	250	400,500	$52,065	$1,360	$460,000	9
All Site Total	18.4	1,533,563	2,550	4,085,100	$531,063	$13,872	$5,112,000	10

[39] The calculations in Appendix A assume that the 30% federal tax credit is secured.

Table B-2. Third Site Visit—Assumptions for Calculations for Ground-Mounted PV Systems Assuming $7.00/W for Crystalline Silicon Fixed-Tilt Systems, $10.00/W for Single-Axis Tracking Systems, and $6.40/W for Thin-Film Fixed-Tilt Systems

Location	Array Tilt (Deg)	Max Usable Area (ft^2)	Rounded PV System Size (kW)	Annual Output (kWh/year)	Annual Cost Savings ($/year)	Annual O&M ($/year)	System Cost with Incentives ($)	Payback Period (years)
Crystalline Silicon (Fixed Tilt)								
Carolina	18.4	171,580	650	1,041,300	$135,369	$7,735	$3,085,000	24
Cayey	18.4	89,806	350	560,700	$72,891	$4,165	$1,615,000	23
Fajardo	18.4	51,812	200	320,400	$41,652	$2,380	$880,000	22
Humacao	18.4	929,141	3,700	5,927,400	$770,562	$44,030	$18,030,000	25
Juncos	18.4	141,431	550	881,100	$114,543	$6,545	$2,595,000	24
Vega Baja	18.4	149,791	600	961,200	$124,956	$7,140	$2,840,000	24
All Site Total	18.4	1,533,563	6,950	9,692,100	$1,259,973	$71,995	$29,045,000	24
Crystalline Silicon (Single-Axis Tracking)								
Carolina	0	171,580	550	1,096,970	$142,606	$19,250	$3,750,000	30
Cayey	0	89,806	300	598,347	$77,785	$10,500	$2,000,000	30
Fajardo	0	51,812	150	299,174	$38,893	$5,250	$950,000	28
Humacao	0	929,141	3,000	5,983,470	$777,851	$105,000	$20,900,000	31
Juncos	0	141,431	450	897,521	$116,678	$15,750	$3,050,000	30
Vega Baja	0	149,791	500	997,245	$129,642	$17,500	$3,400,000	30
All Site Total	0	1,533,563	4,950	9,872,726	$1,283,454	$173,250	$34,050,000	31
Thin Film (Fixed Tilt)								
Carolina	18.4	171,580	300	480,600	$62,478	$3,264	$1,244,000	21
Cayey	18.4	89,806	150	240,300	$31,239	$1,632	$572,000	19
Fajardo	18.4	51,812	100	160,200	$20,826	$1,088	$348,000	18
Humacao	18.4	929,141	1,550	2,483,100	$322,803	$16,864	$6,844,000	22
Juncos	18.4	141,431	200	320,400	$41,652	$2,176	$796,000	20
Vega Baja	18.4	149,791	250	400,500	$52,065	$2,720	$1,020,000	21
All Site Total	18.4	1,533,563	2,550	4,085,100	$531,063	$27,744	$10,824,000	22

Table B-3. Third Site Visit—Other Assumptions, Including Assumptions for Costs and System Types

Cost Assumptions				
Variable	**Quantity of Variable**	**Unit of Variable**		
Buyback Electricity Rate	$0.13	$/kWh		
Annual O&M (Fixed)	0.17%	% of installed cost		
Annual O&M (Tracking)	0.35%	% of installed cost		
System Assumptions **System Type**	**Annual Energy (kWh/kW)**	**Low Installed Cost Assumption ($/W)**	**High Installed Cost Assumption ($/W)**	**Energy Density (W/ft^2)**
Ground Crystalline Fixed	1,602	$3.50	$7.00	4.0
Ground Single-Axis Tracking	1,994	$5.00	$10.00	3.3
Ground Thin-Film Fixed	1,602	$3.20	$6.40	1.7
Roof Crystalline Fixed	1,602	$6.00	$9.33	10.0
Roof Thin-Film Fixed	1,602	$5.40	$8.73	4.3
Other Assumptions	Ground Utilization	90% of available area		
	Incentives	Federal tax credit and state incentives		

Appendix C. Assumptions for Calculations for Vieques[40]

Table C-1. Vieques—Assumptions for Calculations for Ground-Mounted PV Systems Assuming $3.50/W for Crystalline Silicon Fixed-Tilt Systems, $5.00/W for Single-Axis Tracking Systems, and $3.20/W for Thin-Film Fixed-Tilt Systems

