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Feasibility Study of Economics and Performance of Solar Photovoltaics at the Tronox Facility in Savannah, Georgia

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

Kosol Kiatreungwattana, Jesse Geiger, Victoria Healey, and Gail Mosey

Produced under direction of the Environmental Protection Agency (EPA) by the National Renewable Energy Laboratory (NREL) under Interagency Agreement IAG-09-1750 and Task No. WFD6.1001.

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-7A30-57958
March 2013
Contract No. DE-AC36-08GO28308

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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 Tronox Facility site in Savannah, Georgia, 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 Tronox site is located at 1 Kerr-McGee Road in Savannah, Chatham County, Georgia. It is about 1 mile northeast of the intersection of Kerr-McGee Road and East President Street. Plant operations occupy about 250 acres on the north central portion of the approximately 1,480-acre facility. The main plant includes former titanium dioxide and sulfuric acid production facilities and a former wastewater treatment plant, including five effluent settling ponds, a former in-plant neutralization basin, and several rail lines. The entire facility is regulated under the Georgia Hazardous Site Response Act (State Superfund) for releases of metals, volatile organic compounds (VOCs), and semi volatile organic compound (SVOCs) to soil and groundwater and also has three Resource Conservation and Recovery Act (RCRA)-regulated units that require investigation, corrective action, and closure. A portion of the site, referred to as the Deptford Tract, was used by the City of Savannah as an industrial and municipal waste landfill from 1921 until it was closed in 1953. The Savannah Energy Systems Company operated a municipal solid waste incinerator on a leased portion of the facility from 1985 to 2008.

Tronox declared bankruptcy in 2009, and the case was settled in 2011. The case settlement includes creation of a custodial environmental trust to provide cleanup for the Savannah facility. The current trustee is Greenfield Environmental Savannah Trust LLC; the State of Georgia and U.S. Department of Justice are the beneficiaries of the trust. Rather than fencing the Deptford Tract and leaving it unused, Georgia Environmental Protection Division (GA EPD) believes that this would be a suitable location for a renewable energy project, which will benefit the local community in a number of ways.

There are two locations at the Tronox facility that are being proposed for this study as potential locations for renewable energy projects, the Deptford Tract and the former Montenay Municipal Solid Waste (MSW) incinerator. Both locations are excellent for PV because they are nearly flat, have adequate road and solar access, are zoned for industrial use, and have extensive electrical distribution (which can be found throughout the whole site). The plan is to construct a solar PV system on a concrete cap over the former landfill (Areas 1, 2, and 3) and in an area near the former incinerator (Area 4). The renewable energy projects would return these lands to productive use and more effectively mitigate potential exposure to the waste that remains at the landfill. This renewable energy project will perfectly integrate with the need to prevent exposure to the waste left in place.

The total Tronox Facility area for this study is approximately 49 acres, divided into four major areas. Areas 1, 2, 3, and 4 are approximately 17, 23, 9, and 1 acres, respectively. Areas 1 and 3 are currently full of vegetation and would require cleanup and site preparation. All areas are

relatively flat, unshaded land, which makes them suitable candidates for a PV system. Because these sites are contaminated areas and will be capped with concrete, we do not recommend any penetration through the cap. Therefore, the fixed-tilt ballasted PV system is recommended for this site. The PV capacity of a fixed-tilt ballasted system estimated for Areas 1, 2, 3, and 4 are approximately 2,909 kW; 4,007 kW; 1,456 kW; and 162 kW, respectively. The estimated total PV capacity at the Tronox Facility based on the maximum available land area for this study is as much as 8,534 kW (8.5 MW).

The feasibility of a PV system is highly impacted by the available area for an array, solar resources, distance to transmission lines, and distance to major roads. The potential closest electrical tie-in location is at the Georgia Power substation. Having a substation on site makes it an ideal location to tie into a PV system. A detailed interconnection study is recommended and will have to be performed through the local electric utility, Georgia Power, to determine the feasibility of utilizing the onsite substation as a tie-in point for a PV system. The Tronox Facility site is suitable for a large-scale PV system because it is nearly flat, has adequate road and good solar access, is zoned for industrial uses, and has extensive electrical distribution to the whole site. PV cost for crystalline panels comes down dramatically and becomes competitive with thin-film technology. Therefore, we assumed crystalline PV panels for this analysis. Estimated PV system size and generated electricity is presented in Table ES-1.

Table ES-1. Estimated Electricity Production for Each Area

Site	Estimated PV Capacity (kW)	Annual Electricity Production (kWh/yr)	Annual Energy Value ($)
Area 1	2,909	3,813,699	324,164
Area 2	4,007	5,253,177	446,520
Area 3	1,456	1,908,816	162,249
Area 4	162	212,382	18,052
Total	**8,534**	**11,188,074**	**950,986**

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 NREL's System Advisor Model (SAM). Using varied inputs and the assumptions summarized in Section 5 of this report, the SAM tool predicts net present value (NPV), power purchase agreements (PPA), and levelized cost of energy (LCOE), among other economic indicators. According to the modeling software with the given assumptions, every scenario for solar development would have a payback.

To evaluate the employment and economic impacts of the PV project associated with this analysis, NREL's Jobs and Economic Development Impact (JEDI) models are used. 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.

There are three scenarios evaluated as part of this PV project analysis. All detailed assumptions and results for the analysis can be found in the Appendix. The three scenarios are:

Case 1: Investor owned/PPA with 8.5 MW

This case assumes a third-party investor for the PV system. All generated electricity from Case 1 is assumed to be sold. The results of this case are used to estimate the electricity rate needed as part of a PPA to get an acceptable return on investment (15% internal rate of return).

Case 2: Developer owned/PPA with 8.5 MW

This case assumes the developer owns the PV system. All generated electricity from Case 2 is assumed to be sold to Georgia Power at the avoided cost of $0.08/kWh.

Case 3: Developer owned/net metering with 100 kW

This case assumes the developer owns the PV system. All electricity from Case 3 is assumed to be used on site.

Results

The three scenarios were run for the Tronox Facility to encompass the options available for this site. The independent variables include a third-party developer versus existing site ownership and on-site use of electricity versus selling it back to Georgia Power. There are multiple factors that go into choosing which scenario to pursue beyond NPV, PPA, and LCOE. Table ES-2 shows the modeled results from the different scenarios.

- Case 1—Investor owned/PPA will be economically feasible if the investor can sell the electricity of the PPA at $0.1886/kWh. The retail rate of the electricity at $0.085/kWh is lower than a PPA, so the Tronox Facility is not likely to buy this electricity. In addition, Georgia Power’s purchase rate is estimated to be approximately $0.080/kWh. Therefore, a solar investor is unlikely to invest given current conditions.
- Case 2—Developer owned/PPA has negative NPV and shows the low LCOE of $0.089/kWh with a payback period of 24 years. However, further analysis shows that NPV becomes positive if the utility purchase price is $0.135/kWh or above. Therefore, the project can be viable if the purchase rate is increased or the developer can negotiate for that rate.
- Case 3—Economically, a PV system up to 100 kW net metering is the best scenario. It has a positive NPV and a payback of approximately 14 years. This system could generate up to 132,000 kWh annually. We recommend the 100-kW net-metering project for each individual future building/site.

Results of the JEDI analysis show that the total potential system of 8.5 MW is estimated to support 235 direct and indirect jobs per year for the duration of the procurement and construction periods. Total wages paid to workers during the construction period are estimated to be $10,895,200, and total economic output is estimated to be $27,099,700. The annual O&M of the new PV system is estimated to support 3.2 full-time equivalents (FTEs) per year for the life of the system. The jobs and associated spending are projected to account for approximately $176,200 in earnings and $307,900 in economic activity each year for the next 25 years.

Improvements to the incentives field could change these projects to be very favorable. Such incentives would include an increase to the purchase price from Georgia Power; loan guarantees with longer repayment periods; and higher REC payments that would apply to larger systems.

A large PV system can be installed at the Tronox Facility site. Finding potential buyers for the generated electricity at a reasonable price—whether they are future Tronox industries or a local or interstate utility company—will be key to the project's development. Virtual net metering would also be a good option to sell the excess electricity if the state allows. In addition, any environmental considerations shall be included in the request for proposals during project development.

Table ES-2. PV System Summary

Investor-Owned Cases	Capacity	LCOE ($/kWh)	NPV ($)	PPA ($/kWh)	Payback (yr)
Case 1 - Investor owned/PPA	8.50 MW	$0.2124	$1,576,988	$0.1882	N/A
Case 2 - Developer owned PPA	8.50 MW	$0.1132	($5,242,793)	-	24.4
Case 3 - Developer owned/net metering	100 kW	$0.0587	$17,055	-	13.8

Table ES-3. Potential Energy Production and Economic Impacts on Created Jobs

System Type	PV System Size[a]	Array Tilt	Annual Output	Number of Houses Powered[b]	Jobs Created[c]	Jobs Sustained[d]
	(MW)	(deg)	(MWh/year)		(job-year)	(job-year)
Case 1 - Investor owned/ PPA	8.50	20	11,188	1,013	235	3.2
Case 2 - Developer owned/ PPA	8.50	20	11,188	1,013	235	3.2
Case 3 - Developer owned/ net-metering	**0.10**	**20**	**131**	**12**	**13**	**0.1**

System Type	System Cost
Case 1 - Investor owned/ PPA	$ 29,698,320
Case 2 - Developer owned/ net-metering	$ 29,698,320
Case 3 - Developer owned/ net-metering	**$ 348,000**

[a] *Data assume a maximum usable area of 2,000 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 Tronox Facility site in Savannah, Georgia, 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 Tronox Facility site is located at 1 Kerr-McGee Road, in Savannah, Chatham County, Georgia, about 1 mile northeast of the intersection of Kerr-McGee Road and East President Street. As of the 2011 census, Savannah has a population of 139,491. Savannah usually has warm, and frequently hot, humid weather throughout the year. Average high temperature in January is 59.7°F, and the average high is 91.1°F in July. The average low temperature in January is 38.1°F, whereas the average low temperature in July is 72.4°F. Average total precipitation is 49 inches per year. Summer in Savannah tends to be humid with many thunderstorms. However, Savannah has on average 216 days of sunshine each year. Georgia Power is the utility that provides electricity to Tronox; it is a regulated utility.

