Feasibility Study of Economics and Performance of Solar Photovoltaics at the Vincent Mullins Landfill in Tucson, Arizona

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

Matthew Steen, Lars Lisell, and Gail Mosey

Produced under direction of the U.S. Environmental Protection Agency (EPA) by the National Renewable Energy Laboratory (NREL) under Interagency Agreement IAG-08-0719 and Task No. WFD3.1001.

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-7A40-56812
January 2013
Contract No. DE-AC36-08GO28308

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Feasibility Study of Economics and Performance of Solar Photovoltaics at the Vincent Mullins Landfill in Tucson, Arizona

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

Matthew Steen, Lars Lisell, and Gail Mosey

Prepared under Task No. WFD3.1001

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.

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

Technical Report
NREL/TP-7A40-56812
January 2013
Contract No. DE-AC36-08GO28308

NOTICE

This manuscript has been authored by employees of the Alliance for Sustainable Energy, LLC (“Alliance”) under Contract No. DE-AC36-08GO28308 with the U.S. Department of Energy (“DOE”).

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

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 Vincent Mullins Landfill facility managers, engineers, and operators for their generous assistance and cooperation.

Special thanks go to Shea Jones, Lura Matthews, Andria Benner, and Jessica Trice from the EPA; Katie Brown, AAAS Science & Technology Policy fellow hosted by the EPA; and Bruce Plenk, Jeff Drumm, Lisa Cuestas, and Lynn Birkinbine from the City of Tucson for hosting the site visits and providing all the information needed by the team.

Executive Summary

The U.S. Environmental Protection Agency (EPA), in accordance with the RE-Powering America's Land initiative, selected the Vincent Mullins Landfill in Tucson, Arizona, for a feasibility study of renewable energy production. Under the RE-Powering America's Land initiative, the EPA provided funding to the National Renewable Energy Laboratory (NREL) to support the study. NREL provided technical assistance for this project but did not assess environmental conditions at the site beyond those related to the performance of a photovoltaic (PV) system. The purpose of this report is to assess the site for a possible PV installation and estimate the cost and performance of different PV configurations, as well as to recommend financing options that could assist in the implementation of a PV system. In addition to the Vincent Mullins site, four similar landfills in Tucson are included as part of this study.

The feasibility of a PV system depends greatly on both site-specific and economic factors. Site-specific factors include the available area for an array, solar resource, distance to transmission lines, and distance to major roads. In addition, the operating status, ground conditions, and restrictions associated with redevelopment of contaminated sites impact the feasibility of a PV system. Economic factors include purchase price of the electricity produced, power purchase agreement (PPA) price, and retail electric rates along with federal, state, and utility incentives for PV systems. Based on an assessment of these factors, the Vincent Mullins Landfill and other closed landfills in Tucson were found to be suitable sites for deployment of utility-scale PV systems.

This study evaluated two development scenarios for implementing large-scale PV systems on Tucson's landfills—one in which the city owns and operates the system, and one where a private entity is allowed to develop the site using a PPA. Table ES-1 summarizes the predicted economics of the two scenarios along with the system size, energy production, and cost.

Table ES-1. Summary of Tucson Landfill PV Systems

Scenario Summaries

Development Scenario	System Type	Array Tilt	Real LCOE	Savings[a]	PPA Price	Nominal LCOE
		(deg)	($/kWh)	($/kWh)	($/kWh)	($/kWh)
Municipal Purchase	Crystalline Silicon	20.0	0.115	-0.031	-	0.149
Private Purchase/PPA	Crystalline Silicon	20.0	0.043	0.054	0.048	0.054

System Summaries

Landfill	Tie-In Location	System Size	Annual Output	Houses Powered[b]	System Cost	Annual O&M[c]
		(kW)	(kWh/year)			($/year)
Vincent Mullins	Flare/Udall Park	4,300	7,285,725	660	$15,717,900	112,580
Harrison	Flare	9,100	15,418,628	1,397	$33,033,000	236,600
Irvington	Tucson FD Station 17	1,600	2,710,968	246	$5,808,000	41,600
Ryland	n/a	4,100	6,946,854	629	$14,883,000	106,600
Silverbell	n/a	6,500	11,013,306	998	$23,595,000	169,000

a Based on average energy charges for Municipal Service (8.4¢/kWh) and General Service (9.6¢/kWh) from Tucson Electric Power, not including demand charges. Exact values may differ due to rounding.

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

c Average over 25 year system life/analysis period.

The results indicate that private ownership of a PV system is currently the most economically viable option for the City of Tucson. In the case of a city-owned system, the real levelized cost of energy (LCOE) is predicted to be $0.031/kWh above what the city is currently paying for electricity. In the case of a privately owned system, both the LCOE and PPA price are predicted to be less than the commercial rate, a savings of $0.054/kWh and $0.048/kWh, respectively. The difference in price between the two scenarios is due to the federal investment tax credit, which the city is unable to capture as a non-tax-paying entity.

Of the five sites considered in this study, the Harrison, Irvington, and Vincent Mullins Landfills are the most feasible sites for a PV installation. These sites already have existing electrical infrastructure in place or are adjacent to city-owned facilities that could serve as tie-in locations for connecting to the grid. If a PV system is privately owned and designed to solely provide the grid with electricity, the Harrison Landfill would accommodate the largest system (9.1 MW). In contrast, a PV system on the Vincent Mullins or Irvington Landfill could be used to offset the energy consumption of adjacent facilities, but the system size would be limited to 125% of the load by Arizona's net-metering law.

If the city prefers to utilize the energy generated by a landfill PV system directly, one option would be a combined scenario, whereby the city develops a net-metered system to meet the needs of onsite and/or nearby facilities, in addition to allowing a third party to develop the rest of the site. This option would have the benefit of providing the city with a source of renewable energy for its facilities, in addition to providing revenue from production-based incentives and lease payments or revenue sharing for use of the site. In this case, the Vincent Mullins Landfill would allow for the largest system that could also be tied to a city facility, with the Irvington Landfill accommodating a smaller system designed for this purpose. Alternatively, the city could arrange to purchase part of the energy from a privately owned system through a PPA or make it part of the development agreement. For these scenarios, the tradeoffs between the added costs of a city-owned system and the potential revenue from utility incentives and/or the site developer will need to be weighed carefully in order to determine which option is best for the City of Tucson.