Location	Array Tilt (Deg)	Max Usable Area (ft^2)	Rounded PV System Size (kW)	Annual Output (kWh/year)	Annual Cost Savings ($/year)	Annual O&M ($/year)	System Cost with Incentives ($)	Payback Period (years)
Crystalline Silicon (Fixed Tilt)								
Former Vieques Landing Strip	18.4	2,259,893	9,000	14,418,000	$1,874,340	$53,550	$21,950,000	12
Former Naval Training Range	18.4	1,129,982	4,500	7,209,000	$937,170	$26,775	$10,925,000	12
Old Camp Garcia Landfill	18.4	2,497,397	10,000	16,020,000	$2,082,600	$59,500	$24,400,000	12
Old Vieques Municipal Landfill	18.4	259,025	1,000	1,602,000	$208,260	$5,950	$2,350,000	12
All Site Total	18.4	6,146,297	24,500	39,249,000	$5,102,370	$145,775	$59,625,000	12
Crystalline Silicon (Single-Axis Tracking)								
Former Vieques Landing Strip	0	2,259,893	7,400	14,759,226	$1,918,699	$129,500	$25,800,000	14
Former Naval Training Range	0	1,129,982	3,700	7,379,613	$959,350	$64,750	$12,850,000	14
Old Camp Garcia Landfill	0	2,497,397	8,200	16,354,818	$2,126,126	$143,500	$28,600,000	14
Old Vieques Municipal Landfill	0	259,025	850	1,695,317	$220,391	$14,875	$2,875,000	14
All Site Total	0	6,146,297	20,150	40,188,974	$5,224,567	$352,625	$70,125,000	14
Thin Film (Fixed Tilt)								
Former Vieques Landing Strip	18.4	2,259,893	3,800	6,087,600	$791,388	$20,672	$8,412,000	11
Former Naval Training Range	18.4	1,129,982	1,900	3,043,800	$395,694	$10,336	$4,156,000	11
Old Camp Garcia Landfill	18.4	2,497,397	4,200	6,728,400	$874,692	$22,848	$9,308,000	11
Old Vieques Municipal Landfill	18.4	259,025	400	640,800	$83,304	$2,176	$796,000	10
All Site Total	18.4	6,146,297	10,300	16,500,600	$2,145,078	$56,032	$22,672,000	11

[40] The calculations in Appendix A assume that the 30% federal tax credit is secured.

Table C-2. Vieques—Assumptions for Calculations for Ground-Mounted PV Systems Assuming $7.00/W for Crystalline Silicon Fixed-Tilt Systems, $10.00/W for Single-Axis Tracking Systems, and $6.40/W for Thin-Film Fixed-Tilt Systems

Location	Array Tilt (Deg)	Max Usable Area (ft^2)	Rounded PV System Size (kW)	Annual Output (kWh/year)	Annual Cost Savings ($/year)	Annual O&M ($/year)	System Cost with Incentives ($)	Payback Period (years)
Crystalline Silicon (Fixed Tilt)								
Former Vieques Landing Strip	18.4	2,259,893	9,000	14,418,000	$1,874,340	$107,100	$44,000,000	25
Former Naval Training Range	18.4	1,129,982	4,500	7,209,000	$937,170	$53,550	$21,950,000	25
Old Camp Garcia Landfill	18.4	2,497,397	10,000	16,020,000	$2,082,600	$119,000	$48,900,000	25
Old Vieques Municipal Landfill	18.4	259,025	1,000	1,602,000	$208,260	$11,900	$4,800,000	24
All Site Total	18.4	6,146,297	24,500	39,249,000	$5,102,370	$291,550	$119,650,000	25
Crystalline Silicon (Single-Axis Tracking)								
Former Vieques Landing Strip	0	2,259,893	7,400	14,759,226	$1,918,699	$259,000	$51,700,000	31
Former Naval Training Range	0	1,129,982	3,700	7,379,613	$959,350	$129,500	$25,800,000	31
Old Camp Garcia Landfill	0	2,497,397	8,200	16,354,818	$2,126,126	$287,000	$57,300,000	31
Old Vieques Municipal Landfill	0	259,025	850	1,695,317	$220,391	$29,750	$5,850,000	31
All Site Total	0	6,146,297	20,150	40,188,974	$5,224,567	$705,250	$140,650,000	31
Thin Film (Fixed Tilt)								
Former Vieques Landing Strip	18.4	2,259,893	3,800	6,087,600	$791,388	$41,344	$16,924,000	23
Former Naval Training Range	18.4	1,129,982	1,900	3,043,800	$395,694	$20,672	$8,412,000	22
Old Camp Garcia Landfill	18.4	2,497,397	4,200	6,728,400	$874,692	$45,696	$18,716,000	23
Old Vieques Municipal Landfill	18.4	259,025	400	640,800	$83,304	$4,352	$1,692,000	21
All Site Total	18.4	6,146,297	10,300	16,500,600	$2,145,078	$112,064	$45,744,000	23

Table C-3. Vieques—Other Assumptions, Including Assumptions for Costs and System Types