Plant operations occupy about 250 acres on the north central portion of the larger property that covers approximately 1,480 acres. Figure 1 shows the property line of the Tronox Facility.

The main plant includes former titanium dioxide and sulfuric acid production facilities and a former wastewater treatment plant (including five effluent settling ponds, a former in-plant neutralization basin, and several rail lines). The entire facility is regulated under the Georgia Hazardous Site Response Act (State Superfund) for releases of metals, volatile organic compounds (VOCs), and semi volatile organic compounds (SVOCs) to soil and groundwater and also has three Resource Conservation and Recovery Act (RCRA)-regulated units that require investigation, corrective action, and closure. A portion of the site, referred to as the Deptford Tract, was used by the City of Savannah as an industrial and municipal waste landfill from 1921 until it was closed in 1953. The Savannah Energy Systems Company operated a municipal solid waste incinerator on a leased portion of the facility from 1985 to 2008.

The Deptford Tract is regulated under the State Superfund and was listed on the Georgia Hazardous Site Inventory in 1994 for a release of metals to groundwater and metals, VOCs, and SVOCs to soil. The corrective action for the Deptford Tract calls for the excavation of limited hot spots, installation of a barrier fence to prevent access, and institutional controls.

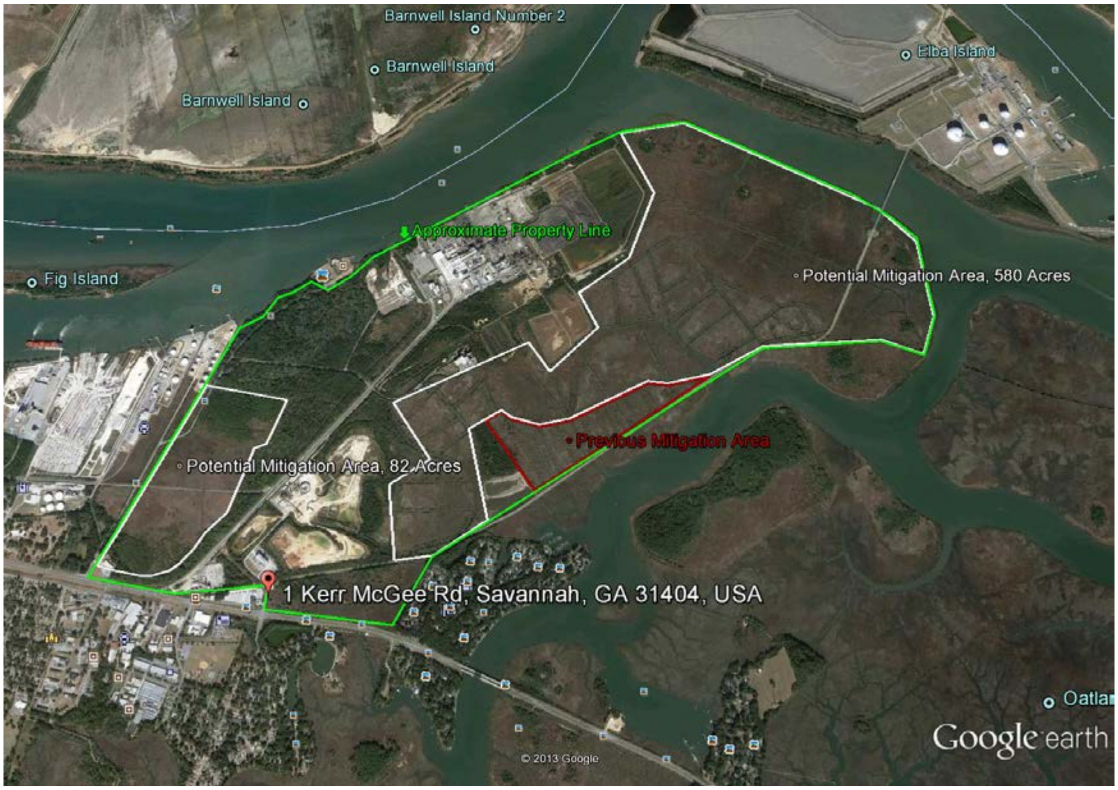


Figure 1. Tronox Facility property line

Illustration done in Google Earth

Tronox declared bankruptcy in 2009, and the case was settled in 2011. The case settlement includes creation of a custodial environmental trust to provide cleanup of the Savannah facility. The current Trustee is Greenfield Environmental Savannah Trust LLC. The State of Georgia and U.S. Department of Justice are the beneficiaries of the trust. Any proceeds from the sale of the site not needed for the Savannah property will be distributed to a multi-state trust for cleanup of other Tronox facilities. If funds remain in any trust when all environmental actions under all trusts are completed, these funds will revert to the USEPA Superfund.

The two main areas of known contamination at the site are the Deptford Tract and the main plant area. The Deptford Tract is a former City of Savannah landfill, operated from 1921–1953. The Deptford Tract has been investigated under the requirements of the Georgia Hazardous Site Response Act (HSRA), which is the Georgia State Superfund statute, and the rules promulgated pursuant thereto. This site was listed on the Georgia Hazardous Site Inventory (HSI) in 1994; the Deptford Tract covers about 60 acres that require corrective action for releases of metals to groundwater and metals, VOCs, and SVOCs to soil. The main plant area is also listed on the HSI and has a footprint of around 250 acres. Over 60 acres of the main plant area have a series of ponds formerly used for solids settling, with only two of these ponds having freeboard to hold water; the others are filled with solids from processes at the site. The main plant area groundwater is contaminated with metals and solvents and the soil is contaminated with metals.

The Deptford Tract has been fully investigated and a Corrective Action Plan (CAP) has been submitted and approved by Environmental Protection Division (EPD). The CAP requires some excavation of highly contaminated areas, restoration of the soil cover, and installation of a 5-foot chain link fence and signage to restrict access. Annual groundwater monitoring is required to demonstrate that groundwater contamination is not increasing or spreading. Quarterly inspection of the soil cover over the landfill is also required. A restrictive covenant has been recorded that requires implementation of the CAP, maintenance of the fence, and prohibition of drinking water wells.

The main plant area was used from 1955–2009 for production of titanium dioxide pigment using both the sulfate and chloride processes. A 300+-ton-per-day sulfuric acid plant continues to operate in this area. Within the main plant area, three discrete locations have been identified as RCRA-regulated units: the ditch system, the chlorinator brick pile, and the washout sump area. All three units have managed releases of low-pH wastewaters and require closure. Investigation of these areas is complete, and closure of these three areas will be finished in 2013. It is expected that corrective action for these areas will consist of excavation. Because previous investigations by former owners of the site indicate that groundwater contamination is not solely attributable to these units, upon certification of closure the remaining investigation and remediation in the main plant area will be conducted under HSRA.

Other environmental concerns at the site include:

- Maintenance of the berms around the ponds adjacent to the Savannah River
- Asbestos siding on the old sulfate plant structure
- Possible contamination at the former Montenay Municipal Solid Waste (MSW) Incinerator
- Possible contamination at the Kemira Water Solutions area
- Groundwater contamination being remediated by Air Liquide
- Maintenance of storm water controls at gypsum stockpile east of the Deptford Tract.

Rather than fencing the Deptford Tract and leaving it unused, Georgia EPD believes that this would be a suitable location for a renewable energy project. The renewable energy project will benefit the local community in a number of ways. There is a need for this facility to be redeveloped to increase the local tax base and provide jobs. The property and surrounding area are largely industrial and are expected to grow with continued expansion of the Savannah port. Renewable energy development in this area is seen as a key inducement for expanding global commerce in this part of Savannah. As a coastal community, there is a need to develop energy sources that do not impact the sensitive environment and ecosystems. The proposed projects will induce the redevelopment of the facility by providing low-cost power, reduce the need for electricity generated by non-renewable sources, and reduce the environmental impact from current power sources.

The Montenay Incinerator is a former MSW incinerator that consists of two mass-fired combustion units. Part of the NREL grant application included evaluating the feasibility of operating the former Montenay Incinerator as a biopower plant. The facility was operated by the Savannah Energy Systems Company from 1985–2008. The facility was designed to process 500 tons per day of non-hazardous waste with higher heating value of 4,500 Btu/lb. The combustion system consists of a Katy-Seghers grate and an underfire and overfire air supply system, a charge system, a grate sifting bottom ash removal system, and controls. Overhead cranes were used to move waste from storage pits to a charging chute. The grate surface of the combustion units can continuously accept waste from the charging unit and move it through the combustion unit as it burns.