Tucson's closed landfills represent an under-utilized resource for renewable energy generation; the results of this study indicate that the energy produced from a privately owned utility-scale PV system will be cost-competitive with traditional grid-purchased electricity. Installing a PV system on one or more of these sites has the potential to add a significant amount of distributed generation to the area, contribute to Arizona's renewable energy standard, offset energy costs, and create additional revenue for the City of Tucson. It is recommended that the city further pursue a utility-scale PV installation on the Harrison, Irvington, or Vincent Mullins Landfills. Potential site developers include Tucson Electric Power or other private energy developers and the city should solicit proposals and bids from interested parties.

Table of Contents

List of Figures

List of Tables

List of Acronyms

AC	alternating current
ADEQ	Arizona Department of Environmental Quality
BOS	balance of system
DC	direct current
EPA	U.S. Environmental Protection Agency
FTE	full-time equivalent
IOU	investor-owned utility
JEDI	Jobs and Economic Development Impact
kV	kilovolt
kW	kilowatt
kWh	kilowatt-hour
LCOE	levelized cost of energy
MW	megawatt
MWh	megawatt-hour
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
PBI	production-based incentive
PPA	power purchase agreement
PV	photovoltaic
REC	renewable energy certificate
REST	renewable energy standard and tariff
SAM	System Advisor Model
TEP	Tucson Electric Power
VNM	virtual net metering
W	watt

1 Study and Site Background

The U.S. Environmental Protection Agency (EPA), in accordance with the RE-Powering America's Land initiative, selected the Vincent Mullins Landfill in Tucson, Arizona, for a feasibility study of renewable energy production. Under the RE-Powering America's Land initiative, the EPA provided funding to the National Renewable Energy Laboratory (NREL) to support the study. NREL provided technical assistance for this project but did not assess environmental conditions at the site beyond those related to the performance of a photovoltaic (PV) system. The purpose of this report is to assess the site for a possible PV installation and estimate the cost and performance of different PV configurations, as well as to recommend financing options that could assist in the implementation of a PV system. In addition to the Vincent Mullins site, four similar landfills in Tucson are included as part of this study.

The feasibility of a PV system depends greatly on both site-specific and economic factors. Site-specific factors include the available area for an array, solar resource, distance to transmission lines, and distance to major roads. In addition, the operating status, ground conditions, and restrictions associated with redevelopment of contaminated sites impact the feasibility of a PV system. Economic factors include purchase price of the electricity produced, power purchase agreement (PPA) price, and retail electric rates along with federal, state, and utility incentives for PV systems. Based on an assessment of these factors, the Vincent Mullins Landfill and other landfills in Tucson were found to be suitable sites for deployment of utility-scale PV systems.

The Vincent Mullins property is a closed 52-acre city-owned landfill located in northeastern Tucson. The city's half-million residents are served by Tucson Electric Power (TEP), the second-largest investor-owned utility (IOU) in the state. TEP is required to comply with the state's renewable energy standard and tariff (REST) passed in 2007, which mandates that IOUs generate or purchase 15% of their annual retail energy requirements from renewable sources by 2025. Additionally, 30% of this renewable energy requirement must be met with distributed generation. To comply with these requirements, TEP currently offers its customers upfront incentives on a dollar-per-kilowatt basis and production- or performance-based incentives (PBI) on a dollar-per-kilowatt-hour basis under its Renewable Energy Credit Purchase Program. In 2011, TEP reported 13.8 MW of PV installations to meet its REST requirement, with annual program funds exhausted in the third quarter of that year.[1]

The site operated as a landfill from 1976 to 1987, receiving only municipal solid waste; it was officially closed in 2007 by the Arizona Department of Environmental Quality (ADEQ).[2] The parcel is zoned "Suburban Ranch" or low density residential, according to the city's Land Use Code, which allows for renewable energy systems. It is bounded to the east by the privately owned and active Speedway Landfill, to the south by an apartment complex, to the west by the Pantano Wash, and to the north by the city-owned Morris K. Udall Park. The landfill is in a former gravel quarry pit and is approximately

[1] Tucson Electric Power 2011 REST Compliance Report. Accessed July 2012: http://arizonagoessolar.org/UtilityIncentives/TucsonElectricPower.aspx.
[2] See Appendix A for ADEQ information.

40 feet deep, unlined, and has a 6-foot engineered soil cap that is stable and designed to minimize erosion and moisture penetration. A landfill gas extraction system controls and maintains gas within the site and removes residual contaminants from the waste and soil. The system consists of underground pipes that collect the gas and deliver it to a station along the north boundary where it is currently flared. The City of Tucson maintains ownership of the site and monitors cap integrity semi-annually, landfill gas monthly, and groundwater semi-annually as part of a 30-year post-closure monitoring cycle.

The city previously completed a feasibility study in 2008 to evaluate the potential for using its landfills to generate electricity.[3] The Vincent Mullins Landfill was specifically identified as a potential site, but the project was delayed due to zoning issues, which were later resolved, and then it was put on indefinite hold pending funding. There are no restrictions for developing the site; however, any proposed infrastructure must be designed for landfill use, not increase leachate or methane production from the landfill, and requires approval from ADEQ. Prior PV projects on landfills have shown effective designs are attainable and only slightly increase the installed cost of a system.

Feasibility assessment team members from NREL, the City of Tucson, and the EPA conducted a project meeting and site visits on March 7 and 8, 2012, to gather information integral to this feasibility study. Site conditions varied slightly between the landfills, but in general all five sites were found to be very similar. The team considered information including site layout, shading analysis, interconnection points, site topography, and ground conditions. The assessment team found conditions well suited for large-scale PV installations. Most of the sites are accessible by road, have flat topography, and are free of shading from infrastructure or vegetation. Additionally, cap settlement did not appear to be an issue given the time since closure and cap depth.