Cost Assumptions				
Variable	**Quantity of Variable**	**Unit of Variable**		
Buyback Electricity Rate	$0.13	$/kWh		
Annual O&M (Fixed)	0.17%	% of installed cost		
Annual O&M (Tracking)	0.35%	% of installed cost		
System Assumptions **System Type**	**Annual Energy (kWh/kW)**	**Low Installed Cost Assumption ($/W)**	**High Installed Cost Assumption ($/W)**	**Energy Density (W/ft^2)**
Ground Crystalline Fixed	1,602	$3.50	$7.00	4.0
Ground Single-Axis Tracking	1,994	$5.00	$10.00	3.3
Ground Thin-Film Fixed	1,602	$3.20	$6.40	1.7
Roof Crystalline Fixed	1,602	$6.00	$9.33	10.0
Roof Thin-Film Fixed	1,602	$5.40	$8.73	4.3
Other Assumptions	Ground Utilization	90% of available area		
	Incentives	Federal tax credit and state incentives		

Appendix D. Renewable Energy Incentives[41]

Table D-1. Redevelopment and Renewable Energy Incentives and Financing Tools

Agency	Incentive Name	Incentive (I), Finance Tool (FT)	Public	Private	Funding Range
HUD	Brownfield Economic Development Initiative (BEDI) Competitive Grant Program	I	X	X[a]	$17.5 million appropriated in FY2010; Award cap TBD as of 2/27/10
HUD	Section 108 Loan Guarantee Program	FT	X	X[b]	Up to five times public entity's latest approved Community Development Block Grants (CDBG) amount

[a] Must be used in conjunction with Section 108 loan guarantee commitment.
[b] Through re-loan from public entity.

[41] The calculations in Appendix B assume that the 30% federal tax credit is secured.

Table D-2. Renewable Energy Development Incentives and Financing Tools Applicable to PV

Agency	Incentive Name	Incentive (I), Finance Tool (FT)	Public	Private	Funding Range
DOE	Loan Guarantee Program	FT	X	X	Not specified
DOE	Renewable Energy Production Incentive (REPI)	I	X		$0.021/kW
HUD	CDBG	I	X		Based on community needs formula
Treasury	1603 Renewable Energy Grant Program *option to ITC	I		X	30% of the cost basis of the renewable energy project
Treasury	Business Energy ITC *option to 1603	I		X	30% of project expenditures
Treasury	Clean Renewable Energy Bonds (CREB)	FT	X		Varies
Treasury	Modified Accelerated Cost-Recovery System (MACRS)	FT		X	Various depreciation deductions
Treasury	Qualified Energy Conservation Bonds (QECB)	FT	X		Varies
USDA	Rural Energy for America Program (REAP) Grants	I	X	X	25% of project cost; payment range $2.5K–$500K
USDA	Rural Energy for America Program (REAP) Loan Guarantees	FT	X	X	Up to 75% of project costs; max. $25 million/min. $5,000

Source: DSIRE. http://www.dsireusa.org/. Accessed September 2010.

Table D-3. State Rebates for Commercial-Sector PV Projects

The programs included here are ongoing rebate and grant programs administered by state agencies or by third-party organizations on behalf of state governments. In addition to the programs highlighted, about 75 utilities in the United States offer PV rebates. In some states, such as Colorado and Arizona, solar rebates from utilities are available nearly statewide that must comply with state RPSs, but these are not shown in the table. Finally, programs that are purely performance-based, such as Washington's production incentive and California's feed-in tariff, are not included in this table.

State	Program Name	Incentive Amount	REC Ownership	Funding Source
California	California Solar Initiative	Varies by sector and system size	Remains with project owner	Rate-payer funded
California	CEC - New Solar Homes Partnership	Varies. Incentives are adjusted based on expected performance and will decline over time based on the total installed capacity.	Remains with system owner	Rate-payer funded
Connecticut	Connecticut Clean Energy Fund (CCEF) - On-Site Renewable DG Program	For-profit owners: $3.00/W for first 100 kW, $2.00/W for next 100 kW. Not-for-profit owners: $4.50/W for first 100 kW, $4.00/W for next 100 kW. Additional $0.10/W premium for buildings that meet LEED Silver certification; CCEF also compensates system owners based on the estimated present value of the system's RECs.	RECs transfer to CCEF for systems 50 kW-PTC and larger. CCEF compensates system owners based on estimated present value of the system's RECs over 15 years.	CCEF (public benefits fund)
Delaware	Green Energy Program Incentives	Delmarva: 25% of installed cost (35% for non-profits and government); DEC: 33.3% of installed cost; Minis: 33.3% of installed cost, except 25% for Dover and Seaford; PV system cost may not exceed $12/W	Remains with project owner	Green Energy Fund (Delmarva), DEC Renewable Resources Fund, Municipal Utility Green Energy Fund (public benefits funds)
District of Columbia	Renewable Energy Incentive Program	$3/DC-Watt for first 3 kW; $2/DC-Watt for next 7 kW; $1/DC-Watt for next 10 kW	Remains with system owner	Sustainable Energy Trust Fund (public benefits fund)
Florida	Solar Energy System Incentives Program	$4/DC-Watt	Remains with system owner	General Revenue Funds (appropriated annually)

