Feasibility Study of Economics and Performance of Solar Photovoltaics at the Standard Chlorine of Delaware Superfund Site in Delaware City, Delaware

A Study Prepared in Partnership with the Environmental Protection Agency for the RE-Powering America's Land Initiative: Siting Renewable Energy on Potentially Contaminated Land and Mine Sites

James Salasovich, Jesse Geiger, Gail Mosey, and Victoria Healey

Produced under direction of the U.S. Environmental Protection Agency by the National Renewable Energy Laboratory (NREL) under Interagency Agreement IAG-09-1751 and Task No. WFD4.1001.

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-7A40-58323
June 2013

Contract No. DE-AC36-08GO28308

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Cover Photos: (left to right) PIX 16416, PIX 17423, PIX 16560, PIX 17613, PIX 17436, PIX 17721

Printed on paper containing at least 50% wastepaper, including 10% post consumer waste.

Acknowledgments

The National Renewable Energy Laboratory (NREL) thanks the U.S. Environmental Protection Agency (EPA) for its interest in securing NREL's technical expertise. In particular, NREL and the assessment team for this project are grateful to the Standard Chlorine of Delaware facility managers, engineers, and operators for their generous assistance and cooperation.

Special thanks go to Brigid Lowery, Patricia Corbett, Hilary Thornton, Charles Howland, Brad White, Jessica Trice, Shea Jones, and Lura Matthews from EPA; Katie Brown, AAAS Science & Technology Policy fellow hosted by EPA; and Todd Keyser and Jessica Quinn from the Delaware Department of Natural Resources and Environmental Control for hosting the site visit.

Executive Summary

The U.S. Environmental Protection Agency (EPA), in accordance with the RE-Powering America's Land initiative, selected the Standard Chlorine of Delaware site in Delaware City, Delaware, for a feasibility study of renewable energy production. The National Renewable Energy Laboratory (NREL) provided technical assistance for this project. The purpose of this report is to assess the site for a possible photovoltaic (PV) system installation and estimate the cost, performance, and site impacts of different PV options. In addition, the report recommends financing options that could assist in the implementation of a PV system at the site. This study did not assess environmental conditions at the site.

The Standard Chlorine of Delaware site is located in New Castle County, approximately 3 miles northwest of Delaware City, Delaware, and 35 miles southwest of Philadelphia. The Standard Chlorine site is approximately 65 acres, and a majority of the buildings and infrastructure have been demolished, but there is an onsite water treatment building. The Standard Chlorine of Delaware site opened in 1966 and was originally used to manufacture chlorinated benzene products. Operations at the Standard Chlorine of Delaware site were closed in 2002 after the site owner declared bankruptcy.

The feasibility of a PV system installed on a Superfund site is highly impacted by the available area for an array, solar resource, distance to transmission lines, and distance to major roads. In addition, the remediation status, ground conditions, and restrictions associated with redevelopment of the Superfund site impact the feasibility of a PV system. Based on an assessment of these factors, the Standard Chlorine of Delaware site could be suitable for deployment of a large-scale PV system following the capping of the operable unit 3 (OU-3) (plant-area soils).

The Standard Chlorine of Delaware site has a high potential to build out the site with ground-mounted PV but very little potential to build out the site with a roof-mounted PV system, due to the low concentration of buildings on the site. There are 27.4 acres (1,193,544 ft^2) potentially available for ground-mounted PV systems. The area available for roof-mounted PV on the treatment system building is 2,165 ft^2. While the entire area does not need to be developed at one time due to the possibility of staging installation as area or funding becomes available, calculations for this analysis reflect the solar potential if the total feasible area is used. It should be noted that the purpose of this report is not to determine how to develop the site but to investigate both options and present the results in an unbiased manner.

Of the three scenarios considered, all had a positive net present value and had a payback within the 25-year analysis period. Two applications were analyzed for the Standard Chlorine of Delaware site. The first application would be to offset the power consumption of the onsite pumping, and the second application would be to lease or use the open land for a large commercial PV system. The economic feasibility of a potential commercial PV system on the Standard Chlorine of Delaware site depends greatly on the price of solar renewable energy certificates (SRECs); without SRECs, the PV system would only be economically feasible in a net zero application where the electricity use of the onsite pumping would be offset by a PV system. The economics were analyzed using the Delmarva Medium Commercial Rate Schedule downloaded with the modeling software System Advisory Model (SAM). The generated

electricity sale rate used is $0.0456/kWh. Table ES-1 shows the current incentives considered. The net metering is available up to 2 MW, and the Delmarva Power incentives for PV are available only for systems up to 50 kW in size, and thus are applicable only to the small rooftop system case.

Table ES-1. Summary of Incentives Evaluated

Incentive Title	Modeled Value	Expected End
Solar Renewable Energy Certificates (SRECs)	As of August 2012, approximately $189/MWh	N/A; modeled as 20 years
Federal Investment Tax Credit	30% of total investment	2016
Net Metering	Net meter up to 2 MW capacity	N/A
Delmarva Power—Green Energy Program Incentives	$1/W; less than $24,000 Up to 50 kW	Annually funded

Table ES-2 summarizes the system performance and economics of potential systems that would use all available areas that were surveyed at the Standard Chlorine of Delaware site and one smaller variation. The table shows the annual energy output from the systems, along with the number of average American households that could be powered off of such a system and estimated jobs created. With the current SREC sale price in Delaware, the most economically beneficial system would be one that pursues a virtual net metering opportunity and maximizes land coverage by using single-axis tracking modules and covering the water treatment building roof in flat panels. The single-axis ground-mounted system would be 3,149 kW in capacity, generate 5,014,100 kWh of electricity, and have a net present value of $852,452 with a payback of 10.2 years. This includes the current cost of energy, expected installation cost, site solar resource, and existing incentives for the proposed PV system. The savings and payback is deemed reasonable and as such, maximizing land coverage with a virtual net metering PV system represents a viable reuse for the site under analyzed conditions.

Table ES-2. Standard Chlorine of Delaware Site PV System Summary

Tie-In Location	System Type	PV System Size[a] (kW)	Array Tilt (deg)	Annual Output (kWh/year)	Number of Houses Powered[b]	Jobs Created[c] (job-year)	Jobs Sustained[d] (job-year)
	Crystalline Silicon (Fixed Axis Ground System)	3,819	20	4,821,325	437	89.0	1.1
	Crystalline Silicon (1-Axis Ground System)	3,149	20	5,014,100	454	96.1	0.9
	Crystalline Silicon (Fixed Axis Ground System) - Net Metering	2,000	20	2,524,915	229	61.1	0.6
	Crystalline Silicon (1-Axis Ground System) - Net Metering	2,000	20	3,184,567	288	46.6	0.6
	Crystalline Silicon (Fixed Axis Roof System)	9	20	10,933	1	0.2	0.0
	Crystalline Silicon (Fixed-Axis Ground System) - Virtual Net Metering	3,819	20	4,821,325	437	89.0	1.1
	Crystalline Silicon (1-Axis Roof System) - Virtual Net Metering	3,149	20	5,014,100	1	96.1	0.9

Tie-In Location	System Type	System Cost	Maximum Base Incentives	PPA ¢/kWh	NPV ($)	Annual O&M ($/year)	Period with Incentives (years)
	Crystalline Silicon (Fixed Axis Ground System)	$ 14,144,725	$ 4,243,418	7.16	$ (1,055,142)	$ 114,570	16.0
	Crystalline Silicon (1-Axis Ground System)	$ 13,441,929	$ 4,032,579	4.83	$ (398,255)	$ 94,470	13.3
	Crystalline Silicon (Fixed Axis Ground System) - Net Metering	$ 7,479,000	$ 2,243,700	N/A	$ 51,952	$ 60,000	11.5
	Crystalline Silicon (1-Axis Ground System) - Net Metering	$ 8,592,000	$ 2,577,600	N/A	$ 521,496	$ 60,000	11.8
	Crystalline Silicon (Fixed Axis Roof System)	$ 25,369	$ 7,611	N/A	$ 7,354	$ 260	4.4
	Crystalline Silicon (Fixed-Axis Ground System) - Virtual Net Metering	$ 14,144,725	$ 4,243,418	N/A	$ 148,844	$ 114,570	12.0
	Crystalline Silicon (1-Axis Roof System) - Virtual Net Metering	$ 13,441,929	$ 4,032,579	N/A	$ 852,452	$ 94,470	10.2

a Data assume a maximum usable area of 27.4 acres

b Number of average American households that could hypothetically be powered by the PV system assuming 11,040 kWh/year/household.

c Job-years created as a result of project capital investment including direct, indirect, and induced jobs.

d Jobs (direct, indirect, and induced) sustained as a result of operations and maintenance (O&M) of the system.

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1 Study and Site Background

The U.S. Environmental Protection Agency (EPA), in accordance with the RE-Powering America's Land initiative, selected the Standard Chlorine of Delaware site for a feasibility study of renewable energy production. The National Renewable Energy Laboratory (NREL) provided technical assistance for this project. The purpose of this report is to assess the site for a possible photovoltaic (PV) system installation and estimate the cost, performance, and site impacts of different PV options. In addition, the report recommends financing options that could assist in the implementation of a PV system at the site. This study did not assess environmental conditions at the site.

The Standard Chlorine of Delaware site is located in New Castle County, Delaware. The site is located approximately 3 miles northwest of Delaware City, Delaware, which is 35 miles southwest of Philadelphia. The Standard Chlorine of Delaware site is 65 acres, and the treatment system building is the only permanent building on the site. An existing warehouse building was demolished in December 2012. Delaware City had a population of just under 1,700 people, according to the 2010 census. Delaware City experiences summers that are warm and humid with high temperatures, typically in the mid 80^{o}F range. The winters are moderately cold with some snow and with low temperatures in the 25^{o}F range. Delaware City has an average of 202 days of sunshine each year. Delmarva Power, a deregulated utility, provides electricity to the Standard Chlorine of Delaware site.

The Standard Chlorine of Delaware site opened in 1966 and was originally used to manufacturer chlorinated benzene products. The site was later purchased by Metachem Products, which continued to manufacture chlorinated benzene products there. The Standard Chlorine of Delaware site operations were closed in 2002 after the site owner declared bankruptcy. The majority of the original buildings and infrastructure at the site have since been demolished.

The major contaminants at the site are related to years of manufacturing chlorinated benzene products there. While operational, there were spills of chlorinated benzene products, which is the major contaminant at the site. In 1986, a major spill occurred, during which time it is estimated more than 569,000 gallons of chlorinated benzene compounds were spilled at the site. EPA added the site to the Superfund National Priorities List in 1987. When Metachem Products declared bankruptcy in 2002, the site was closed abruptly. As a result, over 40 million pounds of chlorinated benzene and related compounds were abandoned in insecure storage systems and pipeline. From 2002 to 2006, the EPA removed the hazardous materials at the site. The EPA then installed a low permeability slurry wall around an approximate 30-acre area that is 3 feet wide by an average of 65 feet deep. This slurry wall, combined with a groundwater extraction and treatment system that involves a network of six extraction wells, and the treatment system building, continues to be maintained and operated by EPA. Approximately 152,000 people use the groundwater located within a 3-mile radius of the site.[1]

[1] "Standard Chlorine of Delaware, Inc." U.S. Environmental Protection Agency, 2011. http://www.epa.gov/superfund/eparecovery/standard_chlorine.html.

The next phase of the EPA's remedial process calls for constructing a multilayer geotextile and soil cap and soil gas collection system over an approximately 23-acre area, which is essentially the location of the former plant. The remedial design has been completed and EPA is waiting for funding. Considerations for solar renewable energy generation at the site were incorporated into the final design for the remedy and include limiting the final grade of the site to a slope of 4.5%. In order to maintain the integrity of the cap, future uses of the site will be limited to surface applications. Ballasted ground-mounted PV systems are required for this site because the cap cannot be penetrated. A PV system should be installed only after the cap is installed.

The closest electrical tie-in location is located 0.6 miles (3,250 feet) to the northeast off of Hamburg Corner River Road. Having a substation this close to the site makes it an ideal location for a PV system to tie into. A detailed interconnection study will have to be performed through Delmarva Power to determine the feasibility of utilizing the onsite substation as a tie-in point for a PV system. The site currently has one building using electricity (the treatment system building), and there is no new construction anticipated at the site. The treatment system building is a potential off-taker of the electricity produced by a PV system.

Feasibility assessment team members from NREL, the Delaware Department of Natural Resources and Environmental Control (DNREC), and EPA conducted a site visit on February 9, 2012, to gather information integral to this feasibility study. The team considered information, such as solar resource, transmission availability, community acceptance, and ground conditions.