[3] Landfill Gas to Energy Feasibility Study for Vincent Mullins and Harrison Landfills, Executive Summary, Bryan A. Stirrat and Associates, 2008.

2 Development of a PV System on Landfills

Through the RE-Powering America's Land initiative, the EPA has identified several benefits for siting PV facilities on landfills,[4] noting that they:

- Can be developed in place of greenfields, limiting the amount of new land that becomes disturbed and preserving the carbon storage capacity
- May have environmental conditions that are not well suited for commercial or residential redevelopment and may be adequately zoned for renewable energy
- Are generally located near existing roads and energy transmission or distribution infrastructure
- May 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).

By taking advantage of these potential benefits, PV can provide a viable, beneficial reuse, in many cases generating significant revenue and providing a source of distributed renewable energy on a site that would otherwise go unused. The City of Tucson is interested in potential revenue flows and electricity generation from the Vincent Mullins Landfill as well as its other landfill sites. Often, the local community has significant interest in the redevelopment of public lands. Community engagement is critical to match future reuse options to the community's vision for the site. Also, understanding opportunities studied and realized by other similar sites demonstrates the potential for PV system development.

Although landfills can potentially present unique challenges for installing PV systems, in many ways landfills are ideal locations for renewable energy projects, offering a productive use of unproductive land. PV systems have been successfully installed on a variety of landfill types throughout the country. On landfills where disturbing the waste mass is not a concern, traditional ground-anchored systems can be used, such as on the Fort Carson Army base near Colorado Springs, Colorado.[5] On sites where cap disturbance is restricted or undesirable, ballasted systems with above-ground electrical conduit can be used, such as on the Nellis Air Force Base near Las Vegas, Nevada.[6] This configuration is commonly used for installing PV systems on buildings to minimize roof penetrations. For sites that are still in operation, a solar geomembrane system can be used as an alternative to traditional capping methods, such as on the Hickory Ridge Landfill

[4] See the EPA's "Best Practices for Siting Solar Photovoltaics on Municipal Solid Waste Landfills (DRAFT)." Accessed August 2012: http://www.epa.gov/oswercpa/docs/best_practices_siting_solar_photovoltaic.pdf.

[5] RE-Powering America's Land: Siting Renewable Energy on Potentially Contaminated Land and Mine Sites. Fort Carson, CO Success Story. http://www.epa.gov/oswercpa/docs/success_fortcarson_co.pdf.

[6] RE-Powering America's Land: Siting Renewable Energy on Potentially Contaminated Land and Mine Sites. Nellis Air Force Base, Nevada Success Story (February 2009), http://www.epa.gov/oswercpa/docs/success_nellis_nv.pdf.

near Atlanta, Georgia.[7] Figures 1 and 2 show examples of PV applications on closed landfills.

Figure 1. Aerial view of the 2-MW ground-anchored PV system at U.S. Army Fort Carson, financed through a PPA

Source: NREL PIX 17394

Figure 2. Ballasted tracking PV system at Nellis Air Force Base, Nevada

Source: NREL PIX 15280

[7] See http://www.hdrinc.com/portfolio/hickory-ridge-landfill-solar-energy-cover for images.

The Vincent Mullins site has potential to be used for other functions beyond the solar PV system proposed in this report. The city has already explored using the landfill gas for heating or to generate electricity, and this remains a viable source of renewable energy. PV[8] was considered the most viable technology for the site because these systems can be installed with minimal disturbance of the landfill surface or the viewshed when compared to wind power and are capable of generating more energy than landfill gas.[9]

[8] For a detailed description of PV systems, see Appendix B.
[9] Landfill Gas to Energy Feasibility Study for Vincent Mullins and Harrison Landfills, Executive Summary, Bryan A. Stirrat and Associates, 2008.

3 Proposed Installation Location Information

This section summarizes the findings of the NREL solar assessment site visits on March 7 and 8, 2012.

3.1 Vincent Mullins Landfill PV System

As mentioned in Section 1, the Vincent Mullins Landfill is an excellent site for a large-scale PV system. The site has large areas of relatively flat ground and is free of obstructions that might add to the cost of construction or cause shading of the system. Additionally, road access and cap stability would facilitate construction of an array on the site. Furthermore, the southwestern United States has the highest available solar resource in the country, which makes it a suitable location for solar energy systems. In Tucson, the average global horizontal annual solar resource—the total solar radiation for a given location, including direct, diffuse, and ground-reflected radiation—is 6.13 kWh/m^2/day. For comparison, Miami, Florida, receives 5.17 kWh/m^2/day, and Seattle, Washington, receives 3.67 kWh/ m^2/day.[10] Figure 3 shows a view of the Vincent Mullins Landfill.

Figure 3. View of the feasible area for PV at the Vincent Mullins Landfill

Photo by Lars Lisell, NREL

From the information collected during the site visit, the team concluded that 90% of the feasible area could accommodate a PV system and the remaining 10% would be unusable due to roads, topography, or other restrictions. The site has been leveled with a slight grade (<2%) to facilitate water runoff, and low growth vegetation (<2 feet tall) has been planted to prevent erosion.

[10] NREL PVWatts Viewer. Accessed July 2012: http://mapserve3.nrel.gov/PVWatts_Viewer/index.html.

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 PV system. With proper forethought, the roads, equipment pads, and panel spacing can be optimized to allow for more than 90% of the available area to be utilized to incorporate more PV panels.

Figure 4 shows an aerial view of the Vincent Mullins Landfill taken from Google Earth; the feasible area for PV is shaded in orange with the electrical tie-in point for the PV system noted. As shown, there are large expanses of relatively flat, un-shaded land, which makes it a suitable candidate for a PV system. The area of the site that appears feasible for PV is 24.8 acres (1,081,874 ft^2).

Figure 4. Aerial view of the feasible area for PV at the Vincent Mullins Landfill site

Illustration made using Google Earth

3.2 Additional Landfill PV Systems

Although the primary focus of this study was the Vincent Mullins Landfill, four additional closed landfills owned by the city were evaluated for potential PV systems. Figures 5–8 show aerial views of the Harrison, Irvington, Ryland, and Silverbell Landfills with the approximate feasible area and potential electrical tie-in points shown (if available).