State	Program Name	Incentive Amount	REC Ownership	Funding Source
Illinois	DCEO - Solar and Wind Energy Rebate Program	Note (02/2010): Funding for FY 2010 has been fully allocated; no additional rebates are available. Residential and commercial: 30%; non-profit and public: 50%	Remains with customer/producer	Illinois Renewable Energy Resources Trust Fund (public benefits fund)
Maine	Solar and Wind Energy Rebate Program	$2/AC-Watt	Remains with customer/producer	Funded by assessment of up to 0.005 cents/kWh on transmission and distribution utilities; plus $500,000 per fiscal year (FY2009–2010 and FY2010–2011) for two years using Recovery Act funding.
Maryland	Mid-Size Solar Energy Grant Program	$500/kW for first 20 kW; $250/kW for next 30 kW; $150/kW for next 50 kW	Remains with project owner	Recovery Act
Maryland	Solar Energy Grant Program	$1.25/DC-Watt for first 2 kW; $0.75/W for next 6 kW; $0.25/W for next 12 kW	Remains with project owner	General Revenue Funds (appropriated annually); FY 2009 funds supplemented with RGGI proceeds
Massachusetts	CEC - Commonwealth Solar II Rebates	$1.00/DC-Watt base; $0.10/DC-Watt adder for MA components; $1.00/DC-Watt adder for moderate home value or for moderate income	Remains with project owner	Massachusetts Renewable Energy Trust
Massachusetts	CEC - Commonwealth Solar Stimulus	$1.50/DC-Watt for first 25 kW; $1.00/DC-Watt for 25–100 kW; $0.50/DC-Watt for 100–200 kW	Remains with project owner	Recovery Act
Nevada	NV Energy – Renewable Generations Rebate Program	(2010–2011 program year) Residential and small business: $2.30/AC-Watt; public facilities/schools: $5.00/AC-Watt	NV Energy	Rate-payer funded

State	Program Name	Incentive Amount	REC Ownership	Funding Source
New Jersey	New Jersey Customer-Sited Renewable Energy Rebates	Standard residential: $1.55/DC-Watt; Residential with energy efficiency: $1.75/DC-Watt; residential new construction: varies by efficiency, $1.00–1.75/DC-Watt; standard non-residential: $0.90/DC-Watt; non-residential with efficiency: $1.00/DC-Watt	Remains with project owner	New Jersey Societal Benefits Charge (public benefits fund)
New Jersey	Renewable Energy Manufacturing Incentives (for end-use PV installations)	Varies by equipment type, sector, and system size; ranges from $0.05–$0.55/DC-Watt.	Not applicable	New Jersey Societal Benefits Charge (public benefits fund)
New York	NYSERDA - PV Incentive Program	Residential (first 5 kW): $1.75/DC-Watt; non-residential (first 50 kW): $1.75/DC-Watt; non-profit, government, schools (first 25 kW): $1.75/DC-Watt; bonus incentive: $0.50/W for Energy Star homes and BIPV systems	First 3 years: NYSERDA; thereafter customer/generator	RPS surcharge
Ohio	ODOD - Advanced Energy Program Grants - Non-Residential Renewable Energy Incentive	$3.50/DC-Watt, may be reduced by shading	Not specified	Ohio Advanced Energy Fund
Oregon	Energy Trust - Solar Electric Buy-Down Program	Residential: $1.50/DC-Watt for Pacific Power; $1.75/DC-Watt for PGE; residential, third-party: $1/DC-Watt for Pacific Power; $1.25/DC-Watt for PGE; commercial: $0.50–1.00/W for Pacific Power; $0.75–1.25/W for PGE; non-profit/government: $0.75–1.25/W for Pacific Power; $1.00–1.50/W for PGE	Residential: RECs for first 5 years owned by customer/producer; non-residential: RECs for first 5 years owned by consumer/producer, then Energy Trust owns RECs for years 6–20	Energy Trust of Oregon (public benefits fund)