2 Development of a PV System on Brownfield Sites

Through the RE-Powering America's Lands initiative, EPA has identified several benefits for siting solar PV facilities on Superfund and other environmentally impaired sites, noting that they:

- Offer development opportunities
- Can be developed in place of scarce greenfields, preserving the land carbon sink
- Could have environmental conditions that are not well-suited for commercial or residential redevelopment and might be adequately zoned for renewable energy
- Generally are located near existing roads and energy transmission or distribution infrastructure
- Might provide an economically viable reuse for sites that could have significant cleanup costs or low real estate development demand
- Can provide job opportunities in urban and rural communities
- Can advance cleaner and more cost-effective energy technologies and reduce the environmental impacts of energy systems (e.g., reduce greenhouse gas emissions).

By taking advantage of these potential benefits, PV can provide a viable, beneficial reuse, and in many cases, generate significant revenue on a site that would otherwise go unused.

The Standard Chlorine of Delaware site was last owned by Metachem Products, which went bankrupt in 2002. For many Superfund and other contaminated sites, the local community has significant interest in the redevelopment of the site, and community engagement is critical to match future reuse options to the community's vision for the site. The purpose of this study is to analyze all options so that an informed decision can be made on how to best utilize the site.

Understanding opportunities studied and realized by other similar sites demonstrates the potential for PV system development. For example, the City Solar project in Chicago, Illinois, is the largest urban PV system in the United States, and it is built on a contaminated site. The brownfield site is a former industrial site that had been vacant for 30 years. The 41-acre site is owned by the City of Chicago, who leases the land to a solar developer. The City Solar project was completed in 2010 and uses a 10-MW single-axis tracking system.[2]

The Standard Chlorine of Delaware site has potential to be used for other functions beyond the solar PV systems proposed in this report. Any potential use should align with the community vision for the site and should work to enhance the overall utility of the property. It should be noted that there is potential to build wind turbines on the site as demonstrated by the wind turbine at the neighboring site to the south.

[2] "Exelon City Solar." Exelon Corporation, 2013. Accessed July 2012: www.exeloncorp.com/PowerPlants/exeloncitysolar/Pages/Profile.aspx.

There are many compelling reasons to consider moving toward renewable energy sources for power generation instead of fossil fuels, including:

- Renewable energy sources offer a sustainable energy option in the broader energy portfolio
- Renewable energy can have a net positive effect on human health and the environment
- Deployment of renewable energy bolsters national energy independence and increases domestic energy security
- Fluctuating electric costs can be mitigated by locking in electricity rates through long-term power purchase agreements (PPAs) linked to renewable energy systems
- Generating energy without harmful emissions or waste products can be accomplished through renewable energy sources.

3 PV Systems

3.1 PV Overview

Solar PV technology converts energy from solar radiation directly into electricity. Solar PV cells are the electricity-generating component of a solar energy system. When sunlight (photons) strikes a PV cell, an electric current is produced by stimulating electrons (negative charges) in a layer in the cell designed to give up electrons easily. The existing electric field in the solar cell pulls these electrons to another layer. By connecting the cell to an external load, this current (movement of charges) can then be used to power the load (e.g., light bulb).

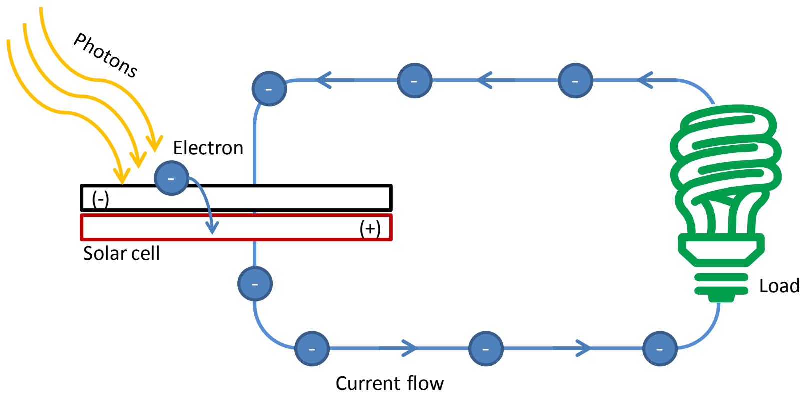

Figure 1. Generation of electricity from a PV cell

Source: EPA

PV cells are assembled into a PV panel or module. PV modules are then connected to create an array. The modules are connected in series and then in parallel as needed to reach the specific voltage and current requirements for the array. The direct current (DC) electricity generated by the array is then converted by an inverter to useable alternating current (AC) that can be consumed by adjoining buildings and facilities, or exported to the electricity grid. PV system size varies from small residential (2–10 kW), to commercial (100–500 kW), to large utility scale (10+ MW). Central distribution plants are also currently being built in the 100+ MW scale. Electricity from utility-scale systems is commonly sold back to the electricity grid.

3.2 Major System Components

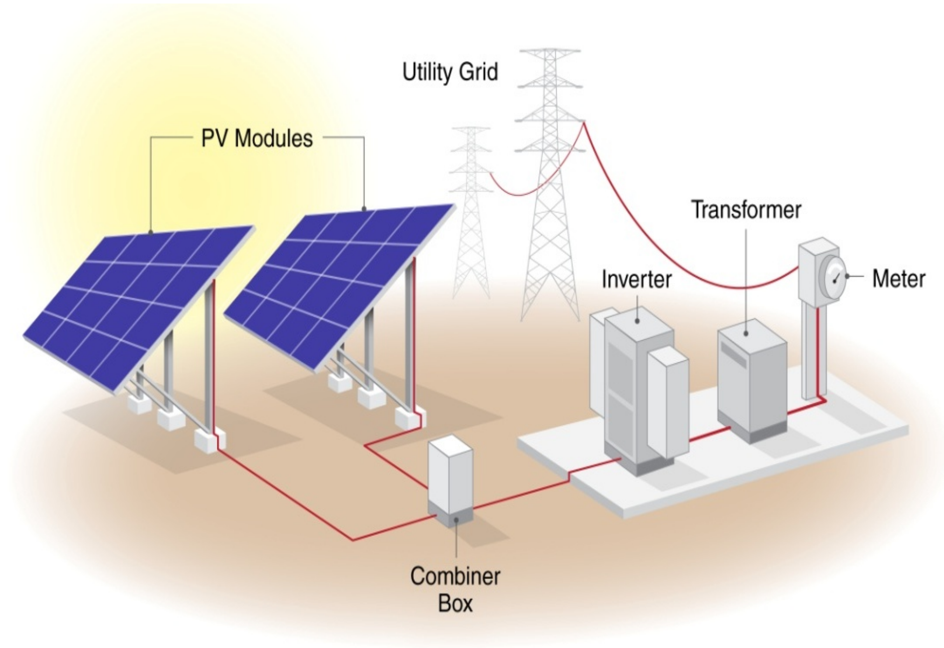

Figure 2. Ground-mounted array diagram

Source: NREL

A typical PV system is made up of several key components, including:

- PV modules
- Inverter
- Balance-of-system (BOS) components.

These, along with other PV system components, are discussed below.

3.2.1 PV Module

Module technologies are differentiated by the type of PV material used, resulting in a range of conversion efficiencies from light energy to electrical energy. The module efficiency is a measure of the percentage of solar energy converted into electricity.

Two common PV technologies that have been widely used for commercial- and utility-scale projects are crystalline silicon and thin film.

3.2.1.1 Crystalline Silicon

Traditional solar cells are made from silicon. Silicon is quite abundant and nontoxic. It builds on a strong industry on both the supply (silicon industry) and product side. This technology has been demonstrated to be consistent and highly efficient for over 30 years in the field. The performance degradation, a reduction in power generation due to long-term exposure, is under 1% per year. Silicon modules have a lifespan in the range of 25-30 years but can keep producing energy beyond this range.

Typical overall efficiency of silicon solar panels is between 12% and 18%. However, some manufacturers of mono-crystalline panels claim an overall efficiency nearing 20%. This range of efficiencies represents significant variation among the crystalline silicon technologies available. The technology is generally divided into mono- and multi-crystalline technologies, which indicates the presence of grain-boundaries (i.e., multiple crystals) in the cell materials and is controlled by raw material selection and manufacturing technique. Crystalline silicon panels are widely used based on deployments worldwide.

Figure 3 shows two examples of crystalline solar panels: mono- and multi-silicon installed on tracking mounting systems.

Figure 3. Mono- and multi-crystalline solar panels. ***Photos from (left) SunPower Corporation, NREL 23816 and (right) SunPower, NREL 13823***

3.2.1.2 Thin Film

Thin-film PV cells are made from amorphous silicon (a-Si) or non-silicon materials, such as cadmium telluride (CdTe). Thin-film cells use layers of semiconductor materials only a few micrometers thick. Due to the unique nature of thin films, some thin-film cells are constructed into flexible modules, enabling such applications as solar energy covers for landfills, such as a geomembrane system. Other thin-film modules are assembled into rigid constructions that can be used in fixed tilt or, in some cases, tracking system configurations.

The efficiency of thin-film solar cells is generally lower than for crystalline cells. Current overall efficiency of a thin-film panel is between 6% and 8% for a-Si and 11% and 12% for CdTe. Figure 4 shows thin-film solar panels.

Figure 4. Thin-film solar panels installed on (left) solar energy cover and (middle and right) fixed-tilt mounting system. ***Pictures from (left) Republic Services, Inc., 23817; (middle) Beck Energy, NREL 14726; and (right) U.S. Coast Guard Petaluma site, NREL 17395***

Industry standard warranties of both crystalline and thin-film PV panels typically guarantee system performance of 80% of the rated power output for 25 years. After 25 years, they will continue producing electricity but at a lower performance level.

3.2.2 Inverter

Inverters convert DC electricity from the PV array into AC and can connect seamlessly to the electricity grid. Inverter efficiencies can be as high as 98.5%.

Inverters also sense the utility power frequency and synchronize the PV-produced power to that frequency. When utility power is not present, the inverter will stop producing AC power to prevent "islanding," or putting power into the grid while utility workers are trying to fix what they assume is a de-energized distribution system. This safety feature is built into all grid-connected inverters in the market. Electricity produced from the system may be fed to a step-up transformer to increase the voltage to match the grid.

There are two primary types of inverters for grid-connected systems: string and micro-inverters. Each type has strengths and weaknesses and may be recommended for different types of installations.

String inverters are most common and typically range in size from 1.5–1,000 kW. These inverters tend to be cheaper on a capacity basis, as well as have high efficiency and lower operation and maintenance (O&M) costs. String inverters offer various sizes and capacities to handle a large range of voltage output. For larger systems, string inverters are combined in parallel to produce a single point of interconnection with the grid. Warranties typically run between 5 and 10 years, with 10 years being the current industry standard. On larger units, extended warranties up to 20 years are possible. Given that the expected life of PV panels is 25–30 years, an operator can expect to replace a string inverter at least one time during the life of the PV system.

Micro-inverters are dedicated to the conversion of a single PV module's power output. The AC output from each module is connected in parallel to create the array. This technology is relatively new to the market and in limited use in larger systems due to potential increase in O&M associated with significantly increasing the number of inverters in a given array. Current micro-inverters range in size between 175 W and 380 W. These inverters can be the most expensive option per watt of capacity. Warranties range from 10 to 20 years. Small projects with irregular modules and shading issues typically benefit from micro-inverters.

With string inverters, small amounts of shading on a solar panel will significantly affect the entire array production. Instead, it impacts only that shaded panel if micro-inverters are used. Figure 5 shows a string inverter.

Figure 5. String inverter. ***Photo by Warren Gretz, NREL 07985***

3.2.3 *Balance-of-System Components*

In addition to the solar modules and inverter, a solar PV system consists of other parts called BOS components, which include:

- Mounting racks and hardware for the panels
- Wiring for electrical connections.

3.2.3.1 Mounting Systems

The array has to be secured and oriented optimally to maximize system output. The structure holding the modules is referred to as the mounting system.

3.2.3.1.1 Ground-Mounted Systems

For ground-mounted systems, the mounting system can be either directly anchored into the ground (via driven piers or concrete footers) or ballasted on the surface without ground penetration. Mounting systems must withstand local wind loads, which range from 90–120 mph for most areas to 130 mph or more for areas with hurricane potential. Depending on the region, snow and ice loads must also be a design consideration for the mounting system. For brownfield applications, mounting system designs will be primarily driven by these considerations coupled with settlement concerns.

Typical ground-mounted systems can be categorized as fixed tilt or tracking. Fixed-tilt mounting structures consist of panels installed at a set angle, typically based on site latitude and wind conditions, to increase exposure to solar radiation throughout the year. Fixed-tilt systems are used at many brownfield sites. Fixed-tilt systems have lower maintenance costs but generate less energy (kWh) per unit power (kW) of capacity than tracking systems.