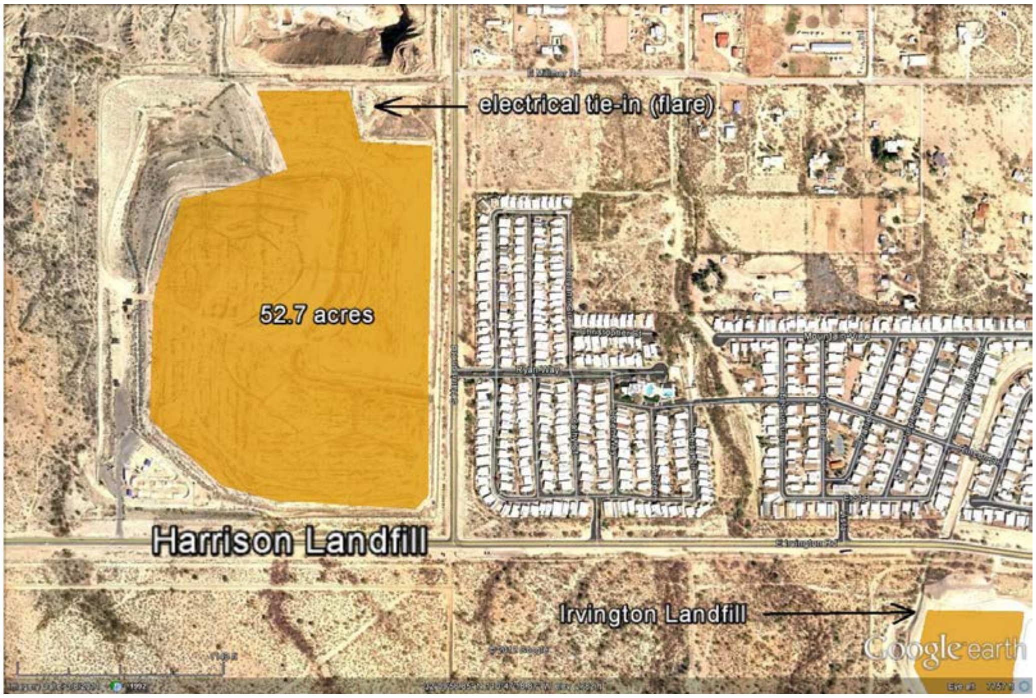

Figure 5. Aerial view of the feasible area for PV at the Harrison Landfill

Illustration made using Google Earth

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

Illustration made using Google Earth

Figure 7. Aerial view of the feasible area for PV at the Ryland Landfill

Illustration made using Google Earth

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

Illustration made using Google Earth

3.3 Utility-Resource Considerations

When considering a ground-mounted system, an electrical tie-in location should be identified to determine how the energy would be fed back into the grid. The expected electrical tie-in point and inverter location for a PV system at the Vincent Mullins Landfill is at the flare station adjacent to and directly north of the site. The flare station has a TEP electric meter, and the site has 48-kV transmission lines running along the western boundary, both of which were assumed to be compatible with a large-scale PV installation needing no additional electrical infrastructure. Before moving forward with a PV project at any of the landfill sites, a grid integration study should be conducted in order to determine definitively whether or not additional infrastructure would be required. The expected electrical tie-in point for the Vincent Mullins site is shown in Figure 9.

Figure 9. Electrical tie-in point at the flare station for the PV system at the Vincent Mullins Landfill

Photo by Lars Lisell, NREL

3.4 Useable Acreage for Landfill PV Systems in Tucson

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 area (e.g., a parking lot or industrial site space), as well as existing building rooftops. The total usable acreage for landfill PV systems in Tucson was determined to be 148.1 acres. Table 1 lists the usable acreage for the five landfills.

Table 1. Usable Acreage for Tucson City Landfills

Landfill	Potential Acreage	Usability Factor	Usable Acreage
Vincent Mullins	27.6	0.9	24.8
Harrison	65.9	0.8	52.7
Irvington	10.5	0.9	9.4
Ryland	26.5	0.9	23.8
Silverbell	46.7	0.8	37.4
Total			**148.1**

3.5 PV Site Solar Resource

The landfills have been evaluated to determine the adequacy of the solar resource available using both onsite data and industry tools. The predicted array performance was found using PVWatts Version 2[11] for Tucson, Arizona. For this summary array performance information, a hypothetical system size of 1 kW was used to show the estimated production for each kilowatt. It is scaled linearly so that additional analyses can be performed to match the proposed system size. Table 2 shows the annual performance results of four different system configurations in Tucson, Arizona, as calculated by PVWatts. The monthly results for each system type are available in Appendix C.

Table 2. Performance Results for 1-kW PV Systems in Tucson, Arizona

System Type	AC Energy (kWh/yr)	Increase from Fixed 20° Tilt
Fixed Axis, 20° Tilt	1,592	0.0%
Fixed Axis, 32° Tilt (latitude)	1,624	2.0%
Single-Axis Tracking	1,997	25.4%
Double-Axis Tracking	2,279	43.2%

3.6 Tucson Landfill Energy Usage

It is important to understand the energy use of the site to determine whether or not energy produced would need to be sold or if it could offset onsite energy use. Several of the landfills in Tucson either consume electricity directly onsite or have city-owned facilities close by that could use the energy produced from a PV system.

The Vincent Mullins Landfill flare consumes approximately 13,200 kWh of energy per year and the adjacent Morris K. Udall Park consumes approximately 1,650,000 kWh per year. Both meters are on the PS-40 Municipal Service rate schedule with an average cost of $0.084/kWh.[12] Together, these two sites would require a PV system of approximately 1 MW to completely meet electricity needs, with an estimated savings of $139,442/yr. A

[11] For additional information about PVWatts, see http://www.nrel.gov/rredc/pvwatts/.
[12] Pricing Plan PS-40 Municipal Service, Tucson Electric Power. Accessed July 2012: https://www.tep.com/doc/customer/rates/PS-40.pdf.

more accurate system size could be calculated using annual energy and power data from the two facilities, which were not available at the time of this study.