State	Program Name	Incentive Amount	REC Ownership	Funding Source
Pennsylvania	Pennsylvania Sunshine Solar Rebate Program	Residential: $2.25/DC-Watt; commercial: $1.25/DC-Watt for first 10 kW, $1.00/DC-Watt for next 90 kW, $0.75/DC-Watt for next 100 kW; low-income: 35% of installed costs	Not specified; net-metering customers generally retain title to RECs	Pennsylvania Energy Independence Fund (state bonds)
Puerto Rico	Puerto Rico - State Energy Program - Sun Energy Rebate Program	Solar PV: residential and commercial $4/DC-Watt; governmental $8/DC-Watt	Not addressed	Recovery Act State Energy Program funds
Tennessee	Tennessee Clean Energy Technology Grant	40% of installed cost	Not specified	State of Tennessee Economic and Community Development Energy Division
Vermont	Vermont Small-scale Renewable Energy Incentive Program	Individuals/businesses: $1.75/DC-Watt; multi-family, low-income: $3.50/DC-Watt	Not addressed	Utility settlement funds and the Vermont Clean Energy Development Fund
Wisconsin	Focus on Energy - Renewable Energy Cash-Back Rewards	Residential/businesses: $1.00/kWh for one year; non-profit/government: $1.50/kWh for one year (estimated one-year production using PVWATTS). Efficiency First participants: add $0.25/kWh for one year.	Not addressed	Focus on Energy Program

Source: DSIRE. http://www.dsireusa.org/. Accessed September 2010.
Note: The information provided in this table presents an overview of state incentives, but it should not be used as the only source of information when making purchasing decisions, investment decisions, tax decisions, or other binding agreements. For more information about individual programs listed above, visit the DSIRE website at http://www.dsireusa.org/.

Table D-4. State Tax Credits for Commercial-Sector PV Projects

State	Program Name	Eligible Recipients	Incentive Amount	Third-Party Owner Eligible	Non-Profit/Government Eligible
Arizona	Non-Residential Solar & Wind Tax Credit (Corporate)	Any non-residential installation is eligible, including those for non-profits and governments. Individuals, corporations and S corporations, and partnerships may claim the credit. Third-party financiers/installers/mfrs. of an eligible system may claim the credit.	10%	Yes	Yes
Florida	Renewable Energy Production Tax Credit	A non-residential taxpayer with facility placed in service or expanded after May 1, 2006. The credit is for electricity produced and sold by the taxpayer to an unrelated party during a given tax year. Florida corporate income taxpayers who own an interest in a general partnership, limited partnership, limited liability company, trust, or other artificial entity that owns a Florida renewable energy facility can apply for this credit.	$0.01/kWh	Not specified	Not specified
Georgia	Clean Energy Tax Credit (Corporate)	Taxpayer who has constructed, purchased, or leased renewable energy property and placed it in service.	35%	Yes	Not specified
Hawaii	Solar and Wind Energy Credit (Corporate)	Taxpayer that files a corporate net income tax return or franchise tax return; credit may be claimed for every eligible renewable energy technology system that is installed and placed in service. Third-party taxpaying entities may claim the credit if they install and own a system on a commercial taxpayer's building or on a non-profit or	35%	Yes	Yes

State	Program Name	Eligible Recipients	Incentive Amount	Third-Party Owner Eligible	Non-Profit/Government Eligible
		government building. Multiple owners of a single system may take a single tax credit. The credit is apportioned between the owners in proportion to their contribution to the system's cost.			
Iowa	Renewable Energy Production Tax Credits (Corporate)	Producers or purchasers of renewable energy from qualified facilities; installations must be at least 51% owned by a state resident or other qualifying owner and placed in service on or after July 1, 2005, and before January 1, 2012. Electricity must be sold to an unrelated person to qualify for the tax credit.	$0.015/kWh for 10 years after energy production begins	Yes, credits may be claimed by system owner or by purchaser of electricity. System owners must meet certain eligibility criteria.	Schools and cooperative associations are eligible owners. Credits may be transferred or sold one time.
Kentucky	Renewable Energy Tax Credit (Corporate)	Any installation on a dwelling unit or on property that is owned and used by the taxpayer as commercial property.	$3/DC-Watt	Not specified	Not specified
Kentucky	Tax Credit for Renewable Energy Facilities	Companies that build or renovate facilities that utilize renewable energy.	100% Kentucky income tax or limited liability entity tax	Not specified	Not specified
Louisiana	Tax Credit for Solar and Wind Energy Systems on Residential Property (Corporate)	Taxpayer who purchases and installs an eligible system or who purchases a new home with such a system already in place.	50%	No	No
Maryland	Clean Energy Production Tax Credit (Corporate)	All individuals and corporations that sell electricity produced by a qualified facility to an unrelated person; net-metering arrangements qualify.	$0.0085/kWh for 5 years after facility is placed in service	Not specified	No