Tracking systems rotate the PV modules so they are following the sun as it moves across the sky. This increases energy output but also increases maintenance and equipment costs slightly. Single-axis tracking, in which PV is rotated on a single axis, can increase energy output up to 25% or more. With dual-axis tracking, PV is able to directly face the sun all day, potentially increasing output up to 35% or more. Depending on underlying soiling conditions, single- and dual-axis trackers may not be suitable due to potential settlement effects, which can interfere with the alignment requirements of such systems.

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

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	3.3	2.7
Hybrid High Efficiency	4.8	3.9

The selection of mounting type is dependent on many factors, including installation size, electricity rates, government incentives, land constraints, latitude, and local weather. Contaminated land applications may raise additional design considerations due to site conditions, including differential settlement.

Selection of the mounting system is also heavily dependent on anchoring or foundation selection. The mounting system design will also need to meet applicable local building code requirements with respect to snow, wind, and seismic zones. Selection of mounting types should also consider frost protection needs especially in cold regions, such as New England.

3.2.3.1.2 Roof-Mounted Systems

The Standard Chlorine of Delaware site could use the roof area of the treatment system building for PV. Installing PV on rooftops has many of the same considerations as installing ground-mounted PV systems. Factors, such as available area for an array, solar resource, shading, distance to transmission lines, and distance to major roads at the site, are just as important in roof-mounted systems as in ground-mounted systems. Rooftop systems can be ballasted or fixed to the roof, and it is recommended that the roof be relatively new (with 25 years or more useful life left) to avoid having to move the PV system in order to repair or replace the roof.

There are currently no plans to build new construction buildings on the site. However, if the site does plan to construct buildings on the site, there are many relatively easy low-cost/no-cost measures that can be taken during the design phase so that the buildings are optimally built for rooftop PV systems. Design strategies, such as orienting the buildings so that the southern exposure is maximized and reducing the amount of mechanical equipment on the roof, are examples of measures that can be taken to optimize rooftop PV systems. A solar-ready design guide was published in order to help design teams optimize rooftop PV systems when designing buildings.[3]

[3] Lisell, L.; Tetreault, T.; Watson, A. *Solar Ready Buildings Planning Guide*. NREL/TP-7A2-46078. Golden, CO: National Renewable Energy Laboratory, 2009. www.nrel.gov/docs/fy10osti/46078.pdf.

Table 2. Rooftop Energy Density by Panel

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

3.2.3.2 Wiring for Electrical Connections

Electrical connections, including wiring, disconnect switches, fuses, and breakers, are required to meet electrical code (e.g., NEC Article 690) for both safety and equipment protection.

In most traditional applications, wiring from (1) the arrays to inverters and (2) inverters to point of interconnection is generally run as direct burial through trenches. In brownfield applications, this wiring may be required to run through above-ground conduit due to restrictions with cap penetration or other concerns. Therefore, developers should consider noting any such restrictions, if applicable, in requests for proposals in order to improve overall bid accuracy. Similarly, it is recommended that PV system vendors reflect these costs in the quote when costing out the overall system.

3.2.3.3 PV System Monitoring

Monitoring PV systems can be essential for reliable functioning and maximum yield of a system. It can be as simple as reading values, such as produced AC power, daily kilowatt-hours, and cumulative kilowatt-hours locally on an LCD display on the inverter. For more sophisticated monitoring and control purposes, environmental data, such as module temperature, ambient temperature, solar radiation, and wind speed, can be collected. Remote control and monitoring can be performed by various remote connections. Systems can send alerts and status messages to the control center or user. Data can be stored in the inverter’s memory or in external data loggers for further system analysis. Collection of this basic information is standard for solar systems and not unique to landfill applications.

Weather stations are typically installed in large-scale systems. Weather data, such as solar radiation and temperature, can be used to predict energy production, enabling comparison of the target and actual system output and performance and identification of under-performing arrays. Operators can also use this data to identify, for example, required maintenance, shade on panels, and accumulating dirt on panels. Monitoring system data can also be used for outreach and education. This can be achieved with publicly available, online displays, wall-mounted systems, or even smartphone applications.

3.2.4 Operation and Maintenance

PV panels typically have a 25-year performance warranty. Inverters, which come standard with a 5-year 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 annually. This economic analysis uses an annual O&M cost computed as $20/kW/yr, which is based on the historical O&M costs of installed fixed-axis grid-tied PV systems. In addition, the system should expect a replacement of system inverters in year 15 at a cost of $0.25/W.

3.3 Siting Considerations

PV modules are very sensitive to shading. When shaded (either partially or fully), the panel is unable to optimally collect the high-energy beam radiation from the sun. As explained above, PV modules 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. If an individual cell is shaded, it acts as resistance to the whole series circuit, impeding current flow and dissipating power rather than producing it.

The NREL solar assessment team uses a Solmetric SunEye solar path calculator to assess shading at particular locations by analyzing the sky view where solar panels will be located. By finding the solar access, the NREL team can determine if the area is appropriate for solar panels.

Following the successful collection of solar resource data using the Solmetric SunEye tool and determination that the site is adequate for a solar installation, an analysis to determine the ideal system size must be conducted. System size depends highly on the average energy use of the facilities on the site, PPAs, incentives available, and utility policy.

4 Proposed Installation Location Information

This section summarizes the findings of the NREL solar assessment site visit on February 9, 2012.

4.1 Standard Chlorine of Delaware Site PV System

As discussed in Section 1, the Standard Chlorine of Delaware site was previously owned by Metachem Products. Metachem Products declared bankruptcy in 2002, and DNREC and EPA took over the remediation at the site.

In order to get the most out of the ground and roof areas available, it is important to consider whether the layout can be improved to better incorporate a solar system. If there are unused structures that can be removed, the unshaded area can be increased to incorporate more PV panels.

The Standard Chlorine of Delaware site is approximately 65 acres, and there is a high potential to build out the site with ground-mounted PV and some potential to build out the site with a roof-mounted PV system on the treatment system building. There are 15.4 acres (670,800 ft^2) potentially available for ground-mounted PV systems. The area available for roof-mounted PV on the treatment system building is 2,165 ft^2. While the entire area does not need to be developed at one time due to the feasibility of staging installation as area or funding becomes available, calculations for this analysis reflect the solar potential if the total feasible area is used. It should be noted that the purpose of this report is not to determine how to develop the site but to investigate both options and present the results in an unbiased manner.

Figure 6 shows an aerial view of the potential areas for PV at the Standard Chlorine of Delaware site taken from Google Earth (the feasible area for ground-mounted PV is shaded in yellow and the feasible area for roof-mounted PV on the treatment system building is shaded in red). It should be noted that the area for a ground-mounted PV system assumes the final design for the cap is implemented, which includes filling and grading of the lagoon. As shown, there are large expanses of unshaded area, which makes it a suitable candidate for ground-mounted PV systems. Note that the site would need the multilayer cap to be installed before a PV system could be installed.

Figure 6. Aerial view of the feasible areas for PV at the Standard Chlorine of Delaware site (ground-mounted PV in yellow and treatment system building with roof-mounted PV in red)

Source: Illustration done in Google Earth

PV systems are well-suited to the Delaware City, Delaware, area, where the average global horizontal annual solar resource—the total solar radiation for a given location, including direct, diffuse, and ground-reflected radiation—is 4.63 kWh/m^2/day. Figure 7 and Figure 8 show various views of the Standard Chlorine of Delaware site where PV could be feasible.

Figure 7. Views of the feasible area for ground-mounted PV at the Standard Chlorine of Delaware site (photos taken from the treatment system building). ***Photos by James Salasovich, NREL***

Figure 8. Views of the feasible area for ground-mounted PV at the Standard Chlorine of Delaware site (photos taken from the temporary soil storage area). ***Photos by James Salasovich, NREL***

4.2 Utility-Resource Considerations

The closest electrical tie-in location is located 0.6 miles (3,250 feet) to the northeast off of Hamburg Corner River Road. Having a substation this close to the site makes it an ideal location for a PV system to tie into. A detailed interconnection study will have to be performed through Delmarva Power to determine the feasibility of utilizing the onsite substation as a tie-in point for a PV system. The site currently has one building using electricity (the treatment system building), and there is no new construction anticipated at the site. The treatment system building is a potential off-taker of the electricity produced by a PV system.

Figure 9. Location of the closest substation in relation to the Standard Chlorine of Delaware site

Source: Illustration done in Google Earth

4.3 Useable Acreage for PV System Installation

Typically, a minimum of 2 useable acres is recommended to site commercial-scale PV systems. Useable acreage is typically characterized as "flat to gently sloping" southern exposures that are free from obstructions and get full sun for at least a 6-hour period each day. For example, eligible space for PV includes underutilized or unoccupied land, vacant lots, and/or unused paved area (e.g., a parking lot or industrial site space), as well as existing building rooftops.

4.4 PV Site Solar Resource

The Standard Chlorine of Delaware site has been evaluated to determine the adequacy of the solar resource available using both onsite data and industry tools.

The assessment team for this feasibility study collected multiple Solmetric SunEye data points and found a solar access of 90% or higher.

The predicted array performance was found using PVWatts Version 2 for Delaware City, Delaware. [4] Table 3 shows the station identification information, PV system specifications, and energy specifications for the site. For this summary, array performance information and a hypothetical system size of 1 kW was used to show the estimated production for each kilowatt so that additional analysis can be performed using the data indicated below. It is scaled linearly to match the proposed system size.

[4] For more information on NREL's PVWatts Version 2, see www.nrel.gov/rredc/pvwatts/.

Table 3. Site Identification Information and Specifications

Station Identification	
Cell ID	0266373
State	Delaware
Latitude	39.8° N
Longitude	75.3° W
PV System Specifications	
DC Rating	1.00 kW
DC to AC Derate Factor	0.8
AC Rating	0.8 kW
Array Type	Fixed Tilt
Array Tilt	20°
Array Azimuth	South
Energy Specifications	
Cost of Electricity	$0.18/kWh

Table 4 shows the performance results for a 20-degree fixed-tilt PV system in Delaware City, as calculated by PVWatts.

Table 4. Performance Results for 20-Degree Fixed-Tilt PV

Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	2.80	70	12.60
2	3.53	80	14.40
3	4.96	120	21.60
4	5.39	123	22.14
5	5.96	137	24.66
6	6.25	135	24.30
7	5.95	131	23.58
8	5.75	127	22.86
9	5.17	113	20.34
10	4.19	98	17.64
11	2.96	69	12.42
12	2.55	62	11.16
Year	4.63	1,265	227.70

Table 5 shows the performance results for a 20-degree single-axis tracking PV system in Delaware City, as calculated by PVWatts.

Table 5. Performance Results for 20-Degree Single-Axis PV

Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	3.43	89	16.02
2	4.28	99	17.82
3	6.21	153	27.54
4	6.67	155	27.90
5	7.36	171	30.78
6	7.82	171	30.78
7	7.47	167	30.06
8	7.14	159	28.62
9	6.40	142	25.56
10	5.25	125	22.50
11	3.56	85	15.30
12	3.06	76	13.68
Year	5.73	1,592	286.56

4.5 Standard Chlorine of Delaware Energy Usage

The Standard Chlorine of Delaware site currently has one building on the site that uses electricity, which is the treatment system building. The treatment system building is a potential off-taker of the electricity produced by a PV system. It is important to understand the energy use of the site to allow for a full analysis of whether or not energy produced would need to be sold or if it could offset onsite energy use.

4.5.1 Current Energy Use

The treatment system building is currently the only building on site that uses electricity. No detailed electricity usage or cost data was available for the site, but the staff associated with the site estimate the pump energy use to be 170,000 kWh/yr, which could be offset with a 130-kW PV system.

4.5.2 Net Metering

Net metering is an electricity policy for consumers who own renewable energy facilities. In this context, "net" is used to mean "what remains after deductions"—in this case, the deduction of any energy outflows from metered energy inflows. Under net metering, a system owner receives retail credit for at least a portion of the electricity it generates. As part of the Energy Policy Act of 2005, under Sec. 1251, all public electric utilities are required upon request to make net metering available to their customers:

> (11) NET METERING.—Each electric utility shall make available upon request net metering service to any electric consumer that the electric utility serves. For purposes of this paragraph, the term 'net metering service' means service to an electric consumer under which electric energy generated by that electric consumer from an eligible on-site generating facility and delivered to the local distribution facilities may be used to offset electric energy provided by the electric utility to the electric consumer during the applicable billing period.

Delaware's net-metering law, which was significantly expanded in 2007, allows for various renewable energy technologies, addresses issues related to who owns the renewable energy certificates (RECs), and has a system capacity limit of 2 MW for non-residential systems within Delmarva's service territory.

4.5.3 Virtual Net Metering

Some states and utilities allow for virtual net metering (VNM). This arrangement can allow certain entities, such as a local government, to install renewable generation of up to a 1-MW limit at one location within its geographic boundary and to generate credits that can be used to offset charges at one or more other locations within the same geographic boundary. Delaware is one of seven states (Delaware, California, Colorado, Connecticut, Massachusetts, New Jersey, and Pennsylvania) that currently allows for VNM.