During its operation, the plant processed an average of 157,000 tons per year and had a boiler efficiency of 67%. Rather than leave this plant idle, the Georgia EPD is interested in operating the facility as a biopower plant. In addition to numerous industrial facilities in the area that could supply used wooden pallets and other organic industrial debris, there are two pulp and paper mills within 50 miles of this location that could provide pulp and paper mill residues. With highway, rail, and deep-water river access, there are numerous sources of biofuels that could be utilized by this project. While not included as part of this project, determining the future feasibility of a biopower plant is recommended.

There are two locations at the Tronox Facility that are being evaluated in this study as potential locations for PV system projects, the Deptford Tract and the area around the former Montenay MSW Incinerator. Both locations are excellent for PV because they are nearly flat, have suitable road and solar access, are zoned for industrial use, and have extensive available electrical distribution. The plan is to construct a solar PV system on a concrete cap over the former landfill and in the area around the former incinerator. The renewable energy projects would return these lands to productive use and be a more effective method of eliminating potential exposure to the waste that remains at the landfill. This renewable energy project will perfectly meet the need to prevent exposure to that waste.

In addition, EPD has received a commitment from Georgia Power to purchase any excess electricity generated by these projects. Further, Georgia Power is actively working with EPD regarding the installation of solar power generating equipment on closed landfills and is looking to gain experience through this process in order to apply renewable energy projects like this study to other properties.

Feasibility assessment team members from NREL, EPD, and EPA conducted a site visit on April 3, 2012, to gather information integral to this feasibility study for solar PV systems. The team considered information including solar resource, transmission availability, community acceptance, and ground conditions.

2 Development of a PV System on Contaminated Lands

Through the RE-Powering America's Lands initiative, EPA has identified several benefits for siting solar PV facilities on contaminated lands, noting that they:

- Can be developed in place of limited greenfields, preserving the land carbon sink
- Might have environmental conditions that are not well suited for commercial or residential redevelopment and may 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 may 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 (GHGs)].

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

The Tronox Facility is managed by Greenfield Environmental Savannah Trust LLC, which is interested in developing renewable projects on the site. For many contaminated land 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.

Understanding opportunities studied and realized at other similar sites demonstrate the potential for PV system development. Due to the contamination with hazardous waste, the Tronox site has limited building development opportunities. It is within a location in need of locally produced power. Remediation of contamination is at a stage that will allow for installation of PV systems in the future. PV development that provides community energy and jobs may be the highest and best use of the site.[1]

There are considerations for installation of solar PV system on contaminated lands, including potential impacts to the cover system, erosion, storm water management, compaction, construction, and vegetation. In addition, financial assurance would be required to remove the solar facility and maintain the installed concrete cap at the end of the project life. These considerations shall be included in the request for proposals (RFP) during project development.

[1] For more information on similar projects, see the RE-Powering America's Lands website at www.epa.gov/oswercpa/.

The subject 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 enhance the overall utility of the property.

Beyond the financial benefits of installing a large-scale PV system, there are additional non-financial benefits in renewable energy deployment. Property owners can consider many additional 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 easily emit electrons. The electric field in the solar cell pulls these electrons to another layer, connecting the cell to an external load. This current (movement of charges) can then be used to power the load (e.g., light bulb).

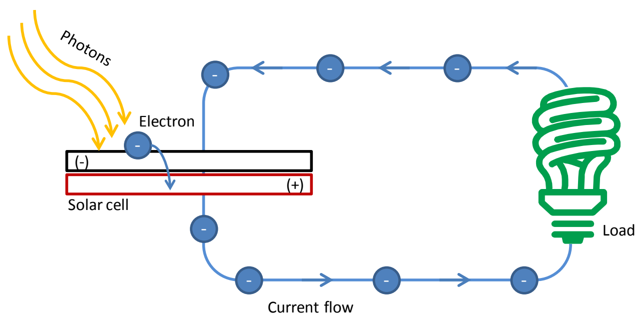


Figure 2. Generation of electricity from a PV cell

Source: EPA

PV cells are assembled into a PV panel or module. PV modules are then connected in a series and then in parallel as needed to reach the specific voltage and current requirements for the array in which they are arranged. The direct current (DC) electricity generated by the array is 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 sizes vary; there are small residential (2–10 kW), commercial (100–500 kW), and large utility-scale (10+ MW) sizes. 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

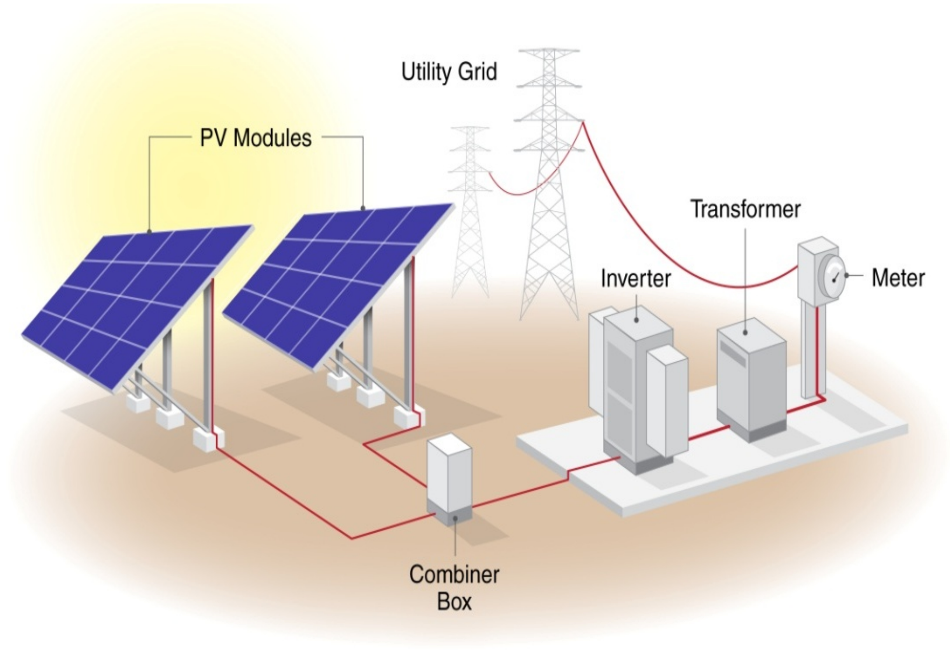


Figure 3. Ground-mounted array diagram

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 in turn 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, which is quite abundant and non-toxic. It builds on a strong industry on both the supply (silicon industry) and product sides. This technology has demonstrated a consistent and high efficiency of over 30 years in the field. The performance degradation, a reduction in power generation due to long-term exposure to environment, is under 1% per year. Silicon modules have a lifespan in the 25- to 30-year range 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, the distinction of which indicates the presence of grain-boundaries (i.e., multiple crystals) in the cell materials; this is controlled by raw material selection and manufacturing technique. Crystalline silicon panels are widely used based on deployments worldwide.

Figure 4 shows two examples of crystalline solar panels: mono- and multi-crystalline installed on tracking mounting systems.

Figure 4. Mono- and multi-crystalline solar panels. ***Photos by (left) SunPower, 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 5 shows thin-film solar panels.



Figure 5. Thin-film solar panels installed on (left) solar energy cover and (middle/right) fixed-tilt mounting system. ***Photos by (left) Republic Services Inc., NREL 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 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 on the market. Electricity produced from the system may be fed to a step-up transformer to increase the voltage in order to match the grid.

There are two primary types of inverters for grid-connected systems: string and micro-inverters. Each type has strengths and weakness 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, and they also tend to have high efficiency and lower operations 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 the 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 10–20 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. With micro-inverters, it impacts only that particular shaded panel. Figure 6 shows a string inverter.

Figure 6. 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 or 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 reclaimed mine site or contaminated land 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 reclaimed mine sites and on contaminated lands. 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. However, the movable trackers require more space between roles. System capacity for tracking systems is less than that for the fixed-tilt at the same land area. 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. 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 might 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.

3.2.3.2 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. With reclaimed mine sites or contaminated lands, 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 request for proposals (RFPs) 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 via 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 may also use this data to identify required maintenance, shade on panels, and accumulating dirt on panels, for example. Monitoring system data can also be used for outreach and education (e.g., publicly available online displays, wall-mounted systems, or smart phone applications).

3.2.4 Operation and Maintenance

PV panels typically have a 25-year performance warranty. The 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 April 3, 2012.

4.1 Tronox Facility Site PV System

The Tronox Facility site is suitable for PV. There are two proposed locations for renewable energy projects for this study: the Deptford Tract (Areas 1, 2, and 3) and the area around the former Montenay Incinerator (Area 4). All locations are suitable for PV because they are nearly flat, have adequate road and solar access, and have extensive electrical distribution. Electricity generated at the site can be sold to Georgia Power.

In order to get the most out of the ground area available, it is important to consider whether the site layout can be improved to better incorporate a solar system. If there are unused structures, fences, or electrical poles that can be removed, the unshaded area can be increased to incorporate more PV panels. Figure 7 shows an aerial view of the Tronox Facility sites. The feasible areas for PV are outlined in orange, and the electrical tie-in point for the PV system is given.

Figure 7. Aerial view of proposed areas for PV projects at the Tronox Facility

Illustration done in Google Maps

There are four proposed areas for PV projects for the Tronox Facility. Potential utility tie-in for Areas 1, 2, and 3 is at the Georgia Power substation at the southwest corner of the site, as shown in Figure 7. For Area 4, the utility tie-in is at the existing Montenay Incinerator. Area acreage and distance to utility tie-in was estimated by using Google Earth; area size for each site, estimated PV capacity, and distance to utility tie-in are presented in Table 2.