State	Program Name	Eligible Recipients	Incentive Amount	Third-Party Owner Eligible	Non-Profit/Government Eligible
Montana	Alternative Energy Investment Tax Credit (Corporate)	Corporation, partnership, or small business corporation that makes a minimum investment of $5,000.	35%	No	No
New Mexico	Advanced Energy Tax Credit (Corporate)	Any taxpayer.	6%	No	No
New Mexico	Renewable Energy Production Tax Credit (Corporate)	Taxpayer who holds title to a qualified energy generator that first produced electricity on or before January 1, 2018, or a taxpayer who leases property upon which a qualified energy generator operates from a county or municipality under authority of an industrial revenue bond and if the qualified energy generator first produced electricity on or before January 1, 2018.	Varies annually over 10 years; $0.027/kWh average	Not specified	Not specified
New Mexico	Solar Market Development Tax Credit	Residents and non-corporate businesses, including agricultural enterprises.	10% of purchase and installation costs	No	No
North Carolina	Renewable Energy Tax Credit (Corporate)	Taxpayer who has constructed, purchased, or leased renewable energy property and placed it in service.	35% (distributed 7% per year for 5 years for non-residential installations)	Yes. For leasing, a taxpayer may take credit for property that the taxpayer leases if written verification is received from the owner that states that owner will not take credit for renewable energy installation.	No

State	Program Name	Eligible Recipients	Incentive Amount	Third-Party Owner Eligible	Non-Profit/Government Eligible
North Dakota	Renewable Energy Tax Credit	Corporate taxpayers filing a North Dakota income tax return. System must be installed on a building or on property owned or leased by the taxpayer in North Dakota.	15% (distributed 3% per year for 5 years)	A pass-through entity that installs the system at a property it owns or leases is considered the taxpayer. The credit amount allowed is determined at the pass-through entity level and must be passed through proportionally to corporate partners, shareholders, or members.	No
Oklahoma	Zero-Emission Facilities Production Tax Credit	Non-residential taxpayer who sells electricity to an unrelated person; non-taxable entities, including agencies of the State of Oklahoma, may transfer their credit to a taxpayer.	$0.0050/kWh for first 10 years of operation	Yes	Yes, nontaxable entities, including agencies of the State of Oklahoma, or political subdivisions thereof, can take advantage of the tax credit by transferring it to a taxable entity.
Oregon	Business Energy Tax Credit	Trade, business, or rental property owners who pay taxes for a business site in Oregon are eligible for the tax credit. The business, its partners, or its shareholders may use the credit. A project owner also can be an Oregon non-profit organization, tribe, or public entity that partners with an Oregon business or resident who has an Oregon tax liability. This can be done using the pass-through option.	50% (distributed 10% per year for 5 years)	Yes	A project owner can be a non-profit, tribe, or public entity that partners with a business or resident to take advantage of the pass-through option. The pass-through option allows a project owner to transfer the 35% Business Energy Tax Credit project eligibility to a pass-through partner for a lump-sum cash payment. The pass-through option rate for 5-year Business Energy Tax Credits effective October 1, 2003, is 25.5%. The pass-through option rate

State	Program Name	Eligible Recipients	Incentive Amount	Third-Party Owner Eligible	Non-Profit/Government Eligible
					for 1-year Business Energy Tax Credits (those with eligible costs of $20,000 or less) effective October 1, 2003, is 30.5%.
Puerto Rico	Puerto Rico - Solar Tax Credit (Corporate)	Any Puerto Rican taxpayer who has acquired, assembled, and installed eligible solar electric equipment.	75% during FY 2007–2008 and FY 2008–2009; 50% during FY 2009–2010 and FY 2010–2011; 25% starting FY 2011–2012	Not specified	Potentially; the tax credit may be transferred, sold, or otherwise given to "any other person."
Rhode Island	Residential Renewable Energy Tax Credit (Corporate)	Taxpayer who (1) owns, rents, or is the contract buyer of the dwelling(s) served by the system; the dwelling or dwellings must be in the main or secondary residence of the person who applies for the tax credit or of a tenant; (2) owns or is the contract buyer of the system and pays all or part of the cost of the system; or (3) is the contractor that owns the dwelling for speculative sale in which the system is installed.	25%	Yes. Credit is available to taxpayers who are the contract buyers of eligible systems and pay all or part of the cost of the system.	No
South Carolina	Solar Energy and Small Hydropower Tax Credit (Corporate)	Taxpayers who purchase and install an eligible system in or on a facility owned by the taxpayer.	25% for 2010; was 30% in 2009	No	No
Utah	Renewable Energy Systems Tax Credit (Corporate)	Any company that owns a qualified system.	Residential: 25%; Commercial: 10%	No	No

State	Program Name	Eligible Recipients	Incentive Amount	Third-Party Owner Eligible	Non-Profit/Government Eligible
Vermont	Business Tax Credit for Solar (Corporate)	Corporations that pay corporate income tax in Vermont that do not receive grants/funding from CEDF.	30% of expenditures for systems placed into service on or before December 31, 2010	Not specified	No

Source: DSIRE. http://www.dsireusa.org/. Accessed September 2010.
Note: The information provided in this table presents an overview of state incentives, but it should not be used as the only source of information when making purchasing decisions, investment decisions, tax decisions, or other binding agreements. For more information about individual programs listed above, visit the DSIRE Web site at http://www.dsireusa.org/.