The Harrison Landfill also has a flare station with an electric meter; a PV system at this site could be used to offset onsite energy use as well. The smaller Irvington Landfill does not have a flare station or meter, but it is adjacent to a Tucson fire station, which could serve as both a tie-in location and electrical load for a PV system. The Ryland and Silverbell landfills do not have electrical infrastructure or adjacent city facilities, which would make PV installations on these sites more restrictive.

3.6.1 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. 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:[13]

> (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.

Arizona's net-metering law, which took effect in 2009, requires utilities to offer net metering to all customers who generate electricity from solar, wind, hydroelectric, geothermal, biomass, biogas, combined heat and power (CHP), or fuel cell technologies up to 125% of the customer's total load.[14]

3.6.2 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 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. TEP's "Bright Tucson" Community Solar Program allows residential and commercial customers to purchase blocks of electricity produced from solar installations in the Tucson metropolitan area.[15]

---

[13] Energy Policy Act of 2005, Title XII—Electricity, Subtitle E—Amendments to PURPA, Section 1251—Net Metering and Additional Standards. http://www.gpo.gov/fdsys/pkg/PLAW-109publ58/pdf/PLAW-109publ58.pdf.

[14] For the full text of this bill, see: http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=AZ24R&re=0&ee=0.

[15] Tucson Electrical Power, Bright Tucson Community Solar program. Accessed September 2012: https://www.tep.com/Renewable/Business/Bright/.

4 Economics and Performance

The economics and performance of a PV system at each site was 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. To model PV system economic performance, this study used the NREL System Advisor Model (SAM).[16]

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 projects that buy and sell power at retail rates, including 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.

SAM makes performance predictions for grid-connected solar, small wind, and geothermal power systems, and it makes economic estimates for distributed energy and central generation projects. The model calculates the cost of generating electricity based on information the user provides about a project's location, installation and operating costs, type of financing, applicable tax credits and incentives, and system specifications.

4.1 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 since 2010, the average cost for utility-scale[17] ground-mounted systems has declined from $4.80/W in the first quarter (Q1) of 2010 to $2.90/W in Q1 2012. The cost for smaller commercial-scale systems has fallen to $4.63/W during the same period and is consistent with projects in Tucson, which have shown an average cost of $4.32/W.[18] With an increasing demand and supply, the potential for further cost reduction is expected as market conditions evolve. Figure 10 shows the cost per watt of PV systems from 2010 to 2012.

[16] For additional information about the NREL Solar Advisor Model, see https://sam.nrel.gov/cost.
[17] For a description of PV system sizes, see Appendix B.
[18] Tucson Electrical Power Non-Residential Incentive Status. Accessed September 2012: https://www.tep.com/doc/renewable/incentive-status-nonres.pdf.

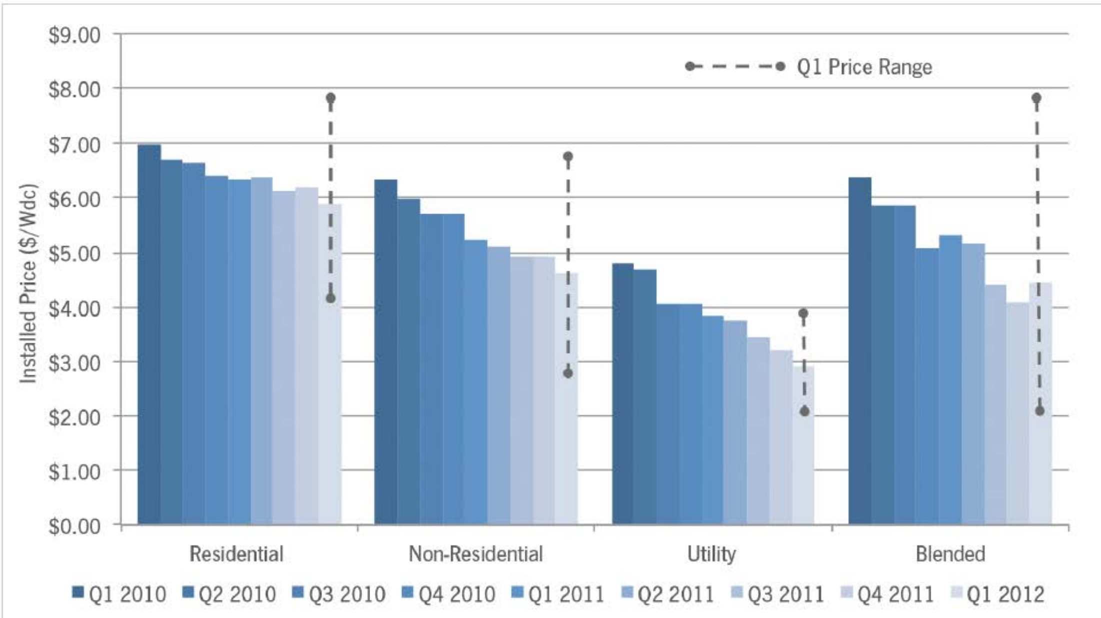

Figure 10. Solar market insight Q1 2012 national weighted average system prices[19]

Source: Solar Energy Industries Association

For this analysis, the following input data were used. The installed cost of fixed-tilt ground-mounted systems was assumed to be $3.63/W. The increased cost is due to limitations placed on design and construction methods due to the ground conditions at the site and is estimated to be 25% for a ballasted system. Such limitations include restrictions on storm water 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 3.

Table 3. Installed System Cost Assumptions

	Fixed-Tilt ($/Wp)
Baseline system	2.90
With ballast	0.73
Total installed cost	3.63

These prices include the PV array and the components for the system, including the inverter and electrical equipment. 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. For this analysis, the cost of electricity was based

[19] Data and figure drawn from the Solar Energy Industries Association "SEIA/GTM Research U.S. Solar Market Insight" Q1 2012 Report. See http://www.seia.org/research-resources/solar-market-insight-report-2012-q1.

on TEP's GS-10 General Service and PS-40 Municipal Service rates.[20] The annual average commercial (general service) and municipal rates were calculated to be $0.096/kWh and $0.084/kWh, respectively.