5 Economics and Performance

The economic performance of a PV system installed on the site is evaluated using a combination of the assumptions and background information discussed previously, as well as a number of industry-specific inputs determined by other studies. In particular, this study uses the System Advisor Model (SAM).[5]

SAM is a performance and economic model designed to facilitate decision making for people involved in the renewable energy industry, ranging from project managers and engineers to incentive program designers, technology developers, and researchers.

SAM makes performance predictions for grid-connected solar, solar water heating, wind, and geothermal power systems and makes economic calculations for both projects that buy and sell power at retail rates and power projects that sell power through a PPA.

SAM consists of a performance model and financial model. The performance model calculates a system's energy output on an hourly basis (sub-hourly simulations are available for some technologies). The financial model calculates annual project cash flows over a period of years for a range of financing structures for residential, commercial, and utility projects.

The model calculates the cost of generating electricity based on information provided about a project's location, installation and operating costs, type of financing, applicable tax credits and incentives, and system specifications.

5.1 Assumptions and Input Data for Analysis

Cost of a PV system depends on the system size and other factors, such as geographic location, mounting structure, and type of PV module. Based on significant cost reductions seen in 2011, the average cost for utility-scale ground-mounted systems has declined from $4.80/W in the first quarter of 2010 to $2.79/W in the first quarter of 2012. With an increasing demand and supply, potential of further cost reduction is expected as market conditions evolve.

For this analysis, the installed cost of the baseline fixed-tilt roof-mounted systems was assumed to be $2.79/W. This same cost was assumed for the fixed-axis ground-mounted systems. Single-axis tracking systems were assumed in this analysis to have a 20% increase over the fixed-axis system cost of $3.35/W. Single-axis tracking is only available for use on the ground. These costs represent remediation consideration cost case scenarios for PV installation price on EPA brownfields. Additional costs apply to systems built on landfills and land that require minimal disturbance. These systems use ballasting to minimize ground impact and increase the overall installation price of 20%.

[5] For additional information on the NREL System Advisor Model, see https://sam.nrel.gov/cost

Table 6. Installed System Cost Assumptions

System Type	Fixed Tilt ($\$/W_{DC}$)	Single-Axis Tracking ($\$/W_{DC}$)
Baseline System	2.79	3.35
+20% Ballast	+0.56	+0.67
Ballasted Ground-Mounted System	3.49	4.02

This price includes the PV array and BOS components for each system, including the inverter and electrical equipment, as well as the installation cost. This includes an estimated national average labor rate but does not include land cost. The economics of grid-tied PV depend on incentives, the cost of electricity, the solar resource, and panel tilt and orientation.

It was assumed for this analysis that relevant federal and state incentives are received for taxable entities, whom would be the owners of the system either through PPA or site leasing. It is important to consider all applicable incentives or grants to make PV as cost-effective as possible. The full list of incentives used in this study can be found in Table 7. The net-metering program and the Delmarva power incentive were only applied to the roof system case.

Table 7. Summary of Incentives Evaluated

Incentive Title	Modeled Value	Expected End
Solar Renewable Energy Certificates (SRECs)	As of August 2012, approximately $189/MWh for 20 years	N/A
Federal Investment Tax Credit	30% of total investment	2016
Net Metering	Net meter up to 2 MW capacity	N/A
Delmarva Power—Green Energy Program Incentives	$1/W; less than $24,000	Annually funded

For the purpose of this analysis, the project is expected to have a 25-year life, although the systems can be reasonably expected to continue operation past this point. The panel coverage rate is the same for both ground and roof-mounted systems. The SAM modeling software downloaded a utility rate for the Delmarva Medium Commercial Schedule. The generation rate of $0.046/kWh and an estimated sale rate for electricity generated on site of $0.02/kWh were used. A full list of standard assumptions can be found in Appendix A.

5.2 SAM-Forecasted Economic Performance

Using varied inputs and the assumptions summarized in Section 5.1, the SAM tool predicts net present value (NPV) and PPA. Three scenarios were run for the Standard Chlorine of Delaware site. Two models represent filling the entire available space with

PV arrays; the third represents modeling roof coverage. There are multiple factors beyond NPV and PPA that go into choosing the best scenario(s); however, Table 8 shows the different options and their results.

Table 8. Summary of SAM Results

Tie-In Location	System Type	PV System Size[a] (kW)	Array Tilt (deg)	Annual Output (kWh/year)	Number of Houses Powered[b]	Jobs Created[c] (job-year)	Jobs Sustained[d] (job-year)
	Crystalline Silicon (Fixed Axis Ground System)	3,819	20	4,821,325	437	89.0	1.1
	Crystalline Silicon (1-Axis Ground System)	3,149	20	5,014,100	454	96.1	0.9
	Crystalline Silicon (Fixed Axis Ground System) - Net Metering	2,000	20	2,524,915	229	61.1	0.6
	Crystalline Silicon (1-Axis Ground System) - Net Metering	2,000	20	3,184,567	288	46.6	0.6
	Crystalline Silicon (Fixed Axis Roof System)	9	20	10,933	1	0.2	0.0
	Crystalline Silicon (Fixed-Axis Ground System) - Virtual Net Metering	3,819	20	4,821,325	437	89.0	1.1
	Crystalline Silicon (1-Axis Roof System) - Virtual Net Metering	3,149	20	5,014,100	1	96.1	0.9

Tie-In Location	System Type	System Cost	Maximum Base Incentives	PPA ¢/kWh	NPV ($)	Annual O&M ($/year)	Period with Incentives (years)
	Crystalline Silicon (Fixed Axis Ground System)	$ 14,144,725	$ 4,243,418	7.16	$ (1,055,142)	$ 114,570	16.0
	Crystalline Silicon (1-Axis Ground System)	$ 13,441,929	$ 4,032,579	4.83	$ (398,255)	$ 94,470	13.3
	Crystalline Silicon (Fixed Axis Ground System) - Net Metering	$ 7,479,000	$ 2,243,700	N/A	$ 51,952	$ 60,000	11.5
	Crystalline Silicon (1-Axis Ground System) - Net Metering	$ 8,592,000	$ 2,577,600	N/A	$ 521,496	$ 60,000	11.8
	Crystalline Silicon (Fixed Axis Roof System)	$ 25,369	$ 7,611	N/A	$ 7,354	$ 260	4.4
	Crystalline Silicon (Fixed-Axis Ground System) - Virtual Net Metering	$ 14,144,725	$ 4,243,418	N/A	$ 148,844	$ 114,570	12.0
	Crystalline Silicon (1-Axis Roof System) - Virtual Net Metering	$ 13,441,929	$ 4,032,579	N/A	$ 852,452	$ 94,470	10.2

a Data assume a maximum usable area of 27.4 acres

b Number of average American households that could hypothetically be powered by the PV system assuming 11,040 kWh/year/household.

c Job-years created as a result of project capital investment including direct, indirect, and induced jobs.

d Jobs (direct, indirect, and induced) sustained as a result of operations and maintenance (O&M) of the system.

The best economic case for the Standard Chlorine of Delaware site is to pursue a VNM system, maximizing land space coverage with single-axis tracking modules and covering the roof with fixed-axis panels. The reason for this economic favorability is the SRECs offered through the Delaware legislature and the VNM provision might allow the system to be used to offset the energy use of many different users. The SREC price currently offered, $0.189/kWh, accounts for more than 80% of the system revenue. The site has a favorable solar resource, and combined with progressive incentives, could produce a NPV of more than $850,000 over 25 years. With such reliance on incentives, however, the site should proceed cautiously and mitigate policy risk. If the site is unable to secure a community virtual provision, the site should pursue leasing the land to a local industry partner for a 2-MW net-metering system using single-axis tracking. Regardless of how the ground-mounted systems are used, the site should place flat panels on the roof of the pump house.

5.2.1 Solar Investor vs. Site Owner

The choice between going with a solar investor or PV system ownership will depend on the desire for involvement and the risk and tax appetite of the owner. While ownership of the system will bring a higher payback for the owner, it will also require hiring the contractors to permit, install, and maintain the system. A solar investor inherits that risk and profit, and the Standard Chlorine of Delaware site owner in turn will receive lease payments from the PV system. The model assumes that an investor will proceed with the investment if they could attain a 15% internal rate of return (IRR) for the duration of the project. The recommendation of the feasibility team is to pursue a solar investor to lease the land to.

5.2.2 Single-Axis Tracking vs. Fixed-Tilt Modules

For the Standard Chlorine of Delaware site, there are two area types that could contain solar panels: roof and ground space. Fixed-axis panels will be the system used for covered roof space regardless of how the ground space is utilized. According to the simulations, single-axis tracking for the ground-mounted system will provide the best NPV for a slightly lower cost. Installation costs could vary from the model due to availability of installers and equipment and might change the scenario favorability. Under current assumptions, it is the recommendation of the feasibility study to pursue a single-axis system for the ground-mounted portions of the Standard Chlorine of Delaware site.

The single-axis tracking system is able to gather a significantly greater portion of the sun's energy, with fewer modules than a fixed-axis system. However, the same capacity system requires a larger footprint. The fixed-axis system gathers less solar energy but has no moving parts. The fixed-axis tracking system is also economically feasible but not as favorable as the single-axis panels. If the fixed-axis price were to drop to about $0.82 below the single-axis price, the fixed-axis tracking system would become more favorable from a NPV basis.

5.2.3 Policy Dependence of the System

The economics of this system are highly dependent on the SREC market. With the best-known price point, a PV investment is highly favorable, but that price may not remain for the entirety of the project planning process or once the project is installed. The breakeven SREC price before none of the modeled systems are favorable is $160/MWh. A more thorough study should be conducted to determine a more accurate breakeven price and the overall risk of the PV investment.

The entire results and summary of inputs to the SAM is available in Appendix B.

5.3 Job Analysis and Impact

To evaluate employment and economic impacts of the PV project associated with this analysis, the NREL Jobs and Economic Development Impact (JEDI) models are used.[6] JEDI estimates the economic impacts associated with the construction and operation of distributed-generation power plants. It is a flexible input-output tool that estimates, but does not precisely predict, the number of jobs and economic impacts that can be reasonably supported by the proposed facility.

[6] The JEDI models have been used by the U.S. Department of Energy, the U.S. Department of Agriculture, NREL, and the Lawrence Berkeley National Laboratory, as well as a number of universities. For information on the NREL Jobs and Economic Development Impact tool, see www.nrel.gov/analysis/jedi/about_jedi.html.

JEDI represents the entire economy, including cross-industry or cross-company impacts. For example, JEDI estimates the impact the installation of a distributed-generation facility would have on not only the manufacturers of PV modules and inverters but also the associated construction materials, metal fabrication industry, project management support, transportation, and other industries that are required to enable the procurement and installation of the complete system.

For this analysis, inputs, including the estimated installed project cost ($/kW), targeted year of construction, system capacity (kW), O&M costs ($/kW), and location, were entered into the model to predict the jobs and economic impact. It is important to note that JEDI does not predict or incorporate any displacement of related economic activity or alternative jobs due to the implementation of the proposed project. As such, the JEDI results are considered gross estimates as opposed to net estimates.

For the Standard Chlorine of Delaware site, the values in Table 9 were assumed from the single-axis ground net-metering system.

Table 9. JEDI Analysis Assumptions

Input	Assumed Value
Capacity	2,000 kW
Placed In Service Year	2013
Installed System Cost	$8,592,000
Location	New Castle, Delaware

Using these inputs, JEDI estimates the gross direct and indirect jobs, associated earnings, and total economic impact supported by the construction and continued operation of the proposed PV system.

The estimates of jobs associated with this project are presented as either construction period jobs or sustained operations jobs. Each job is expressed as a whole, or fraction, full-time equivalent (FTE) position. An FTE is defined as 40 hours per week for one person for the duration of a year. Construction period jobs are considered short-term positions that exist only during the procurement and construction periods.

As indicated in the results of the JEDI analysis provided in Appendix C, the total proposed system is estimated to support 61.1 direct and indirect jobs per year for the duration of the procurement and construction period. Total wages paid to workers during the construction period are estimated to be $2,992,200, and total economic output is estimated to be $7,453,300. The annual O&M of the new PV system is estimated to support 0.6 FTEs per year for the life of the system. The jobs and associated spending are projected to account for approximately $32,600 in earnings and $53,600 in economic activity each year for the next 25 years.

5.4 Financing Opportunities

The procurement, development, construction, and management of a successful utility-scale distributed-generation facility can be owned and financed a number of different ways. The most common ownership and financing structures are described below.