Table D-5. U.S. Department of Energy Brightfields Program Grants[a]

Award Year	Award Amount	Project	Project Description	Project Status
2000	$30,000	Brockton, MA: Brownfields to Brightfields Project	"This project involved attracting a PV system manufacturer to a Brockton Brownfield and building a solar array on a second site. Anticipation: This array will bring into productive use up to 27 acres of idle property and the array could also generate up to 6 MW of electricity. To create sufficient local demand to attract the manufacturer, other potential sites for photovoltaic applications will be surveyed."	425 kW facility commercially operational since September 27, 2006. Expanded by 35 kW to 460 kW in July 2007; grid-connected selling 100% of output into New England Power Pool
	$50,000	Atlantic City, NJ: Cityscape Solar-Powered Bed and Breakfast on an Urban Brownfield.	"Involves the construction of a solar-powered bed and breakfast on an urban brownfield site in Atlantic City, New Jersey, as part of an overall neighborhood redevelopment plan with a sustainability theme. The project will showcase the use of PV in supplying renewable energy and also contain sustainable features such as recycled building materials and Energy Star appliances and will be located in the "Cityscape Neighborhood," an area designed to promote renewable energy, sustainable building materials, and concepts of New Urbanism."	Project canceled
	$50,000	Hanford, WA: Brightfield Project	"This project will ultimately be the largest PV installation of its kind and will bring the Brightfield concept to one of the worst Super Fund sites in the nation. The funding provided will cover a portion of the pilot phase of the project, involving 40 kW. Later phases will use a wind/solar green energy blending strategy to finance development up to 1 MW or larger. This solar array will act as a nucleation site around which Energy Northwest intends to grow a renewable energy industrial park."	38.7 kW system installed in May 2002
2004	$65,400	Cedar Rapids, IA: Bohemian Commercial Historic District Solar Development Program	"The Iowa Department of Natural Resources (IDNR) will partner with the City of Cedar Rapids, the Iowa Renewable Energy Association, Alliant Energy, and Thorland Company to install a 7,200-watt solar array in Cedar Rapids on a multiuse converted former warehouse building in a designated brownfields redevelopment area. The IDNR has established partnerships with the City of Cedar Rapids, Alliant Energy, the Iowa Renewable Energy Association, and the building owner to increase the economic and environmental viability of a redeveloped brownfield area and expand the value and viability of solar projects."	7.2 kW installed

$59,400	Brockton, MA: Solar Energy Park: Deploying a Solar Array on a Brownfield	"The City of Brockton will build New England's largest solar array at a remediated 27-acre brownfield site in fall 2004. The 500-kW solar PV array—or 'Brightfield'—will be installed in an urban park setting with interpretive displays. The Brightfield could include as many as 6,720 solar panels connected in strings that span the site. The Brightfield will grow incrementally to 1 MW with expansions financed through positive annual cash flow generated by the sale of RECs and electricity."	425-kW facility commercially operational since September 27, 2006. Expanded by 35 kW to 460 kW in July 2007; grid-connected selling 100% of output into New England Power Pool
$125,000	Raleigh, NC: Brightfield Technology Demonstration at NCSU	"Carolina Green Energy, LLC proposes to partner with the North Carolina Solar Center to design and install a 30-kW grid-tied PV system. As part of its continued efforts to bolster support for renewable energy, the Solar Center will incorporate the "Brownfield to Brightfield" project at Lot 86 into its ongoing education and outreach programs."	75.6-kW PV-generation project operational since October 2007

Source: U.S. DOE State Energy Program. http://www.hud.gov/offices/cpd/affordablehousing/training/web/energy/programs/doe.cfm. Accessed September 2010.

According to EPA, the term brightfields refers to "the conversion of contaminated sites into usable land by bringing pollution-free solar energy and high-tech solar manufacturing jobs to these sites, including the placement of PV arrays that can reduce cleanup costs, building integrated solar energy systems as part of redevelopment, and solar manufacturing plants on brownfields." For more information, see http://epa.gov/ and brownfields/partners/brightfd.htm.

Table D-6. State Policy and Incentive Comparisons: Massachusetts, North Carolina, and Colorado