Table 2. Area Size for Each Site, Estimated PV Capacity, and Distance to Utility Tie-in

Site	Acreage	Estimated PV Capacity (kW)	Distance to Utility Tie-in (ft)
Area 1	16.7	2,909	600
Area 2	23.0	4,007	2,250
Area 3	8.4	1,456	3,000
Area 4	0.9	162	100

The total Tronox Facility area for this study is approximately 49 acres, divided into four major areas. Areas 1, 2, 3, and 4 are approximately 17, 23, 9, and 1 acres, respectively. Areas 1 and 3 are currently full of vegetation requiring cleanup and site preparation. Once the vegetation is cleared, the areas are relatively flat, unshaded land, which make them a suitable candidate for a PV system. Because Areas 1, 2, and 3 are contaminated areas with leftover waste, we do not recommend any ground penetration. Therefore, the fixed-tilt ballasted PV system is recommended for this study. The PV capacity of a fixed-tilt ballasted system estimated for Areas 1, 2, 3, and 4 are approximately 2,909 kW; 4,007 kW; 1,456 kW; and 162 kW, respectively. Estimated total PV capacity of the Tronox Facility based on maximum available land area for this study is up to 8,534 kW (approximately 8.5 MW).

PV systems are well suited to the Savannah, Georgia, 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 5.11 kWh/m^2/day. Figures 8 and 9 show various views of the studied areas at the Tronox Facility.

Figure 8. Views of the feasible area for PV at Areas 1 and 3 of the Deptford Tract. ***Photos by Kosol Kiatreungwattana, NREL***

Figure 9. Views of the feasible area for PV at Area 4 of the Montenay Incinerator. ***Photos by Kosol Kiatreungwattana, NREL***

4.2 Utility-Resource Considerations

The expected electrical tie-in point and inverter for the PV system at the Tronox Facility is located at the Georgia Power Station southwest of Area 1. Areas 1, 2, and 3 can tie in to 13.2-kV or 115-kV power lines. Area 4 can potentially tie in to the 13.8-kV power line at Montenay Incinerator. Per conversation with Georgia Power personnel, the power line at the Tronox Facility has adequate capacity to accommodate a large PV system. A technical analysis of line capacity is recommended.

4.3 Useable Acreage for PV System Installation

Typically, a minimum of 2 useable acres is recommended to site PV systems. Useable acreage is typically characterized as "flat to gently sloping" with 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 under-utilized or unoccupied land, vacant lots, and/or unused paved areas (e.g., a parking lot or industrial site space) as well as existing building rooftops. The total of 49 acres (Area 1, 17 acres; Area 2, 23 acres; Area 3, 9 acres; and Area 4, 1 acre) is flat and free of all major shading obstructions after a vegetation cleanup.

4.4 PV Site Solar Resource

The Tronox Facility has been evaluated to determine the adequacy of the solar resource available using both on-site data and industry tools.

Currently, Areas 1 and 3 are full of vegetation and require site preparation and vegetation cleanup. The assessment team for this feasibility study collected multiple Solmetric SunEye data points and found a solar access of 95% or higher. All data gathered using this tool are available in Appendix C.

The predicted array performance was found using PVWatts Version 2[2] for Savannah, Georgia. Table 3 shows the station identification information, PV system specifications, and energy specifications for the site. For this summary array performance information, a hypothetical 20-degree fixed-tilt 1-kW system 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.

[2] http://www.nrel.gov/rredc/pvwatts/.

Table 3. Site Identification Information and Specifications

Station Identification	
City	Savannah
State	Georgia
Latitude	32.13° N
Longitude	81.20° 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	180°
Energy Specifications	
Cost of Electricity (retail)	$0.085/kWh

Table 4 shows the performance results for a 20-degree fixed-tilt PV system in Savannah, Georgia, as calculated by PVWatts. Estimated electricity production and the value of the energy for each system at each site are presented in Table 5.

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

Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	3.47	79	6.71
2	4.52	94	7.99
3	5.54	125	10.62
4	6.03	130	11.05
5	6.18	132	11.22
6	5.99	121	10.29
7	6.14	128	10.88
8	5.65	119	10.12
9	5.15	106	9.01
10	4.93	107	9.10
11	4.15	90	7.65
12	3.49	80	6.80
Year	5.11	1,311	111.44

Table 5. Estimated Electricity Production for Each Site

Site	Estimated PV Capacity (kW)	Annual Electricity Production (kWh/yr)	Annual Energy Value ($)
Area 1	2,909	3,813,699	324,164
Area 2	4,007	5,253,177	446,520
Area 3	1,456	1,908,816	162,249
Area 4	162	212,382	18,052
Total	8,534	11,188,074	950,986

4.5 Tronox Facility Energy Usage

The only current activity at the Tronox Facility is the operation of a 300+ ton-per-day sulfuric acid plant and its support systems. The monthly average electricity consumption is 2,112,000 kWh. The average power cost is around $0.085/kWh with power provided by Georgia Power. Significant utility infrastructure exists at the site, minimizing the need for significant investment in transmission equipment to sell power for grid distribution. Future power needs of the site are unknown at this time, but it is anticipated that additional industry will locate on the site to take advantage of the potential renewable energy produced.

4.5.1 Net Metering

Net metering is an electricity policy for consumers who own renewable energy facilities. "Net" in this context 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. According to Section 1251of the Energy Policy Act of 2005, 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 onsite 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.

With significant future on-site energy consumption at the Tronox Facility, net metering can be a good option for a PV project. Therefore, net metering was included as part of the analysis for this study. However, Georgia Power currently allows only up to a 100-kW PV system to consist of net metering. This means it will be a suitable option for a single small- or medium-sized building/facility in the future.

4.5.2 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 1 MW 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. Unfortunately, Georgia currently does not offer VNM to PV generators.

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 NREL's System Advisor Model (SAM).[3]

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

SAM consists of a performance model and a 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.

SAM makes performance predictions for grid-connected solar, small wind, and geothermal power systems; it makes economic estimates for distributed energy and central generation projects. The model calculates the cost of generating electricity based on information 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

The 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 have 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 further cost reduction is expected as market conditions evolve.

For this analysis, the installed cost of fixed-tilt ground-mounted systems was assumed to be $2.79/W. The cost for PV crystalline panels comes down dramatically and becomes competitive with thin-film technology. Therefore, we assumed crystalline PV panels for this analysis. Because Areas 1, 2, and 3 have waste and will be capped with concrete, we do not recommend any penetration through the cap. Although tracking systems can produce more electricity, they have a higher cost and may put uneven stress to the capping materials. Therefore, the fixed-tilt ballasted PV system is assumed at the Tronox Facility.

The estimated increase in cost from this baseline for a ballasted system is 25% (recommended for this site). The cost is increased because of ground conditions at the

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

site, which place limitations on design and construction methods. Such limitations include restrictions on stormwater runoff, weight loading of construction equipment, inability to trench for utility lines, additional engineering costs, permitting issues, and non-standard ballasted racking systems. The installed system cost assumptions are summarized in Table 6.

Table 6. Installed System Cost Assumptions

System Type	Fixed Tilt ($/Wp)
Baseline System	2.79
With Ballast	0.70
Total Installed Cost	3.49

These prices include the PV array and the BOS components for each system, including the inverter and electrical equipment as well as the installation cost. This includes estimated taxes and a 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 incentives are received for taxable entities. It is important to consider all applicable incentives or grants to make PV as cost-effective as possible. If the PV system is owned by a private tax-paying entity, this entity may qualify for a federal tax credit and accelerated depreciation on the PV system, which can be worth about 30% of the initial capital investment. In fact, the total potential tax benefits to the tax-paying entity can be as high as 45% of the initial system cost. Because state and federal governments do not pay taxes, private ownership of the PV system would be required to capture tax incentives.

Future land use and the power demands of any potential reuse are unknown at this time, but if there is excess electricity, Georgia Power has a number of options through which it can purchase renewable energy. More specifically, customers who generate electricity from solar facilities may sell some or all of that electricity back to Georgia Power via the following programs:

- Small generators (≤100 kW) are eligible to sell their electricity under the Renewable & Non-Renewable Tariff (RNR-7) and the Solar Purchase Tariff (SP-1)
    - Customers preferring a bi-directional metering option will participate in the RNR-7 Tariff. Under the RNR-7 Tariff, energy produced by the solar system will offset kilowatt-hours at the facility and any excess kilowatt-hours generated will be purchased at Georgia Power's avoided energy cost. More information regarding the RNR-7 Tariff can be found at www.georgiapower.com/green/rnr_tariff.asp.

- Customers interested in selling all of the energy produced by a solar facility can participate in the SP-1 Tariff. Under the SP-1 Tariff, all energy produced by the facility will be purchased at $0.17/kWh. More information regarding the SP-1 Tariff can be found at www.georgiapower.com/green/solar_purchase_tariff.asp.

- Larger customers (≤80 MW) could sell their energy as a qualifying facility (QF). Under the QF agreement, all energy produced by the facility will be purchased at Georgia Power's avoided energy cost. More information regarding QFs can be found at: www.georgiapower.com/smallpowerproducers.asp.

For the purposes 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. Inflation is assumed to be 1.5%, the real discount rate to be 6%, financing secured via a 25-year loan at a 7% interest rate and 80% debt fraction. The panels are assumed to have a 1% per year degradation in performance. The O&M expenses are estimated to be $20/kW/yr for the life of the system. In addition, it is expected that there will be a $250/kW charge to O&M in year 15 to replace the inverters associated with the system. A system DC-to-AC conversion of 80% was assumed. This includes losses in the inverter, wire losses, PV module losses, and losses due to temperature effects. PVWatts Version 2 was used to calculate expected energy performance for the system.