5.4.1 Owner and Operator Financing

The owner/operator financing structure is characterized by a single entity with the financial strength to fund all of the solar project costs and, if a private entity, sufficient tax appetite to utilize all of the project's tax benefits. Private owners/operators typically establish a special purpose entity (SPE) that solely owns the assets of the project. An initial equity investment into the SPE is funded by the private entity using existing funds, and all of the project's cash flows and tax benefits are utilized by the entity. This equity investment is typically matched with debt financing for the majority of the project costs. Project debt is typically issued as a loan based on each owner's/operator's assets and equity in the project. In addition, private entities can utilize any of federal tax credits offered.

For public entities that choose to finance, own, and operate a solar project, funding can be raised as part of a larger, general obligation bond; as a standalone tax credit bond; through a tax-exempt lease structure, bank financing, grant and incentive programs, or internal cash; or some combination of the above. Certain structures are more common than others, and grant programs for solar programs are on the decline. Regardless, as tax-exempt entities, public entities are unable to benefit directly from the various tax-credit-based incentives available to private companies. This has given way to the now common use of third-party financing structures, such as the PPA.

5.4.2 Third-Party Developers with Power Purchase Agreements

Because many project site hosts do not have the financial or technical capabilities to develop a capital intensive project, many times they turn to third-party developers (and/or their investors). In exchange for access to a site through a lease or easement arrangement, third-party developers will finance, develop, own, and operate solar projects utilizing their own expertise and sources of tax equity financing and debt capital. Once the system is installed, the third-party developer will sell the electricity to the site host, a local utility [such as one subject to a renewable portfolio standard (RPS)], or a third party via a PPA—a contract to sell electricity at a negotiated rate over a fixed period of time. The PPA typically will be between the third-party developer and the site host if it is a retail "behind-the-meter" transaction or directly with an electric utility or other buyer if it is a wholesale transaction.

Site hosts benefit by either (or both) receiving competitively priced electricity from the project via the PPA or land lease revenues via lease payments for making the site available to the solar developer. These lease payments can take on the form of either a revenue sharing agreement or an annual lease payment. In addition, third-party developers are able to utilize federal tax credits. For public entities, this arrangement allows them to utilize the benefits of the tax credits (low PPA price, higher lease payment) while not directly receiving them. The term of a PPA typically varies from 20–25 years.

5.4.3 Third-Party "Flip" Agreements Opportunities

The most common use of the third-party financing model involves a site host working with a third-party developer who then partners with a tax-motivated investor in an SPE that would own and operate the project. Initially, most of the equity provided to the SPE would come from the tax investor, and most of the benefit would flow to the tax investor (as much as 99%). When the tax investor has fully monetized the tax benefits and achieved an agreed-upon rate of return, the allocation of benefits and majority ownership (95%) would "flip" to the site host (but, in accordance with IRS regulations, not within the first 5 years). After the flip, the site host would have the option to buy out all or most of the tax investor's interest in the project at the fair market value of the tax investor's remaining interest.

A flip agreement can also be signed between a developer and investors within an SPE, where the investor would begin with the majority ownership. Eventually, the ownership would flip to the developer once each investor's return is met.

5.4.4 Hybrid Financial Structures

As the solar market evolves, hybrid financial solutions have been developed in certain instances to finance solar projects. A particular structure, nicknamed "The Morris Model" after Morris County, New Jersey, combines highly rated public debt, a capital lease, and a PPA. Low-interest public debt replaces more costly financing available to the solar developer and contributes to a very attractive PPA price for the site hosts. New markets tax credits have been combined with PPAs and public debt in other locations, such as Denver and Salt Lake City.

5.4.5 Solar Services Agreement and Operating Lease

The solar services agreement (SSA) and operating lease business models have been predominately used in the municipal and cooperative utility markets due its treatment of tax benefits and the rules limiting federal tax benefit transfers from nonprofit to for-profit companies. Under IRS guidelines, municipalities cannot enter capital leases with for-profit entities when the for-profit entities capture tax incentives. As a result, a number of business models have emerged as a workaround to this issue. One model is the SSA, wherein a private party sells "solar services" (i.e., energy and RECs) to a municipality over a specified contract period (typically long enough for the private party to accrue the tax credits). The nonprofit utility typically purchases the solar services with either a one-time up-front payment equal to the turn-key system cost minus the 30% federal tax credit or could purchase the services in annual installments. The municipality could buy out the system once the third party has accrued the tax credits, but due to IRS regulations, the buyout of the plant cannot be included as part of the SSA (i.e., the SSA cannot be used as a vehicle for a sale and must be a separate transaction).

Similar to the SSA, there are a variety of lease options that are available to municipalities that allow the capture of tax benefits by third-party owners, which result in a lower cost to the municipality. These include an operating lease for solar services (as opposed to an equipment capital lease) and a complex business model called a sale/leaseback. Under the sale/leaseback model, the municipality develops the project and sells it to a third-party tax equity investor who then leases the project back to the municipality under an operating lease. At the end of the lease period, and after the tax benefits have been absorbed by the tax equity investor, the municipality may purchase the solar project at fair market value.

5.4.6 Sale/Leaseback

In the widely accepted sale/leaseback model, the public or private entity would install the PV system, sell it to a tax investor, and then lease it back. As the lessee, it would be responsible for operating and maintaining the solar system, as well as have the right to sell or use the power. In exchange for use of the solar system, the public or private entity would make lease payments to the tax investor (the lessor). The tax investor would have rights to federal tax benefits generated by the project and the lease payments. Sometimes the entity is allowed to buy back the project at 100% fair market value after the tax benefits are exhausted.

5.4.7 Community Solar/Solar Gardens

The concept of "community solar" is one in which the costs and benefits of one large solar project are shared by a number of participants. A site owner may be able to make the land available for a large solar project that can be the basis for a community solar project. Ownership structures for these projects vary, but the large projects are typically owned or sponsored by a local utility. Community solar gardens are distributed solar projects wherein utility customers have a stake via a prorated share of the project's energy output. This business model is targeted to meet demand for solar projects by customers who rent/lease their homes or businesses, do not have good solar access at their site, or do not want to install solar system on their facilities. Customer prorated shares of solar projects are acquired through a long-term transferrable lease of one or more panels, or they subscribe to a share of the project in terms of a specific level of energy output or the energy output of a set amount of capacity. Under the customer lease option, the customer receives a billing credit for the number of kilowatt-hours their prorated share of the solar project produces each month; this is also known as VNM (which must be permissible under the state's net-metering regulations). Under the customer subscription option, the customers typically pay a set price for a block of solar energy (i.e., 100 kWh per-month blocks) from the community solar project. Other models include monthly energy outputs from a specific investment dollar amount or a specific number of panels.

Community solar garden and customer subscription-based projects can be owned solely by the utility, owned solely by third-party developers with facilitation of billing provided by the utility, or a joint venture between the utility and a third-party developer leading to eventual ownership by the utility after the tax benefits have been absorbed by the third-party developer.

There are some states that offer solar incentives for community solar projects, including Washington State (production incentive) and Utah (state income tax credit). Community solar is also known as solar gardens depending on the location (e.g., Colorado).

6 Conclusions and Recommendations

Investing or attracting investors in a large PV array is an economically viable option currently, but changes in SREC prices could make a PV system at the Standard Chlorine of Delaware site economically unviable. It is the suggestion of the feasibility study to lease the land to PV investors who would absorb the risk, as well as some of the economic benefit.

Installing an economically feasible PV system on the Standard Chlorine of Delaware site could potentially generate 5,014,169 kWh annually. As summarized in Section 5, the SAM economic analysis predicts the best NPV and LCOE of $852,452 and less than $0.1449/kWh, respectively, for the 3,149 kW single-axis tracking case. In a solar investor/PPA case, the best possible PPA price is $0.0483/kWh.

The economics for the potential PV systems at the Standard Chlorine of Delaware site depend primarily on the SREC market, and if the SREC price were to drop below $0.16/kWh, the system would likely not be economically feasible. A more thorough study is suggested before proceeding forward with the project. This next study should do the following:

- Gauge the interest of local solar developers in developing the site
- Discuss with the local utility interconnection issues and required studies
- Solicit community input
- Better define and determine requirements for the VNM options for local users.

Appendix A. Assessment and Calculations Assumptions

Table A-1. Cost, System, and Other Assessment Assumptions

Cost Assumptions			
Variable	**Quantity of Variable**	**Unit of Variable**	
Cost of Site Electricity	~0.05	$/kWh	
Annual O&M (fixed)	25	$/kW/year	
System Assumptions			
System Type	**Annual energy kWh/kW**	**Installed Cost ($/W)**	**Energy Density (W/sq. ft.)**
Ground Fixed	1,265	$3.49	4.0
Ground Single Axis	1,592	$4.02	3.3
Rooftop Fixed	1,265	$2.93	4.0
Other Assumptions			
	Ground utilization	90% of available area	

Appendix B. Results from the Solar Advisor Model

Figures B-1 through B-12 shows the graphs from the SAM models.