MASSACHUSETTS		
Incentive	**Specifics**	**Sector**
New Generation Energy - Community Solar Lending Program	$5,000–$100,000	Private
Massachusetts DOER - Solar Renewable Energy Credits (SRECs)	$300–$600 (per MWh)	Both
Mass Energy Consumers Alliance - Renewable Energy Certificate Incentive		Both
Renewable Energy Property Tax Exemption	100% exemption for 20 years	Private
CEC - Commonwealth Solar II Rebates	$5,500 (per host customer), up to $250,000 per parent company	Both
CEC - Commonwealth Solar Stimulus	$162,500 per project (up to $1 million for any host customer entity or parent company/organization)	Both
Policy	**Specifics**	**Sector**
Massachusetts - Net Metering		Both
Renewable Energy Trust Fund	Public benefit fund	Private
RPS	In-state PV: mandated target of 400 MW	
NORTH CAROLINA		
Incentive	**Specifics**	**Sector**
Renewable Energy Tax Credit (Corporate)	35% or $2.5 million per installation	Private
Local Option - Revolving Loan Program for Renewable Energy and Energy Efficiency	Interest rate can be no more than 8%	Private
Local Option - Clean Energy Financing	Debt repaid via property assessment	Private
Renewable Energy Tax Credit (Personal)	35% or $2.5 million per installation	Private
NC GreenPower Production Incentive	Payments contingent on program success	Both
Progress Energy Carolinas - SunSense Commercial PV Incentive Program	$0.18/kWh for 20 years	Both
TVA - Generation Partners Program	$1,000 plus $0.12/kWh above the retail rate for solar and $0.03/kWh above the retail rate for all other eligible renewables	Private
Property Tax Abatement for Solar Electric Systems	80% of appraised value	Both
North Carolina Green Business Fund	Grant varies	Both
Energy Improvement Loan Program (EILP)	State Loan Program $500,000 maximum	Both

Policy	Specifics	Sector
North Carolina - Net Metering		
Renewable Energy and Energy Efficiency Portfolio Standard	Solar: 0.2% by 2018	
COLORADO		
Incentive	**Specifics**	**Sector**
Boulder County - ClimateSmart Loan Program	Commercial: $3,000–$210,000	Private
Local Option - Improvement Districts for Energy Efficiency and Renewable Energy Improvements	Debt repaid via property assessment	Both
Renewable Energy Property Tax Assessment	Varies	Private
Boulder - Solar Sales and Use Tax Rebate	15% refund on sales and use tax for the solar installation	Private
Local Option - Sales and Use Tax Exemption for Renewable Energy Systems	Varies	Private
Sales and Use Tax Exemption for Renewable Energy Equipment	100%	Both
New Energy Economic Development Grant Program	Competitive grant, Recovery Act funded	Private
Xcel Energy - Solar*Rewards Program	$2/DC-Watt with a maximum rebate of $200,000; REC payments will step down over time as certain MW levels are reached for each system classification.	Private
Policy	**Specifics**	**Sector**
Colorado - Net Metering		Private
Mandatory Green Power Option for Large Municipal Utilities	Allows retail customers the choice of supporting emerging renewable technologies	Both
Boulder - Climate Action Plan Fund	Public benefits fund	Private
Renewable Energy Standard	Solar-electric (IOUs only): 4% of annual requirement (0.8% of sales in 2020); half of solar-electric requirement must be located on-site at customers' facilities	
Solar, Wind, and Energy-Efficiency Access Laws		

Source: U.S. DOE State Energy Program. http://www.sseb.org/files/renewable-portfolio-standards.pdf. Accessed September 2010.

Table D-7. Key Policy Comparison for Subject States

RPS	Massachusetts	North Carolina	Colorado
Policy In Place	Yes	Yes	Yes
Effective Date	4/1/02	2/29/08	12/1/04
Targets	15% by 2020 and an additional 1% each year thereafter; in-state PV mandated target of 400 MW	12.5% of 2020 retail electricity sales by 2021 with 0.2% from solar	20% by 2020; solar-electric: 4% of annual requirement
PBF	**Massachusetts**	**North Carolina**	**Colorado**
Policy In Place	Yes	No	City of Boulder only
Effective Date	3/1/98	N/A	4/1/07
Charge	$0.0005 per kWh ($0.5 million/kWh) in 2003 and in each following year	N/A	Maximum tax rates for electricity customers: Residential: $0.0049/kWh Commercial: $0.0009/kWh Industrial: $0.0003/kWh
NET METERING	**Massachusetts**	**North Carolina**	**Colorado**
Policy In Place	Yes	Yes	Yes
Effective Date	1982	10/20/05	7/2/06
System Capacity	2 MW for "Class III" systems; 1 MW for "Class II" systems; 60 kW for "Class I" systems	1 MW	120% of the customer's average annual consumption
REC Ownership	Customer owns RECs	Utility owns RECs (unless customer chooses to net meter under an unfavorable demand tariff)	Customer owns RECs (must be relinquished to utility for 20 years in exchange for incentives)
TAX INCENTIVES APPLICABLE TO PV	**Massachusetts**	**North Carolina**	**Colorado**
Incentives	*Property* – 100% exemption for 20 years	*Corporate* – 35% *Property* – 85% of appraised value	*Property* – Amount varies depending on rate set annually by the Division of Property Taxation
Effective Date	1984	Corporate 1/1/09 Property 7/1/08	2001

Source: DSIRE. http://www.dsireusa.org/. Accessed September 2010.