Georgia Power buys energy from solar resources to supply the Green Energy Program through the Solar Purchase Tariff (SP-1). Qualifying customers can sell all of the energy produced from solar installations (≤100 kW in size) to Georgia Power at $0.17/kWh. However, the program is fully subscribed and is not accepting new customers into the program at this time. For small installations (≤100 kW in size), the selling rate was assumed at $0.12/kWh for the analysis. With large systems, Georgia Power currently buys the electricity back at their avoided generation cost of $0.075–$0.12/kWh with capacity credit. The actual buy-in rate is determined on a case-by-case basis. For this analysis, we used the price of $0.08/kWh. The electricity retail price was modeled as $0.085/kWh. PVWatts Version 2 was used to calculate expected energy performance for the system. The list of incentives used in this study can be found in Table 7.

Table 7. Summary of Incentives Evaluated

Incentive Title	Modeled Value	Expected End
Clean Energy Tax Credit (Corporate)	Renewables: 35%; Maximum Incentive: PV: $500,000	12/31/2014
Net Metering	$0.085/kWh	For ≤100-kW System

5.2 SAM Forecasted Economic Performance

Using varied inputs and the assumptions summarized in Section 5.1, the SAM tool predicts NPV, PPA, and LCOE, among other economic indicators. According to the modeling software with the given assumptions, every scenario for solar development would have a payback.

The LCOE (in cents per kilowatt-hour) accounts for a project's installation, financing, tax, and operating costs and the quantity of electricity it produces over its life. The LCOE makes it possible to compare alternatives with different project lifetimes and performance characteristics. Analysts can use the LCOE to compare the option of installing a residential or commercial project to purchasing electricity from an electric service provider or to compare utility and commercial PPA projects with investments in energy efficiency, other renewable energy projects, or conventional fossil fuel projects. The LCOE captures the trade-off between typically higher-capital-cost, lower-operating-cost renewable energy projects and lower-capital-cost, higher-operating-cost fossil-fuel-based projects.

The PPA price is the first-year price that electricity could be sold to the property owner allowing the developer to own a certain internal rate of return. For this analysis, the required internal rate of return used was 15%, and the first-year PPA price escalates at 1.5% per year.

There are three scenarios for the analysis. All detailed assumptions and results for the analysis can be found in Appendix D.

Case 1: Investor-owned/PPA with 8.5 MW

This case assumes a third-party investor for the PV system. All generated electricity from Case 1 is assumed to be sold. The results of this case are used to estimate the needed electricity rate as part of a PPA to achieve acceptable return on investment (15% internal rate of return).

Case 2: Developer-owned/PPA with 8.5 MW

This case assumes the developer owns the PV system. All generated electricity from Case 2 is assumed to be sold to Georgia Power at the avoided cost at $0.08/kWh.

Case 3: Developer-owned/net metering with 100 kW

This case assumes the developer owns the PV system and that all electricity is assumed to be used on site.

5.3 Results

The three above scenarios for the Tronox Facility encompass the options available to this site. The independent variables include: third-party developer versus existing site ownership and on-site use of electricity versus selling it back to Georgia Power. Beyond NPV, PPA, and LCOE, there are multiple factors that go into selecting a scenario. Table 8 shows the modeled results from the different scenarios. The entire results and summary of inputs to SAM is available in Appendix E.

- Case 1 will be economically viable if the investor can sell the electricity of the PPA at $0.1886/kWh. Because the retail rate of the electricity at $0.085/kWh is lower than PPA, the Tronox Facility is not likely to buy electricity at this rate. In addition, Georgia Power's purchase rate is estimated to be approximately $0.080/kWh. Therefore, a solar investor is unlikely to invest given current conditions.

- Case 2 has negative NPV and shows the low LCOE of $0.089/kWh. LCOE is slightly higher than Georgia Power purchase price of $0.08/kWh. Although the case is not economically preferable based on negative NPV, further analysis shows that this case would be economically viable if the utility had a purchase price of $0.135/kWh or higher.

- Case 3 offset the on-site electricity consumption at retail electricity rate of $0.085/kWh. The analysis shows a positive NPV and feasible payback of 13.8 years. Therefore, Case 3 has the best economic scenario.

Table 8. PV System Summary

Investor-Owned Cases	Capacity	LCOE ($/kWh)	NPV ($)	PPA ($/kWh)	Payback (yr)
Case 1 - Investor owned/PPA	8.50 MW	$0.2124	$1,576,988	$0.1882	N/A
Case 2 - Developer owned/PPA	8.50 MW	$0.1132	($5,242,793)	-	24.4
Case 3 - Developer owned/net metering	100 kW	$0.0587	$17,055	-	13.8

Table 9. Potential Energy Production and Economic Impacts on Created Jobs

System Type	PV System Size[a] (MW)	Array Tilt (deg)	Annual Output (MWh/year)	Number of Houses Powered[b]	Jobs Created[c] (job-year)	Jobs Sustained[d] (job-year)
Case 1 - Investor owned/ PPA	8.50	20	11,188	1,013	235	3.2
Case 2 - Developer owned/ PPA	8.50	20	11,188	1,013	235	3.2
Case 3 - Developer owned/ net-metering	**0.10**	**20**	**131**	**12**	**13**	**0.1**

System Type	System Cost
Case 1 - Investor owned/ PPA	$ 29,698,320
Case 2 - Developer owned/ net-metering	$ 29,698,320
Case 3 - Developer owned/ net-metering	**$ 348,000**

[a] *Data assume a maximum usable area of 2,000 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.

5.4 Job Analysis and Impact

To evaluate employment and economic impacts of the subject PV project, NREL's Jobs and Economic Development Impact (JEDI) models are used.[4] 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.

JEDI represents the entire economy, including cross-industry or cross-company impacts. For example, JEDI estimates the impact that 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, JEDI results are considered gross estimates as opposed to net estimates.

For the Tronox Facility, the values in Table 9 were assumed for the 8.5-MW system.

Table 10. JEDI Analysis Assumptions

Input	Assumed Value
Capacity	8.5 MW
Placed In Service Year	2013
Installed System Cost	$29,698,320
Location	Savannah, Georgia

Using these inputs, JEDI estimates the gross direct and indirect jobs, associated earnings, and total economic impacts 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.

[4] 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 more information on JEDI, see http://www.nrel.gov/analysis/jedi/about_jedi.html.

As indicated in the results of the JEDI model analysis provided in Appendix D, the total proposed system of 8.5 MW is estimated to support 235 direct and indirect jobs per year for the duration of the procurement and construction periods. Total wages paid to workers during the construction period are estimated to be $10,895,200, and total economic output is estimated to be $27,099,700. The annual O&M of the new PV system is estimated to support 3.2 FTEs per year for the life of the system. The jobs and associated spending are projected to account for approximately $176,200 in earnings and $307,900 in economic activity each year for the next 25 years.

5.5 Financing Opportunities

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

5.5.1 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; or through a tax-exempt lease structure, bank financing, grant and incentive program, 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 common use of third-party financing structures, such as the PPA.

5.5.2 Third-Party Developers with Power Purchase Agreements

Because many project site hosts do 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 or local utility via a PPA—a contract to sell electricity at a negotiated rate over a fixed period of time. The PPA typically will be an agreement between the third-party developer and the site host if it is a retail "behind-the-meter" transaction or directly with an electric utility if it is a wholesale transaction.

Site hosts benefit by receiving competitively priced electricity from the project via the PPA or land lease revenues for making the site available to the solar developer through a lease payment. This lease payment 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. This arrangement allows public entities 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.

5.5.3 Third-Party "Flip" Agreements

The most common use of this model is a site host working with a third-party developer who then partners with a tax-motivated investor in a special purpose entity (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 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 the investor's return is met.

5.5.4 Hybrid Financial Structures

As the solar market has evolved, hybrid financial solutions have been developed in order to finance solar projects under certain circumstances. 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.

5.5.5 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 to their treatment of tax benefits and the rules limiting federal tax benefit transfers from non-profit 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 work-around 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 non-profit utility usually 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 may purchase the services in annual installments. The municipality may 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 "sales/leaseback." Under the sales/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.

5.5.6 Sales/Leaseback

In the widely accepted sales/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, the public or private entity 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 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 as well as the lease payments. Sometimes, the entity is allowed to buy back the project at 100% fair market value after the tax benefits are exhausted.

5.5.7 Community Solar/Solar Gardens

With the concept of "community solar," 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 pro-rated share of the project's energy output. This business model is targeted to meet demand for solar projects by customers who rent/lease homes or businesses, do not have good solar access at their site, or do not want to install a solar system on their facilities. Customer pro-rated 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, customers receive billing credits for the number of kilowatt-hours their pro-rated shares of the solar project produce each month; this is also known as VNM. Under the customer subscription option, 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 gardens and customer subscription-based projects can be solely owned by the utility, solely owned by third-party developers with facilitation of billing provided by the utility, or be 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 known as “solar gardens” depending on the location (e.g., Colorado). However, Georgia currently does not allow community solar or VNM. It would be a great opportunity to policy development in the community solar garden or VNM in the future. Therefore, nearby communities or towns can take advantage of the solar PV project.