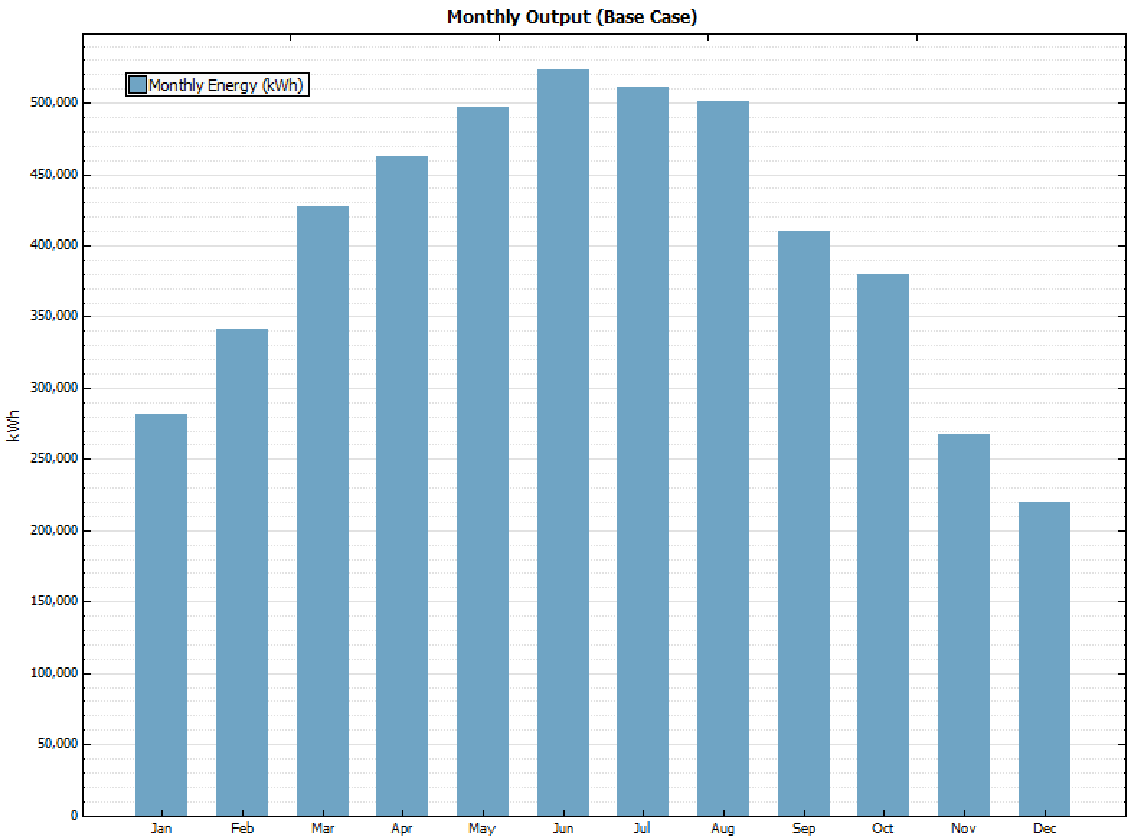

Figure B-1. Modeled output for full coverage fixed-axis ground system

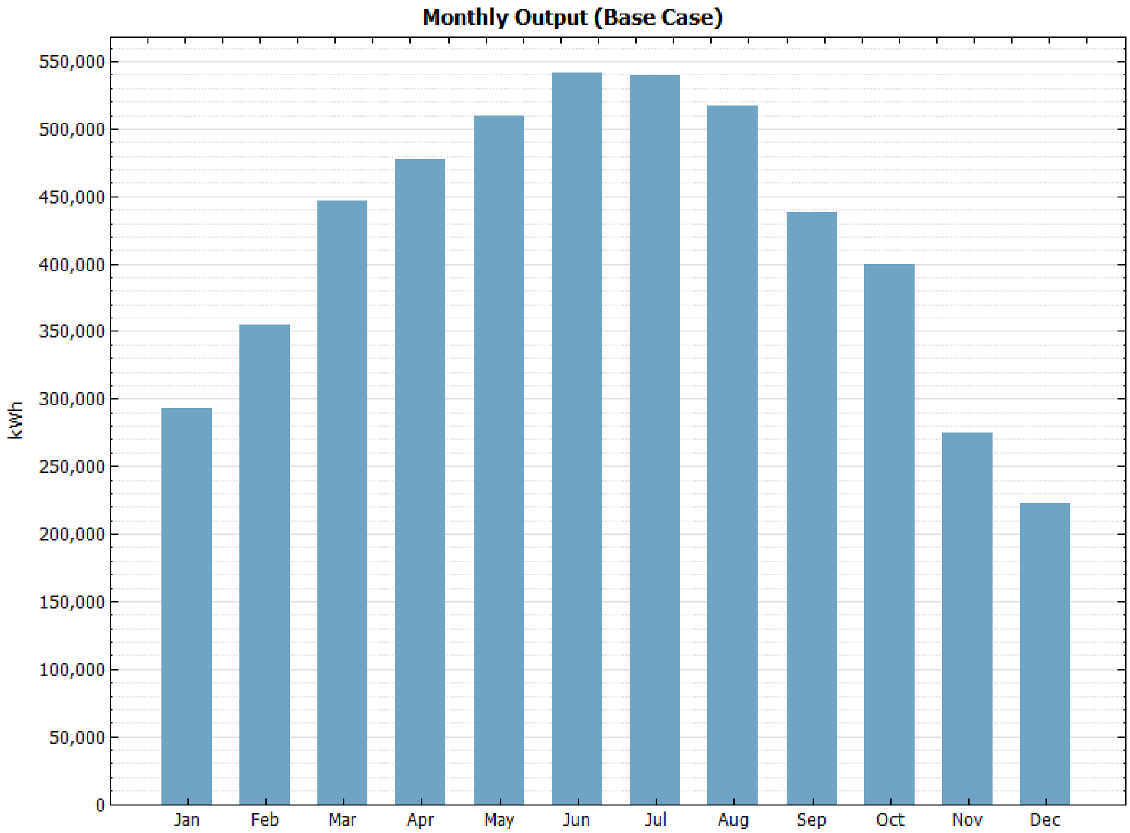

Figure B-2. Modeled output for full coverage single-axis tracking PV system

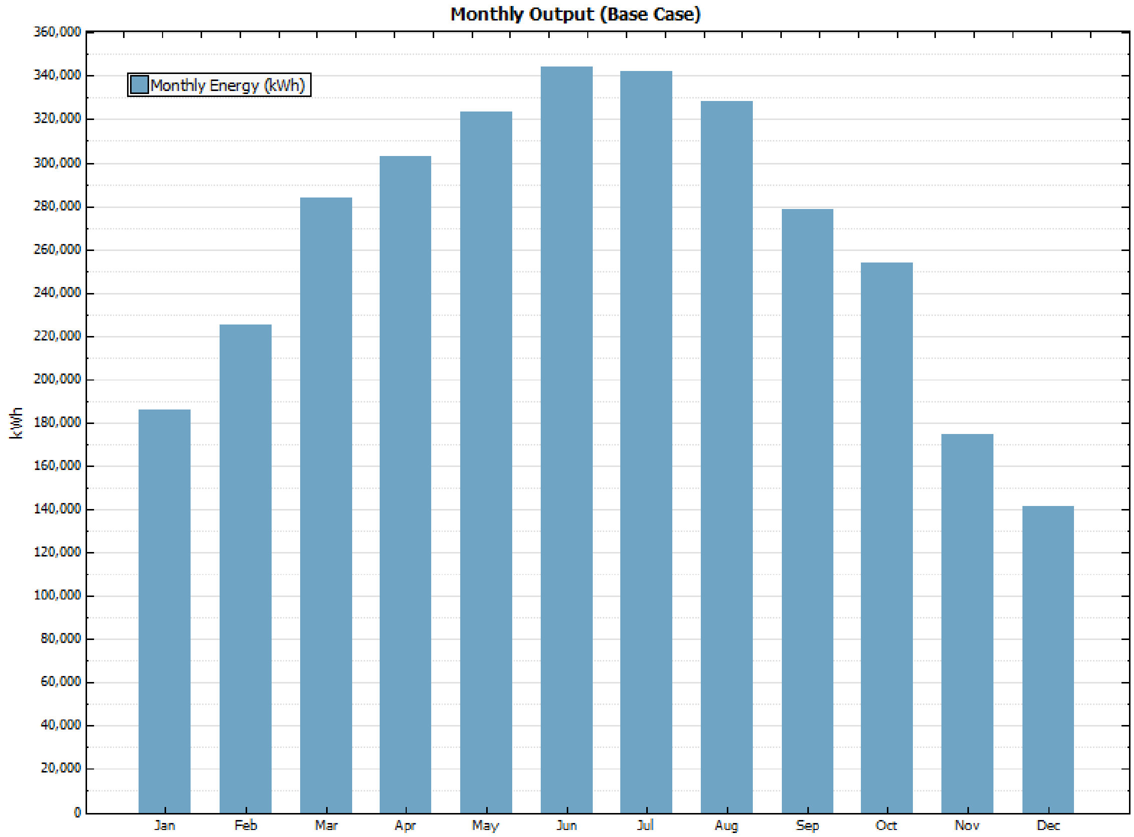

Figure B-3. Modeled output for 2-MW net-metering single-axis tracking PV system

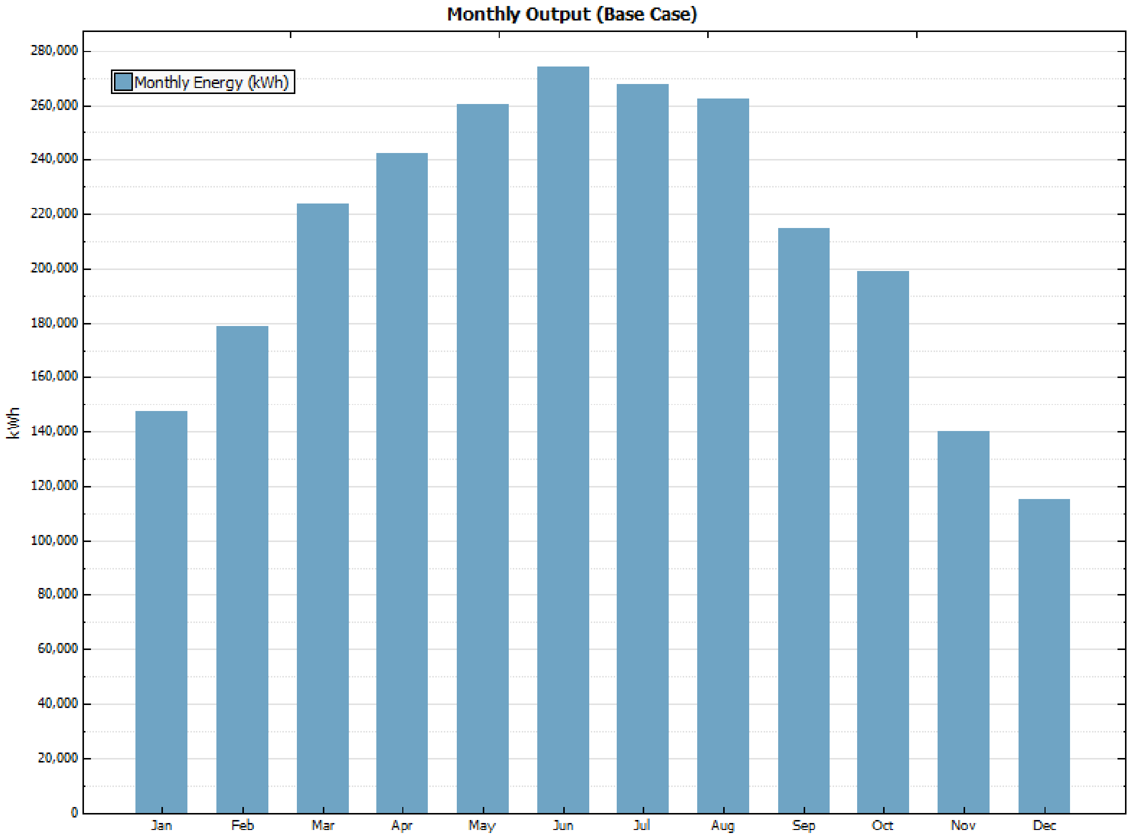

Figure B-4. Modeled output for 2-MW net-metering fixed-axis PV system

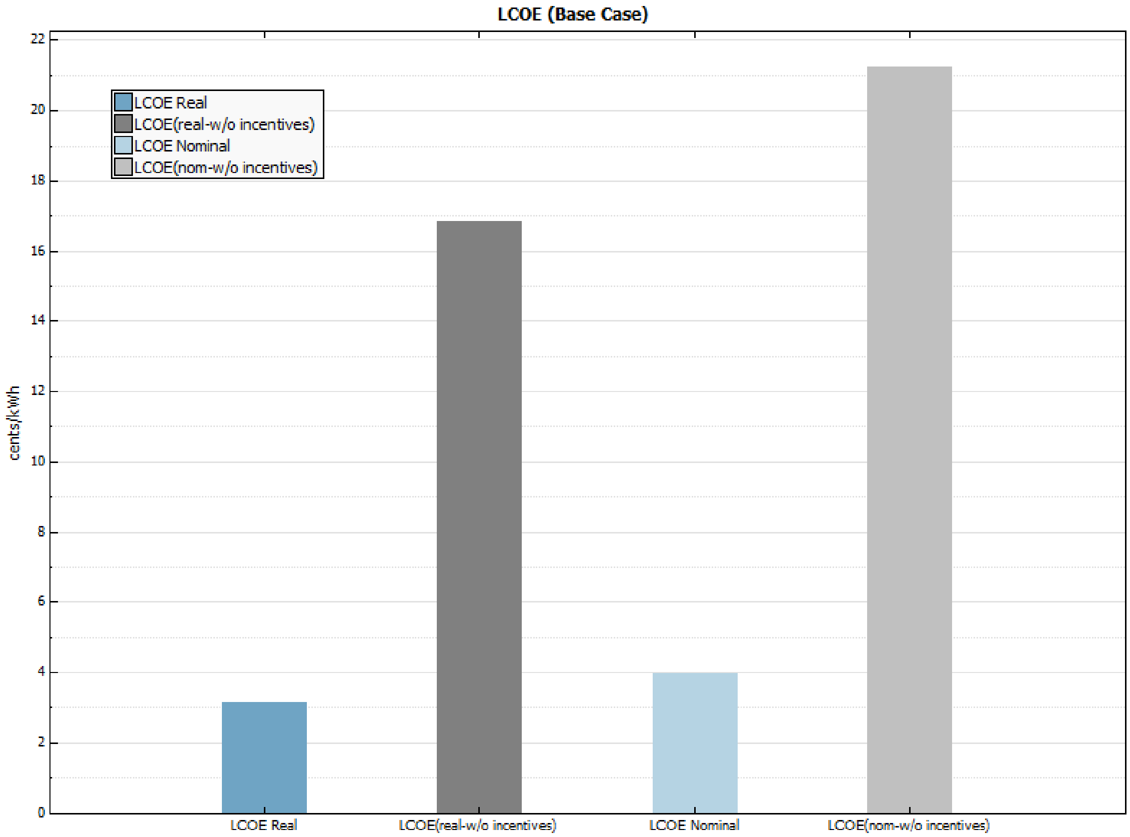

Figure B-5. LCOE for owner purchase of full coverage fixed-axis system

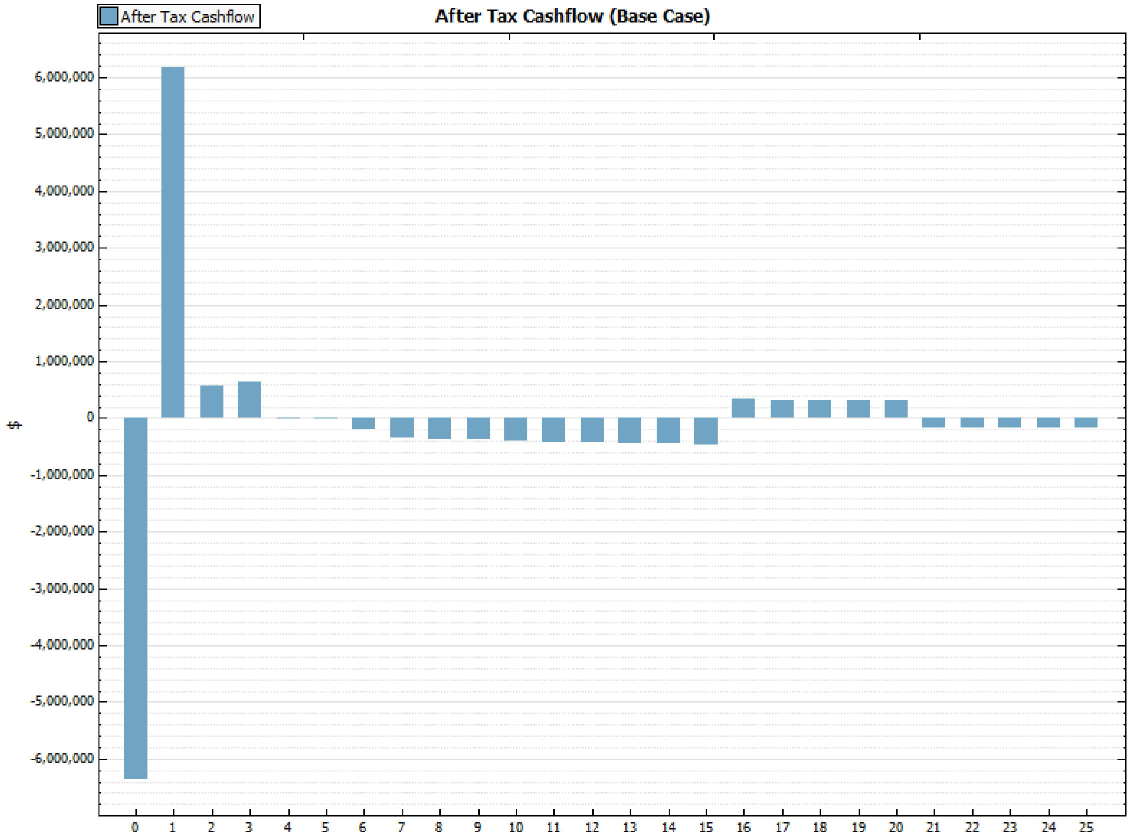

Figure B-6. After tax cash flow for owner purchase of full coverage fixed-axis system