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 (30% of the initial capital investment) and accelerated depreciation on the PV system over 5 years (15%–35% of the capital investment). The total potential tax benefits to the tax-paying entity can be as high as 55% 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.

For the purposes of this analysis, two financial scenarios were considered for installing a landfill PV system—one where the city develops the site, and one in which a private entity is allowed to develop it using a PPA.[21] These scenarios include the current cost of energy, expected installation cost, site solar resource, and existing incentives for the proposed PV system.

For each scenario the project is expected to have a 25-year life, although the systems can be reasonably expected to continue operation past this point. The panels are assumed to have a 0.5% per year degradation in performance. A DC-to-AC system conversion of 80% was assumed, which includes losses in the inverter, wire losses, PV module losses, and losses due to temperature effects. Inflation is assumed to be 2.5% and the loan rate is assumed to be 6% for each scenario. The operations and maintenance (O&M) expenses are estimated to be $30/kW/yr during the first 15 years, followed by $20/kW/yr for years 16–25.

A fixed 20°-tilt system was used as a baseline for evaluating the economics and performance of a PV system in Tucson. The exact system design is beyond the scope of this study and will depend on additional site-specific analyses and input from stakeholders. The PVWatts calculation engine within SAM was used to calculate expected energy performance for the system. The assumptions and inputs for each scenario are included in Table 4 with the differences shaded.

[20] Tucson Electric Power Pricing Plans. Accessed September 2012: https://www.tep.com/Customer/Rates/Pricing/.
[21] For a description of financing opportunities, see Appendix D.

Table 4. SAM Assumptions and Inputs

Parameter	Municipal Purchase	Private Purchase/PPA
Analysis period (years)	25	25
Inflation	2.5%	2.5%
Real discount rate	3.00%	5.85%
Federal tax rate	0%	35%
State tax rate	0%	7.10%
Insurance (% of installed cost)	0.5%	0.5%
Property tax	0%	0%
Construction loan	0%	0%
Loan term (years)	25	15
Loan rate	6%	6%
Debt fraction	100%	60%
Minimum IRR	15%	15%
PPA escalation rate	1.5%	1.5%
Federal depreciation	-	Custom 5-year MACRS[a]
State depreciation	-	-
Federal ITC	-	30.00%
State ITC	-	10% up to $50,000
State production tax credit	-	$0.028/kWh[b]
Production-based incentives	$0.064/kWh for 20 years	
Degradation	0.5%	0.5%
Operational availability	100%	100%
Cost - fixed axis per kW	$3.63	$3.63
Grid interconnection cost	0	0
O&M	$30/kW/yr for years 1-15 & $20/kW/yr for years 16-25	
Derate factor	80%	80%
Tilt	20°	20°

[a] Modified Accelerated Cost Recovery System
[b] Arizona Renewable Energy Production Tax Credit, average over 10 years.

4.2 SAM Forecasted Economic Performance

Using the inputs and assumptions summarized in Table 4, the SAM tool predicts the LCOE and PPA price for a PV system in Tucson, Arizona. Table 5 summarizes the results of the economic analysis for the system configurations and development scenarios considered in this study. The complete results for each scenario are available in Appendix E.

Table 5. Summary of Tucson Landfill PV Systems

Scenario Summaries

Development Scenario	System Type	Array Tilt	Real LCOE	Savings[a]	PPA Price	Nominal LCOE
		(deg)	($/kWh)	($/kWh)	($/kWh)	($/kWh)
Municipal Purchase	Crystalline Silicon	20.0	0.115	-0.031	-	0.149
Private Purchase/PPA	Crystalline Silicon	20.0	0.043	0.054	0.048	0.054

System Summaries

Landfill	Tie-In Location	System Size	Annual Output	Houses Powered[b]	System Cost	Annual O&M[c]
		(kW)	(kWh/year)			($/year)
Vincent Mullins	Flare/Udall Park	4,300	7,285,725	660	$15,717,900	112,580
Harrison	Flare	9,100	15,418,628	1,397	$33,033,000	236,600
Irvington	Tucson FD Station 17	1,600	2,710,968	246	$5,808,000	41,600
Ryland	n/a	4,100	6,946,854	629	$14,883,000	106,600
Silverbell	n/a	6,500	11,013,306	998	$23,595,000	169,000

a Based on average energy charges for Municipal Service (8.4¢/kWh) and General Service (9.6¢/kWh) from Tucson Electric Power, not including demand charges. Exact values may differ due to rounding.

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

c Average over 25 year system life/analysis period.

The results indicate that private ownership of a PV system is currently the most economically viable option for the City of Tucson. In the case of a city-owned system, the real LCOE is predicted to be $0.031/kWh above what the city is currently paying for electricity. In the case of a privately owned system, both the LCOE and PPA price are predicted to be less than the commercial rate, a savings of $0.054/kWh and $0.048/kWh, respectively.

4.3 Job Analysis and Impact

To evaluate the impact on employment and economic impacts of the PV project associated with this analysis, the NREL Jobs and Economic Development Impact (JEDI) model was used.[22] The JEDI models are tools that estimate 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.

[22] 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 http://www.nrel.gov/analysis/jedi/about_jedi.html.

The JEDI models represent 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 the JEDI model 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 model results are considered gross estimates as opposed to net estimates. For this study, the Vincent Mullins Landfill was used as an example of the potential economic impact of a utility-scale PV system in Tucson, and Table 6 shows the assumed values.

Table 6. JEDI Analysis Assumptions for the Vincent Mullins Landfill

Input	Assumed Value
Capacity	4,300 kW
Year Placed In Service	2013
Installed System Cost	$3,630/kW$_{DC}$
Location	Tucson, AZ

Using these inputs, the JEDI tool estimates the gross direct, indirect, and induced 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 model analysis provided in Appendix F, the total proposed system is estimated to support 131 direct, indirect, and induced 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 $5,502,100, and total economic output is estimated to be $13,811,900. The annual O&M of the new PV system is estimated to support 1.7 FTEs per year for the life of the system. The jobs and associated spending are projected to account for approximately $92,800 in earnings and $160,500 in economic activity each year for the next 25 years. Estimates for the other landfills would either be higher or lower depending on the system size relative to Vincent Mullins.