6 Conclusions and Recommendations

The feasibility of installing a PV system is highly impacted by the available area for an array, solar resource, distance to transmission lines, and distance to major roads. The potential closest electrical tie-in location is at the Georgia Power substation at the southwest corner of the Deptford Tract. Having a substation on site makes it an ideal location for a PV system to tie into. The Tronox Facility site is a suitable location for a large-scale PV system because it is nearly flat, has adequate road and good solar access, is zoned for industrial uses, and has extensive electrical distribution to the whole site.

From the SAM analysis:

Case 1—Investor-owned/PPA will work if the investor can sell the electricity of the PPA at $0.1886/kWh. Because the retail rate of the electricity at $0.085/kWh is lower than PPA, the Tronox Facility is not likely to buy this electricity. In addition, Georgia Power's purchase rate is estimated to be approximately $0.08/kWh. Therefore, a solar investor is unlikely to invest given current conditions.

Case 2—Developer-owned/PPA has negative NPV and shows the low LCOE of $0.089/kWh and payback period of 24 years. However, further analysis shows that NPV becomes positive if the utility has a purchase price of $0.135/kWh or above. Therefore, the project can be viable if the purchase rate is increased or the developer can negotiate for that rate.

Pursuing Case 3—PV system up to 100 kW, net-metering case is the best scenario economically. It has a positive NPV and a payback of approximately 14 years. This system could generate up to 132,000 kWh annually. We recommend the 100 kW net-metering project for each individual future building/site.

Results of the JEDI analysis show that the total potential system of 8.5 MW is estimated to support 235 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 $10,895,200, and total economic output is estimated to be $27,099,700. The annual O&M of the new PV system is estimated to support 3.2 FTEs per year for the life of the system. The jobs and associated spending are projected to account for approximately $176,200 in earnings and $307,900 in economic activity each year for the next 25 years.

Improvements to the incentives field could change these projects to very favorable. Such incentives would include an increase to the purchase price from Georgia Power, loan guarantees with longer repayment periods, and higher REC payments that would apply to larger systems.

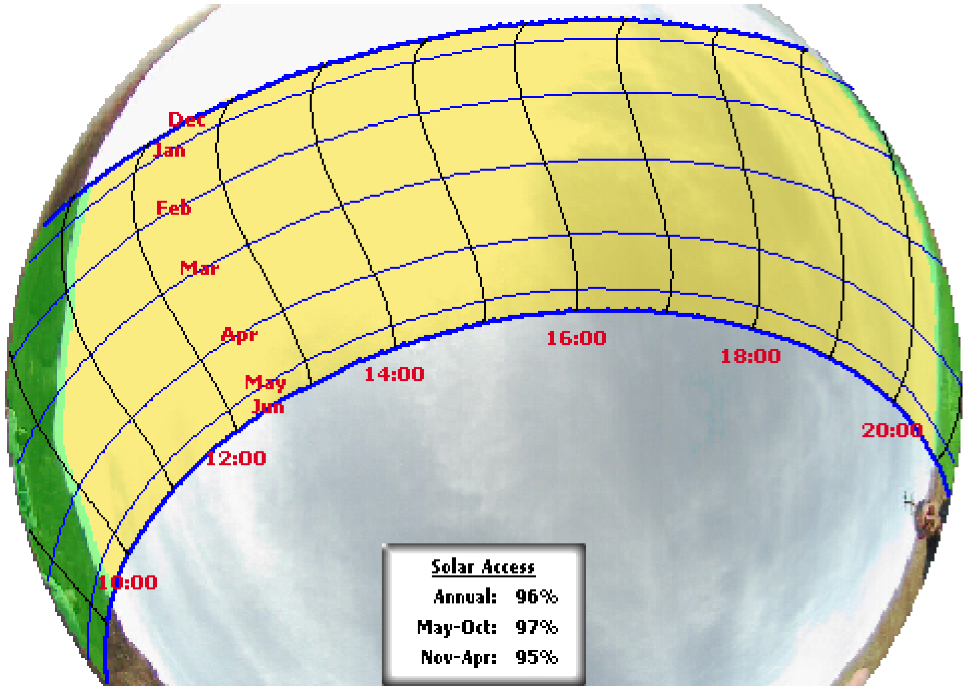
A very large PV capacity can be installed at the Tronox Facility. Finding potential buyers for the generated electricity at a reasonable price, whether they are future Tronox industries or a local or interstate utility company, will be key to the project's development. VNM would also be a good option to sell the excess electricity if the state allows. In addition, any environmental considerations shall be included in the RFP during project development.

Appendix A. Assessment and Calculations Assumptions

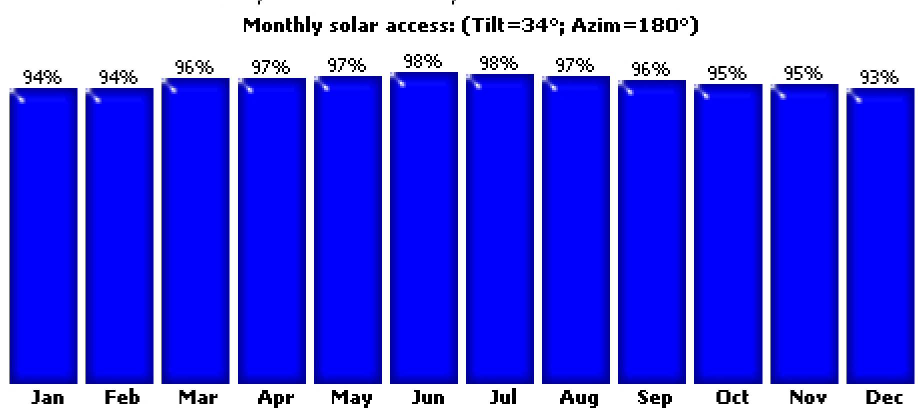
Table A-1. Cost, System, and Other Assessment Assumptions

Cost Assumptions			
Variable	**Quantity of Variable**	**Unit of Variable**	
Cost of Site Electricity (buyback/retail)	0.080/0.085	$/kWh	
Annual O&M (fixed)	20	$/kW/year	
System Assumptions			
System Type	**Annual energy kWh/kW**	**Installed Cost ($/W)**	**Energy Density (W/sq. ft.)**
Fixed-Tilt Ballasted System	1,311	$3.49	4.0
Other Assumptions			
	1 acre	43,560 ft^2	
	1 MW	1,000,000 W	
	Ground utilization	90% of available area	

Appendix B. Solar Access Measurements



Data by Solmetric SunEye™ -- www.solmetric.com



Data by Solmetric SunEye™ -- www.solmetric.com

Figure B-1. Solar access measurements for Tronox Facility PV site

Appendix C. Results of the JEDI Model

Table C-1. Summary Results of the NREL JEDI Model

Project Descriptive Data	
Project Location	Georgia
Population (only required for county/region analysis)	
Year of Construction or Installation	2013
System Application	Utility
Solar Cell/Module Material	Crystalline Silicon
System Tracking	Fixed Mount
Average System Size - DC Nameplate Capacity (kW)	8,500.0
Number of Systems Installed	1.0
Total Project Size - DC Nameplate Capacity (kW)	8,500.0
Base Installed System Cost ($/kWDC)	$3,490
Annual Direct Operations and Maintenance Cost ($/kW)	$25.00
Money Value (Dollar Year)	2012

Local Economic Impacts - Summary Results

	Jobs	Earnings	Output
During construction and installation period		$ (2012)	$ (2012)
Project Development and On-Site Labor Impacts			
Construction and Installation Labor	41.7	$2,703.00	
Construction and Installation Related Services	50.4	$2,303.40	
Subtotal	92.2	$5,006.40	$8,239.90
Module and Supply Chain Impacts			
Manufacturing Impacts	0.0	$0.00	$0.00
Trade (Wholesale and Retail)	9.9	$572.00	$1,648.10
Finance, Insurance, and Real Estate	0.0	$0.00	$0.00
Professional Services	14.3	$614.60	$2,075.10
Other Services	24.8	$1,662.10	$5,759.50
Other Sectors	35.2	$810.00	$1,717.90
Subtotal	84.2	$3,658.60	$11,200.60
Induced Impacts	59.0	$2,230.10	$7,659.30
Total Impacts	235.4	$10,895.20	$27,099.70

During operating years	Annual Jobs	Annual Earnings $ (2012)	Annual Output $ (2012)
On-Site Labor Impacts			
PV Project Labor Only	2.0	$118.40	$118.40
Local Revenue and Supply Chain Impacts	0.7	$36.20	$115.40
Induced Impacts	0.6	$21.60	$74.10
Total Impacts	3.2	$176.20	$307.90

Notes: Earnings and output values are thousands of dollars in year 2012 dollars. Construction and operating period jobs are FTE 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.

Detailed PV Project Data Costs	Georgia		
Installation Costs	Cost	Purchased Locally (%)	Manufactured Locally (Y or N)
Materials and Equipment			
Mounting (rails, clamps, fittings, etc.)	$1,081,817	100%	N
Modules	$11,881,001	100%	N
Electrical (wire, connectors, breakers, etc.)	$1,233,455	100%	N
Inverter	$1,766,918	100%	N
Subtotal	$15,963,191		
Labor			
Installation	$2,703,021	100%	
Subtotal	$2,703,021		
Subtotal	$18,666,212		
Other Costs			
Permitting	$124,903	100%	
Other Costs	$2,760,355	100%	
Business Overhead	$8,113,529	100%	
Subtotal	$10,998,788		
Subtotal	$29,665,000		
Sales Tax (materials and equipment purchases)	$638,528	100%	
Total	$30,303,528		

PV System Annual Operating and Maintenance Costs

	Cost	Local Share	Locally (Y or N)
Labor			
Technicians	$127,500	100%	
Subtotal	$127,500		
Materials and Services			
Materials and Equipment	$85,000	100%	N
Services	$0	100%	
Subtotal	$85,000		
Sales Tax (materials and equipment purchases)	$3,400	100%	
Average Annual Payment (interest and principal)	$3,441,140	0%	
Property Taxes	$0	100%	
Total	$3,657,040		

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	4.00%	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%	

Appendix D. Assumptions and Results of the System Advisor Model

Case 1: Investor owned/PPA with 8.5 MW

This case assumes a third-party investor for the PV system. All generated electricity from Case 1 is assumed to be sold. The results of this case are used to estimate the needed electricity rate as part of a PPA to get acceptable return on investment (15% internal rate of return).