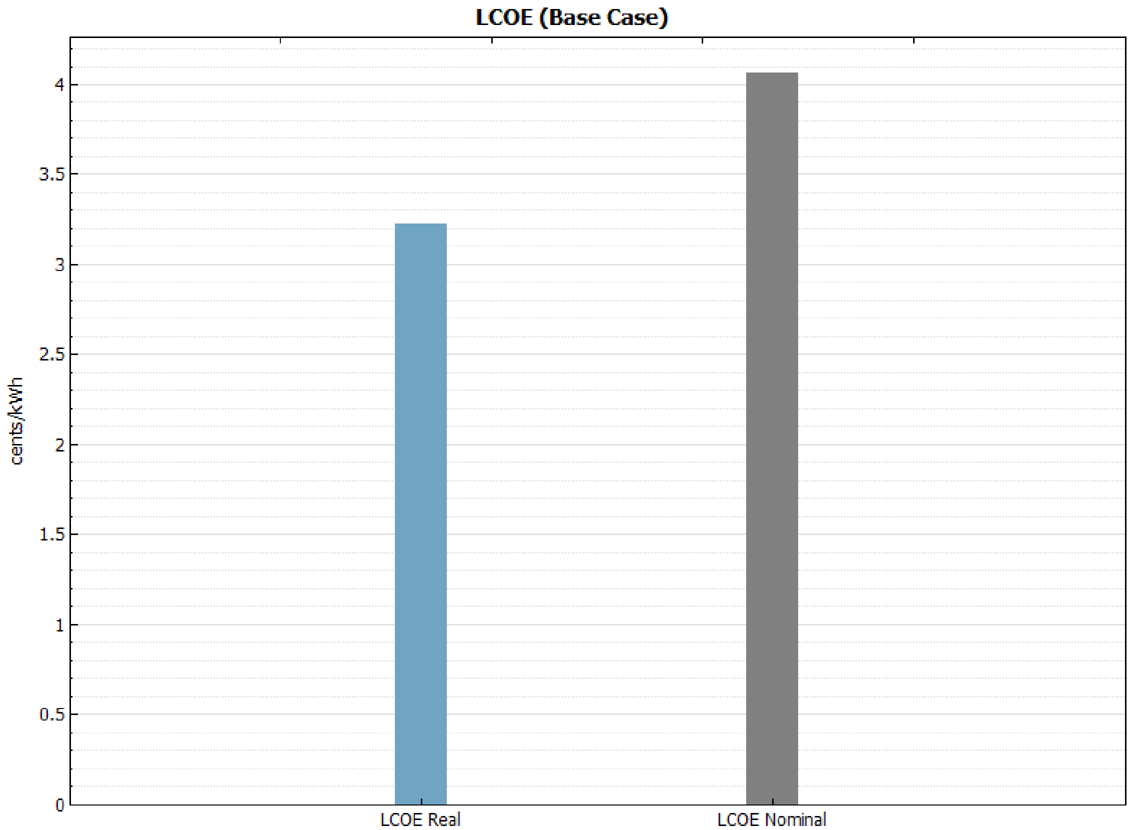

Figure B-7. LCOE for 2-MW net-metering fixed-axis system

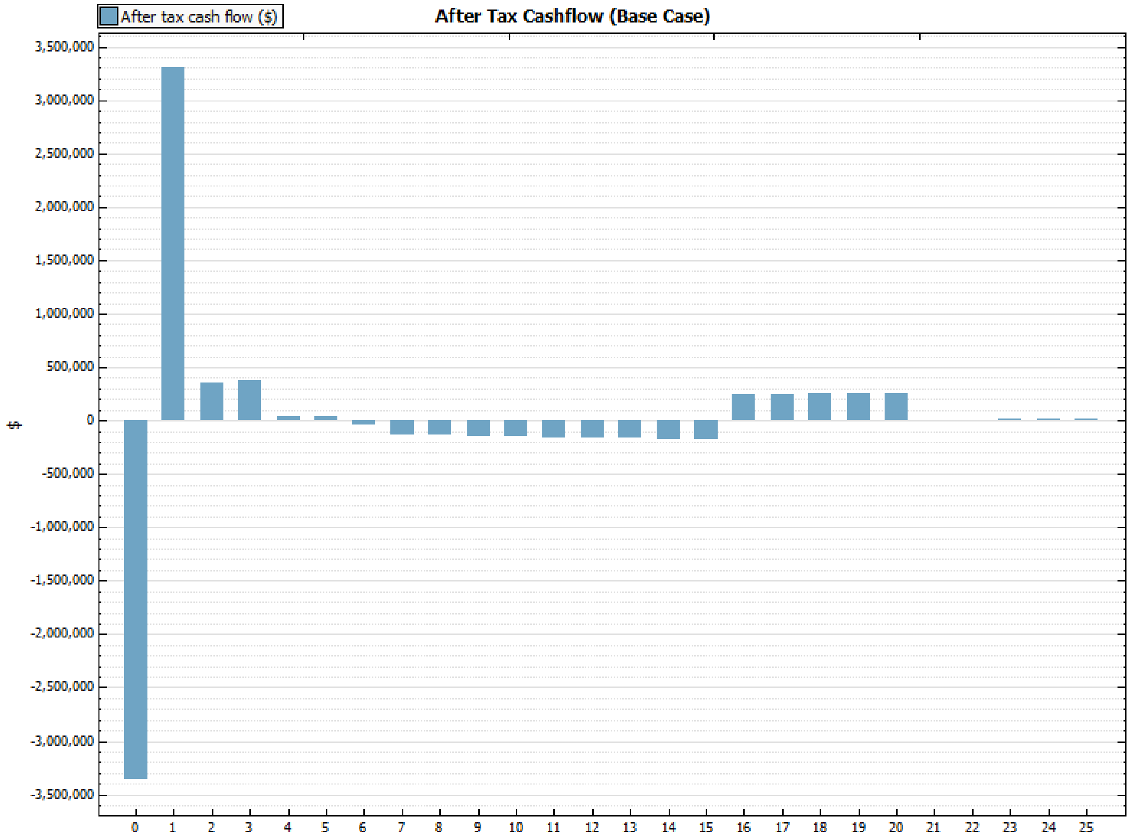

Figure B-8. After-tax cash flow for 2-MW net-metering fixed-axis system

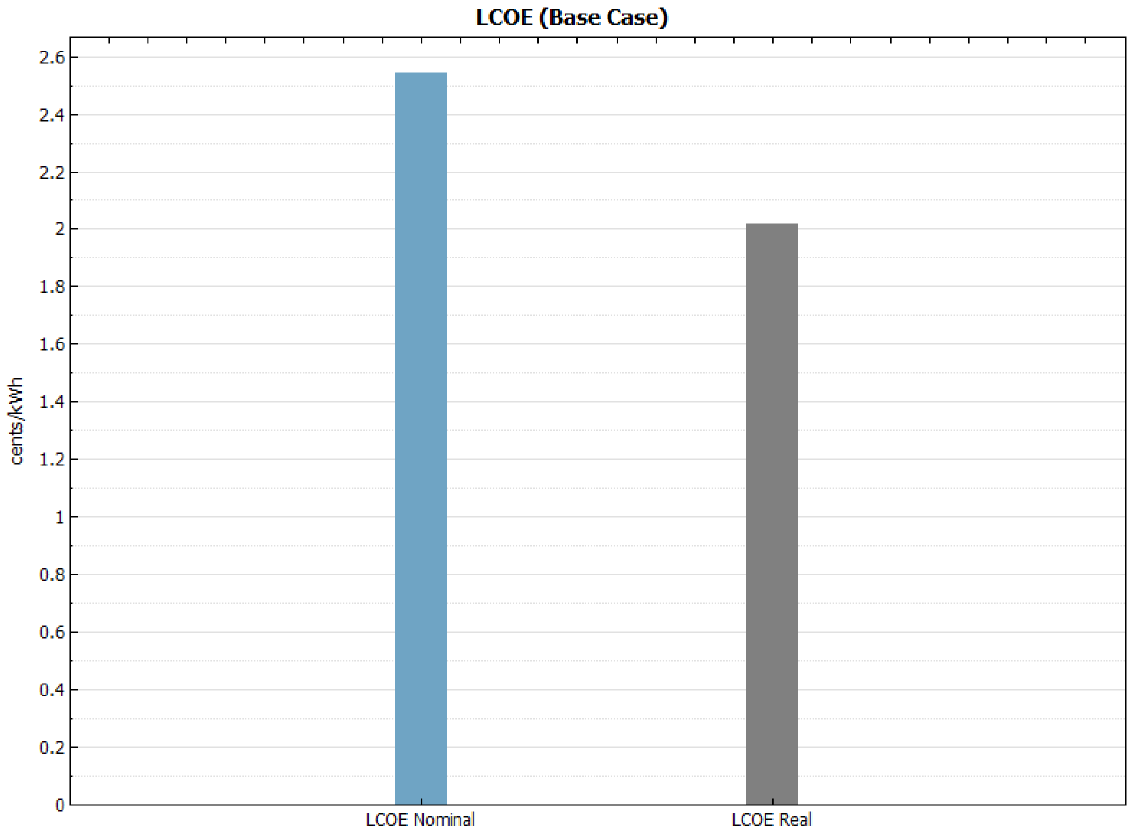

Figure B-9. LCOE for owner purchase of full coverage single-axis tracking PV system

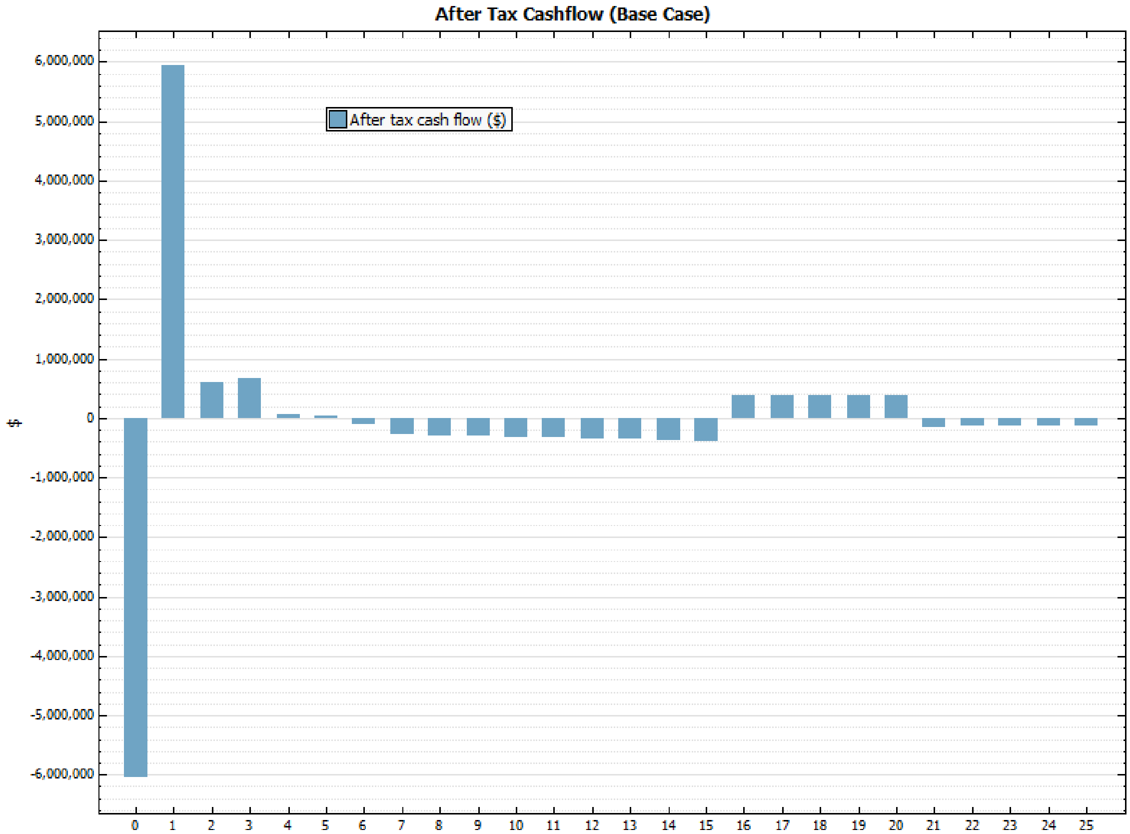

Figure B-10. After-tax cash flow for owner purchase of full coverage single-axis tracking PV system