5 Conclusions and Recommendations

Tucson, Arizona, is a suitable location to implement utility-scale PV systems with a higher-than-average solar resource, strong incentives, and readily available land area. Installing a PV system at one or more of the landfills considered in this study would be a productive use of under-utilized contaminated land and minimize the impacts of developing sites elsewhere. Additionally, a landfill PV system would create a significant distributed generation facility for the area capable of providing 1 MW or more of renewable energy, contributing considerably to Arizona's REST.

Based on the findings of this study, utility-scale PV systems are both technically and economically feasible for the landfill sites in Tucson. The results indicate that private ownership of a PV system will be the most economically attractive development scenario, with a PPA price and LCOE below the current commercial electric rate. Although all five landfills are suitable for large PV installations, the most feasible sites are the Irvington, Harrison, and Vincent Mullins Landfills. These properties already have existing electrical infrastructure in place or are adjacent to city-owned facilities, any of which could serve as a tie-in location for connecting to the grid. If the PV system is privately owned and designed to solely provide the grid with electricity, the Harrison Landfill would accommodate the largest PV installation (9.1 MW). In contrast, a PV system on the Vincent Mullins or Irvington Landfills could be used to offset the energy consumption of adjacent facilities, but the system size would be limited to 125% of the load by Arizona's net-metering law.

If the city prefers to utilize the energy generated by a landfill PV system directly, one possible alternative to the two financial scenarios evaluated in this study may be a combined scenario, whereby the city develops a net-metered system to meet the needs of onsite and/or nearby facilities, in addition to allowing a third party to develop the rest of the site through land use agreements.[23] This option would have the benefit of providing the city with a source of renewable energy for its facilities, in addition to providing revenue from production-based incentives for excess generation and lease payments or revenue-sharing arrangements for use of the site. In this case the Vincent Mullins Landfill would allow for the largest system that could also be tied to a city facility, with the Irvington Landfill accommodating a smaller system designed for this purpose. Alternatively, the city could arrange to purchase part of the energy from a privately owned system through a PPA or make it part of the development agreement. For these scenarios, the added cost of electricity generated by a city-owned PV system could potentially be offset by the combined revenue from utility incentives and a private developer and is an option that warrants further investigation.

It is recommended that the City of Tucson pursue opportunities for PV installations on the Harrison, Irvington, or Vincent Mullins Landfills. Both ballasted and ground-anchored systems with shallow footings are recommended mounting configurations, depending on the specific environmental conditions of the site. When reviewing

[23] For a list of resources and sample contract documents for setting up PPAs and land use agreements, see the Federal Energy Management Program website. Accessed October 2012: http://www1.eere.energy.gov/femp/financing/power_purchase_agreements.html.

proposals for a PV system, evaluation criteria should include the annual output (kWh/yr) as well as price per kilowatt-hour. Tradeoffs between tilt angle, self-shading, tracking configuration, and annual output should be evaluated carefully to maximize production of the system. A design-build contract can enable vendors to optimize system configuration, including tilt angle, tracking requirements, or module specifications, among others. Proposals and bids from potential site developers, such as TEP and other private energy companies, should be solicited through a process dictated by the appropriate city procedures.

Tucson's closed landfills represent an under-utilized resource for renewable energy generation and the results of this study indicate that the energy produced from a privately owned utility-scale PV system will be cost-competitive with traditional grid-purchased electricity. Furthermore, installing a PV system on one or more of these sites has the potential to add a significant amount of distributed generation to the area, contribute to Arizona's REST, offset energy costs, and create additional revenue for the City of Tucson.

Appendix A. Provided Site Information

ADEQ Numbers

Vincent Mullins Landfill: APP No. P-100917

Harrison Landfill: Master Plan Facility No. 10019200.03

Irvington Landfill: APP No. 50044800.

Appendix B. PV Systems

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 stimulated electrons (negative charges) in a layer in the cell designed to lose 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., as in a light bulb).

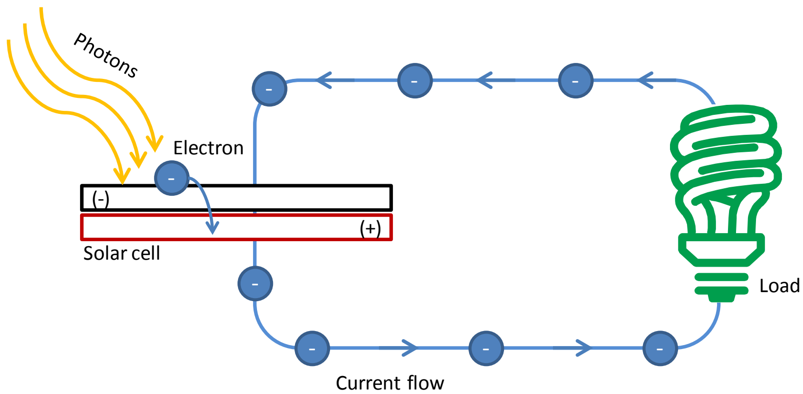

Figure B-1. Generation of electricity from a PV cell

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 DC electricity generated by the array is then converted by an inverter to useable AC that can be consumed by adjoining buildings and facilities or exported to the electricity grid. PV system size varies; a system can be small residential (2–10 kW), commercial (100–500 kW), or 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.