Case 2: Developer owned/PPA with 8.5 MW

This case assumes the developer owns the PV system. All generated electricity from Case 2 is assumed to be sold to Georgia Power at the avoided cost at $0.08/kWh.

Case 3: Developer owned/net metering with 100 kW

This case assumes the developer owns the PV system; all electricity is assumed to be used on site.

Table D-1. Case 3 Results

Metric	Base
Net Annual Energy	136,397 kWh
LCOE Nominal	5.87 ¢/kWh
LCOE Real	4.66 ¢/kWh
First Year Revenue without System	$ -1,561,646.5
First Year Revenue with System	$ -1,550,052.7
First Year Net Revenue	$ 11,593.75
After-tax NPV	$ 17,055.21
Payback Period	13.8426
Capacity Factor	15.6 %
First year kWhac/kWdc	1,364

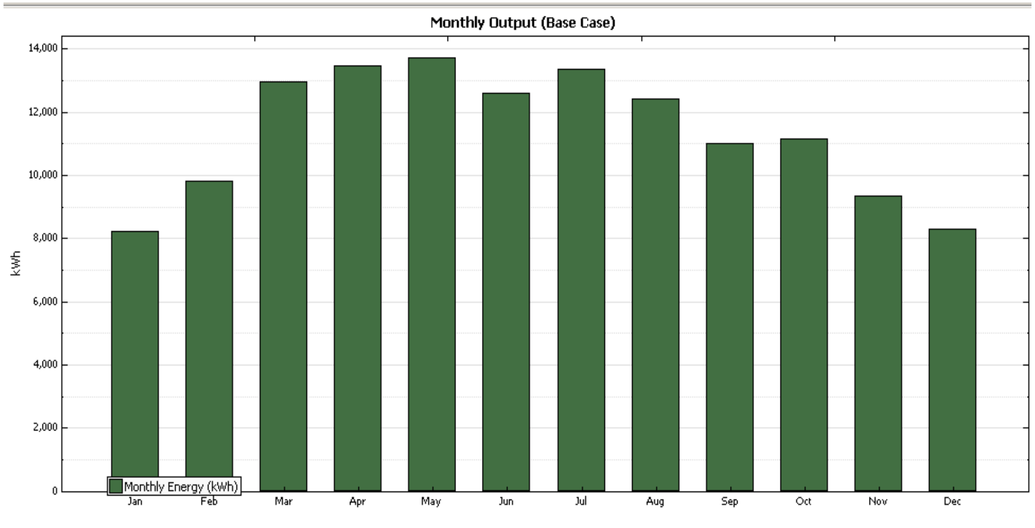


Figure D-1. PV system output

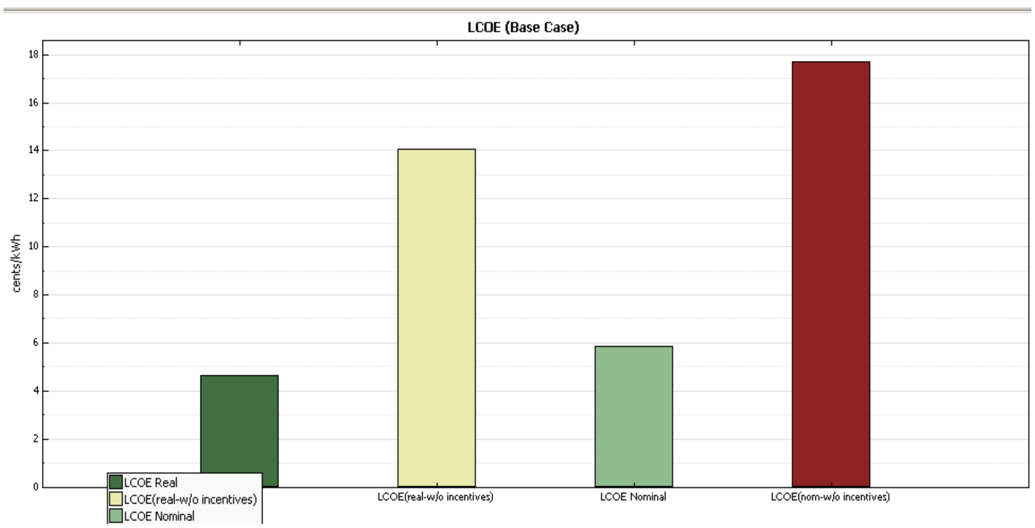


Figure D-2. Levelized cost of energy

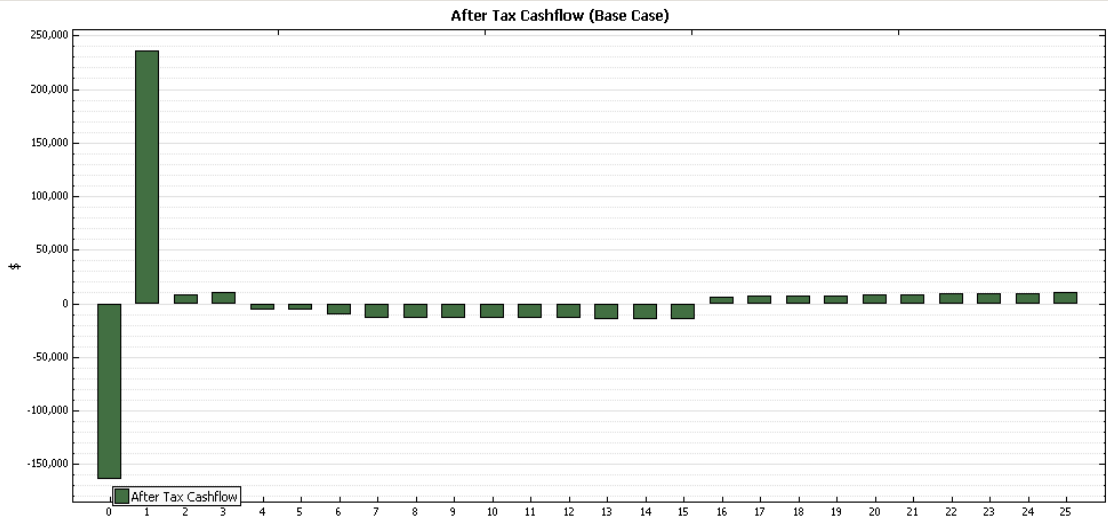


Figure D-3. After-tax cash flow

Assumptions for Inputs (For Case 3 as the best economic results)