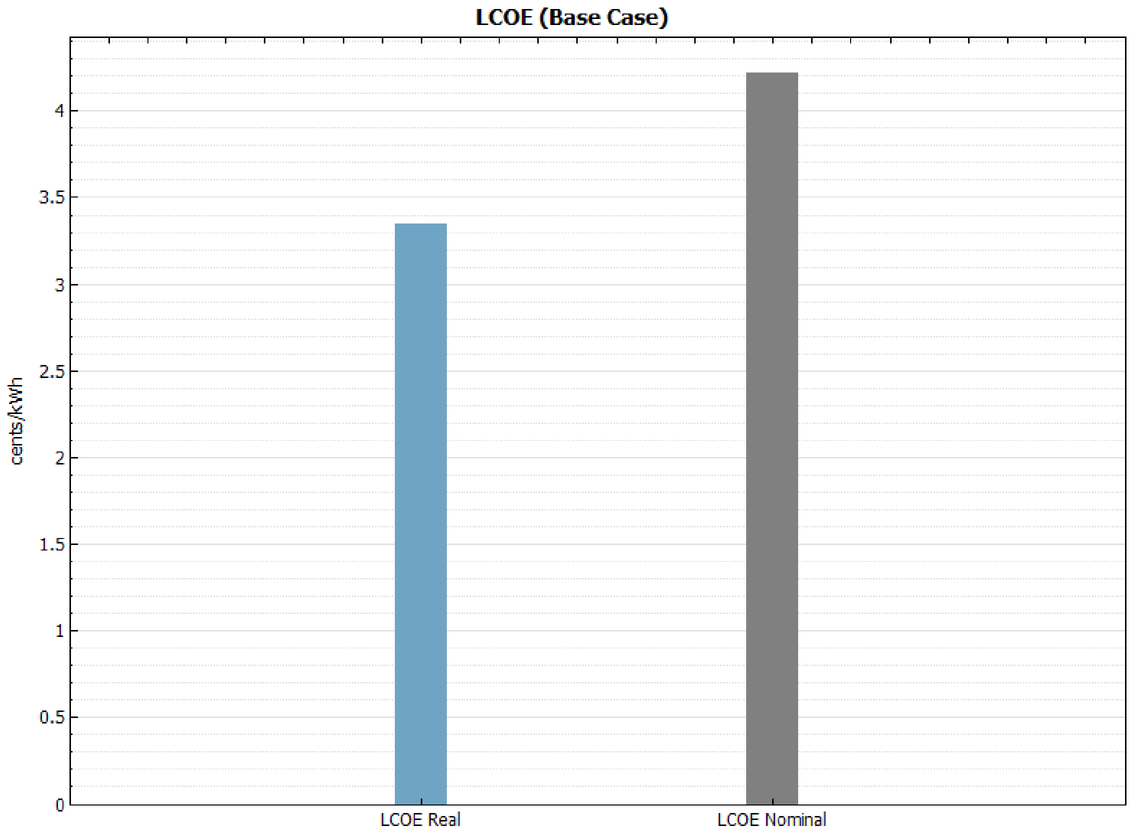

Figure B-11. LCOE for a 2-MW net-metering system single-axis tracking PV system

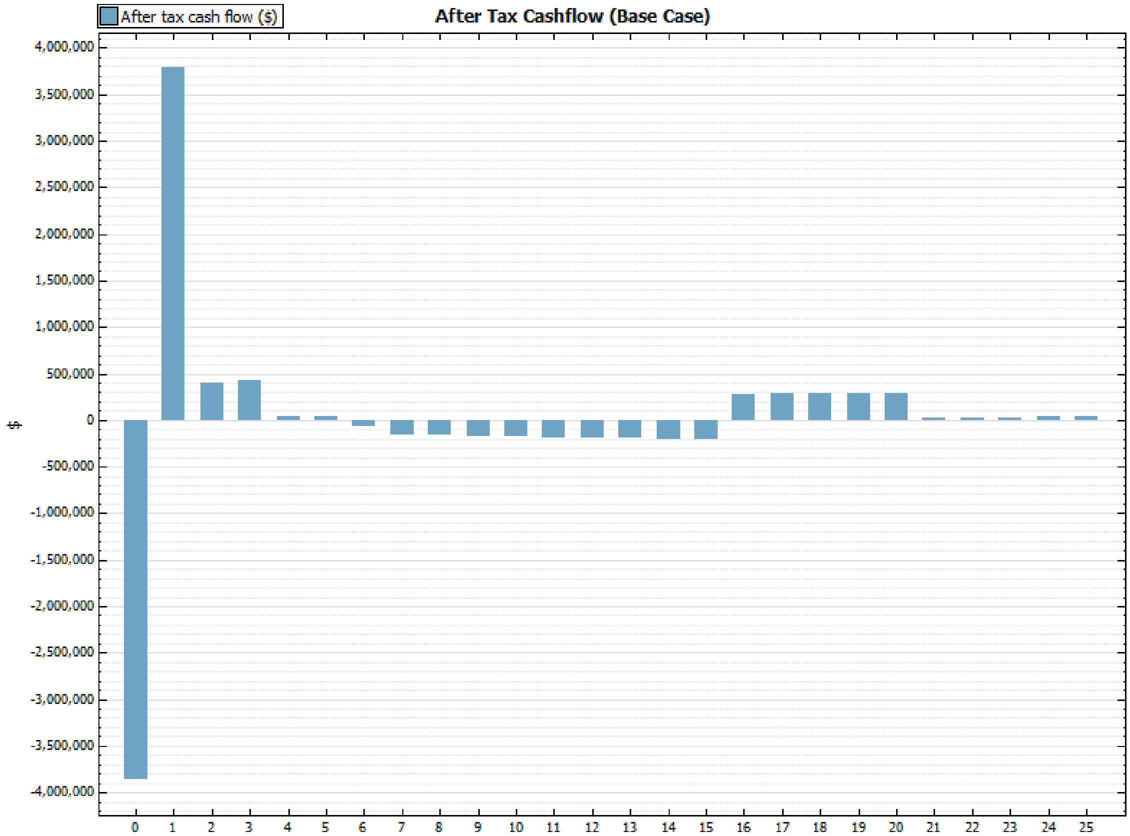

Figure B-12. After-tax cash flow for 2-MW net-metering single-axis tracking PV system

Appendix C. Results from the Job and Economic Development Impact Model

Tables C-1 through C-4 provide results from the JEDI model.

Table C-1. Data Summary for JEDI Model Analysis of Single-Axis Tracking PV System

Project Location	Delaware
Year of Construction or Installation	2013
Average System Size - DC Nameplate Capacity (kW)	2,000.0
Number of Systems Installed	1
Project Size - DC Nameplate Capacity (KW)	2,000.0
System Application	Utility
Solar Cell/Module Material	Crystalline Silicon
System Tracking	Single Axis
Total System Base Cost ($/kW$_{DC}$)	$4,020
Annual Direct Operations and Maintenance Cost ($/kW)	$20.00
Money Value - Current or Constant (Dollar Year)	2012
Project Construction or Installation Cost	$8,040,000
Local Spending	$4,343,995
Total Annual Operational Expenses	$972,640
Direct Operating and Maintenance Costs	$40,000
Local Spending	$36,800
Other Annual Costs	$932,640
Local Spending	$0
Debt Payments	$0
Property Taxes	$0

Table C-2. Summary of Local Economic Impacts for JEDI Model Analysis of Single-Axis Tracking PV System

	Jobs	Earnings	Output
During construction and installation period		**$000 (2012)**	**$000 (2012)**
Project Development and Onsite Labor Impacts			
Construction and Installation Labor	9.6	$623.5	
Construction and Installation Related Services	15.2	$761.3	
Subtotal	24.8	$1,384.9	$2,496.9
Module and Supply Chain Impacts			
Manufacturing Impacts	0.0	$0.0	$0.0
Trade (Wholesale and Retail)	2.9	$186.1	$524.1
Finance, Insurance and Real Estate	0.0	$0.0	$0.0
Professional Services	4.0	$200.9	$607.8
Other Services	6.6	$597.1	$1,867.4
Other Sectors	9.5	$69.5	$218.5
Subtotal	22.9	$1,053.6	$3,217.9
Induced Impacts	13.3	$553.8	$1,738.5
Total Impacts	**61.1**	**$2,992.2**	**$7,453.3**
		Annual	**Annual**
	Annual	**Earnings**	**Output**
During operating years	**Jobs**	**$000 (2012)**	**$000 (2012)**
Onsite Labor Impacts			
PV Project Labor Only	0.4	$22.3	$22.3
Local Revenue and Supply Chain Impacts	0.1	$7.0	$21.0
Induced Impacts	0.1	$3.3	$10.3
Total Impacts	**0.6**	**$32.6**	**$53.6**

Notes: Earnings and Output values are thousands of dollars in year 2012 dollars. Construction and operating period jobs are full-time equivalent for one year (1 FTE = 2,080 hours). Economic impacts "During operating years" represent impacts that occur from system/plant operations/expenditures. Totals may not add up due to independent rounding.

Table C-3. Detailed Summary of Costs for JEDI Model Analysis of Single-Axis Tracking PV System

	Delaware	**Purchased**	**Manufactured**
Installation Costs	**Cost**	**Locally (%)**	**Locally (Y or N)**
Materials & Equipment			
Mounting (rails, clamps, fittings, etc.)	$430,675	100%	N
Modules	$2,750,843	100%	N
Electrical (wire, connectors, breakers, etc.)	$105,386	100%	N
Inverter	$409,100	100%	N
Subtotal	$3,696,005		
Labor			
Installation	$623,544	100%	
Subtotal	$623,544		
Subtotal	$4,319,549		
Other Costs			
Permitting	$43,862	100%	
Other Costs	$969,353	100%	
Business Overhead	$2,707,236	100%	
Subtotal	$3,720,451		
Subtotal	$8,040,000		
Sales Tax (Materials & Equipment Purchases)	$0	100%	
Total	$8,040,000		

Table C-4. Annual O&M Costs for JEDI Model Analysis of Single-Axis Tracking PV System

	Cost	Local Share	Manufactured Locally (Y or N)
Labor			
Technicians	$24,000	100%	
Subtotal	$24,000		
Materials and Services			
Materials & Equipment	$16,000	100%	N
Services	$0	100%	
Subtotal	$16,000		
Sales Tax (Materials and Equipment Purchases)	$0	100%	
Average Annual Payment (Interest and Principal)	$932,640	0%	
Property Taxes	$0	100%	
Total	$972,640		
Other Parameters			
Financial Parameters			
Debt Financing			
Percentage Financed	80%	0%	
Years Financed (term)	10		
Interest Rate	10%		
Tax Parameters			
Local Property Tax (Percent of Taxable Value)	0%		
Assessed Value (Percent of Construction Cost)	0%		
Taxable Value (Percent of Assessed Value)	0%		
Taxable Value	$0		
Property Tax Exemption (Percent of Local Taxes)	0%		
Local Property Taxes	$0	100%	
Local Sales Tax Rate	0.00%	100%	
Sales Tax Exemption (Percent of Local Taxes)	0%		
Payroll Parameters	**Wage Per Hour**	**Employer Payroll Overhead**	
Construction and Installation Labor			
Construction Workers/Installers	$21.39	45.6%	
O&M Labor			
Technicians	$21.39	45.6%	