Climate

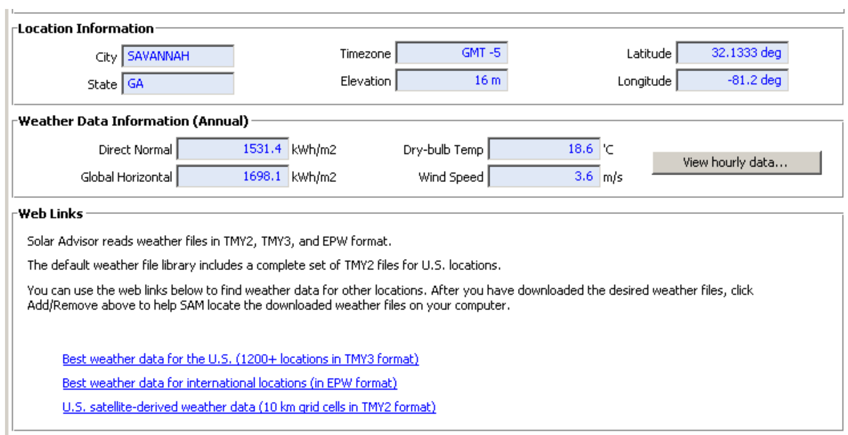


Figure D-4. Climate input

Utility Rate

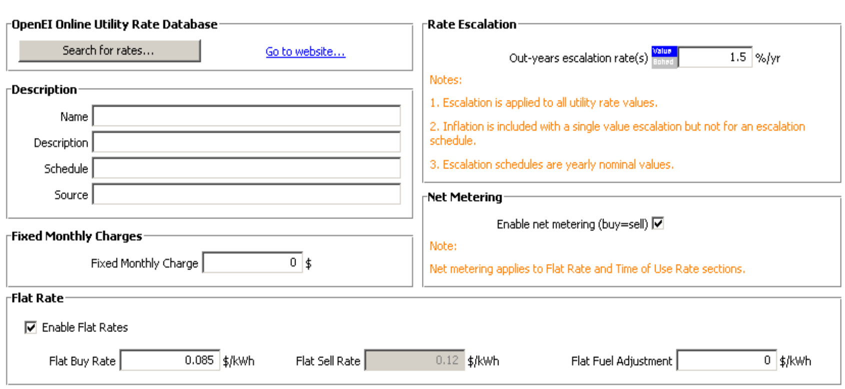


Figure D-5. Utility rate input

Financing

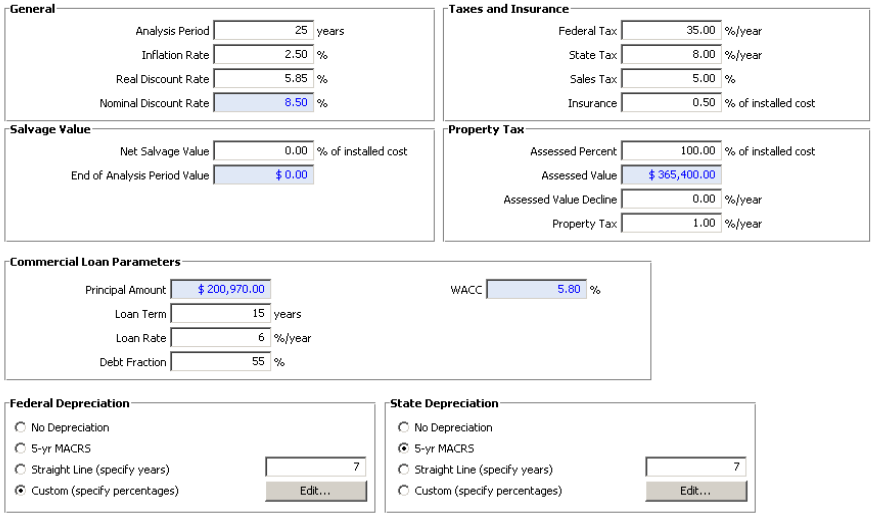


Figure D-6. Financing Input

Tax Credit Incentives

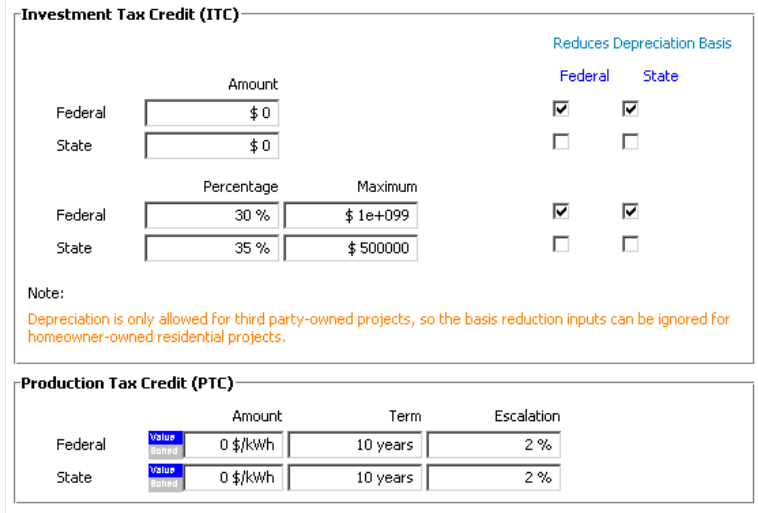


Figure D-7. Tax credit input

Payment Incentives

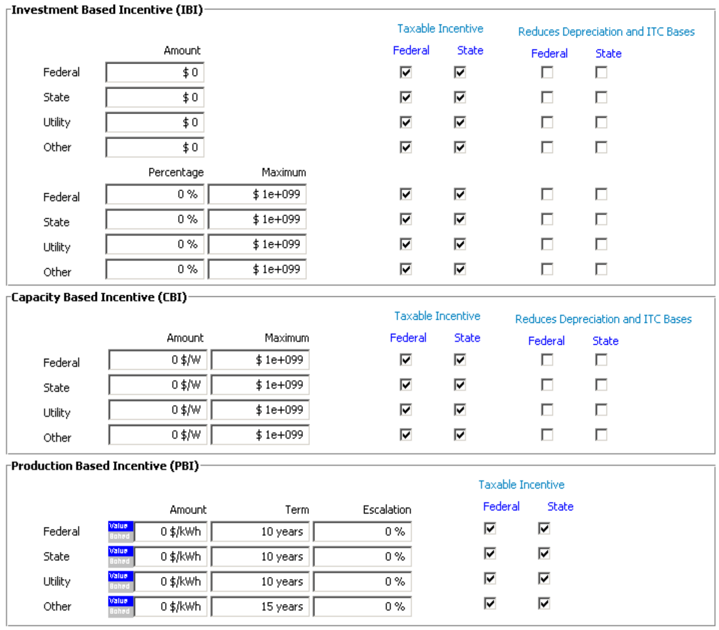


Figure D-8. Payment incentive input

Annual Performance

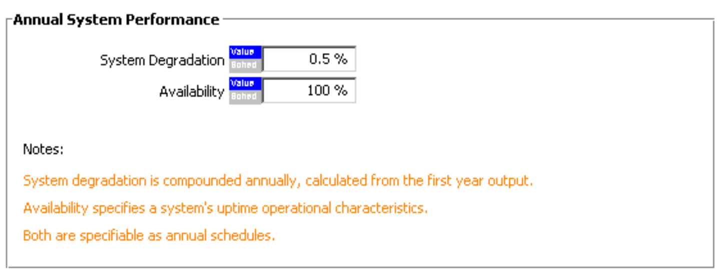


Figure D-9. Annual system performance input

PV System Costs

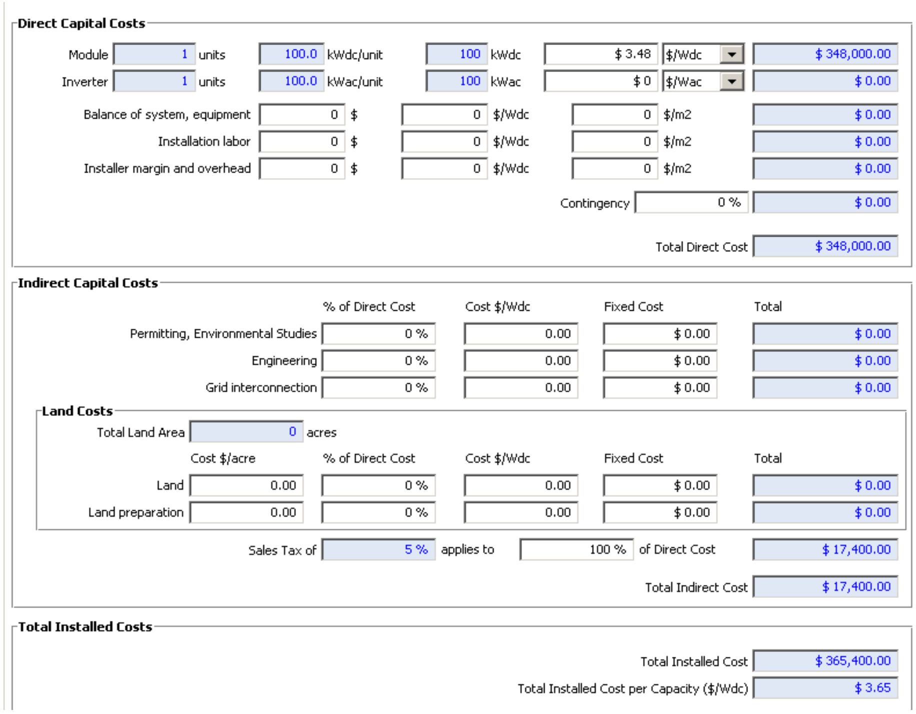


Figure D-10. PV system costs input

PVWatts Solar Array

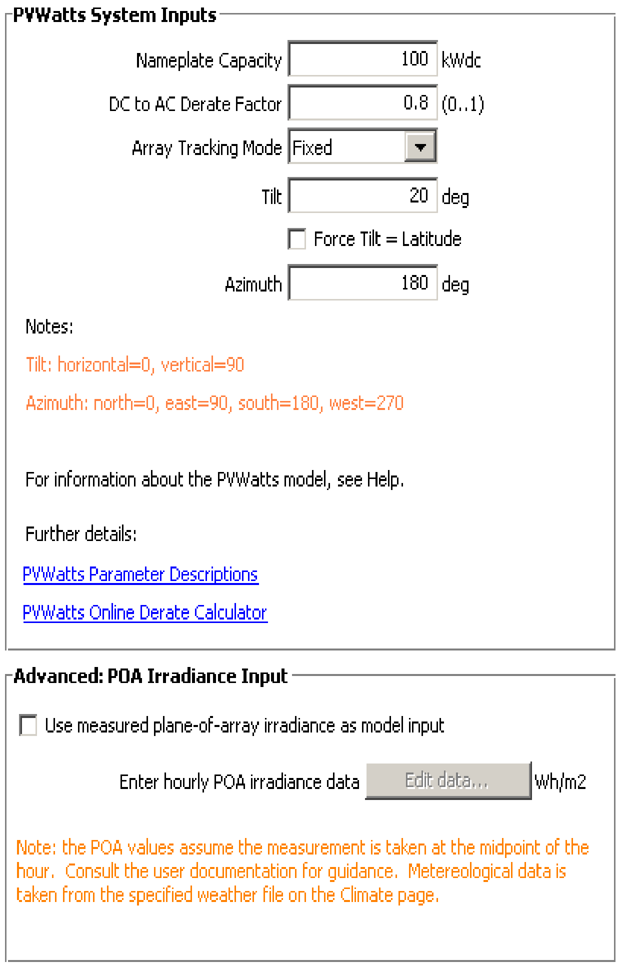


Figure D-11. PVWatts solar array input