Major System Components

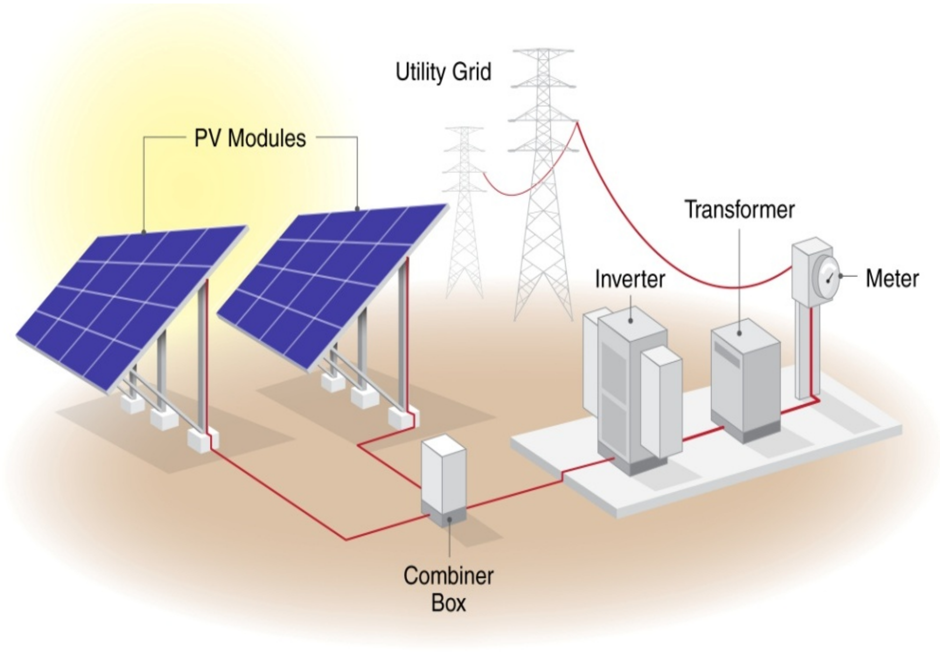

Figure B-2. Ground-mounted array diagram

Source: NREL

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

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

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

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.

Crystalline Silicon

Traditional solar cells are made from silicon, which is abundant and nontoxic. It builds on a strong industry on both supply (silicon industry) and product side. This technology has been demonstrated for a consistent and high efficiency 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 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, which indicates the presence of grain-boundaries (i.e., multiple crystals) in the cell materials, and it is controlled by raw material selection and manufacturing technique. Crystalline silicon panels are widely used based on deployments worldwide.

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

Source: SunPower, NREL PIX 23816

Source: NREL PIX 13823

Figure B-3. Mono- and multi-crystalline solar panels

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 their unique nature, some thin-film cells are constructed into flexible modules, enabling such applications as solar energy covers for landfills such as geomembrane systems. 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 less than for crystalline cells. Current overall efficiency of a thin-film panel is between 6% and 8% for a-Si and 11%–12% for CdTe. Figure B-4 shows thin-film solar panels.

Source: NREL PIX 18068 Source: NREL PIX 14726 Source: NREL PIX 17395

Figure B-4. Thin-film solar panels installed on solar energy cover (left) and fixed-tilt mounting system (middle and right)

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.

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 kW to 1,000 kW. These inverters tend to be cheaper on a capacity basis. They also have high efficiency and lower 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 on inverters are typically 10 years. 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. However, if micro-inverters are used, it impacts only that shaded panel and not the entire array production. Figure B-5 shows a string inverter.

Figure B-5. String inverter

Source: NREL PIX 07985

Balance-of-System Components

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

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

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.

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 landfill applications, mounting system designs will be primarily driven by these considerations, coupled with settlement concerns and ground penetration restrictions.

Typical ground-mounted systems can be categorized as fixed tilt or tracking. Fixed-tilt mounting structures consist of panels installed at a set angle to increase exposure to solar radiation throughout the year, typically based on site latitude and wind conditions. Fixed-tilt systems are used at many landfill sites. They 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, where 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 B-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 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 colder regions.

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 landfill 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.

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 it is 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, 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 smart phone applications.

Operation and Maintenance

The 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 $30/kW/yr for the first 15 years and $20/kW/yr for the remaining 10 years, which is based on the historical O&M costs of installed fixed-axis grid-tied PV systems in addition to amortized cost of inverter replacement.

Siting Considerations

PV modules are very sensitive to shading. When shaded (either partially or fully shaded), 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 collectively 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 the determination that a site is adequate for a solar installation, an analysis must be conducted in order to determine the ideal system size. System size depends highly on the average energy use of the facilities on the site, PPAs, available incentives, and utility policy.

The low growth vegetation coupled with the flat topography and the large open areas at the Tucson landfills resulted in very little shading at the locations for this study. All of the areas investigated resulted in solar access measurements of 96% or higher. The shading at these sites will have a negligible impact on the performance of the proposed systems.

Appendix C. Results from PVWatts

Table C-1. PVWatts Inputs

Station Identification	
Cell ID	0186375
State	Arizona
Latitude	32.2 N
Longitude	-110.8 W
PV System Specifications	
DC Rating	1.0 kW
DC to AC Derate Factor	0.8
AC Rating	0.8 kW
Array Type	*varied*
Array Tilt	*varied*
Array Azimuth	180°
Energy Specifications	
Cost of Electricity	$0.084/kWh

Table C-2. Performance Results for 20° Fixed-Tilt PV System

Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	4.77	112	9.41
2	5.35	111	9.32
3	6.35	145	12.18
4	7.19	155	13.02
5	7.39	159	13.36
6	7.41	150	12.60
7	6.71	141	11.84
8	6.30	134	11.26
9	6.50	135	11.34
10	5.90	131	11.00
11	5.24	117	9.83
12	4.38	103	8.65
Year	**6.13**	**1,592**	**133.73**

Table C-3. Performance Results for 32.2° (latitude) Fixed-Tilt PV System

Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	5.37	126	10.58
2	5.79	120	10.08
3	6.56	150	12.60
4	7.07	153	12.85
5	6.95	150	12.60
6	6.84	139	11.68
7	6.28	132	11.09
8	6.12	130	10.92
9	6.62	138	11.59
10	6.31	139	11.68
11	5.85	130	10.92
12	4.97	117	9.83
Year	**6.23**	**1,624**	**136.42**

Table C-4. Performance Results for Single-Axis Tracking PV System

Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	4.97	121	10.16
2	5.96	128	10.75
3	7.70	180	15.12
4	9.35	206	17.30
5	10.25	224	18.82
6	10.43	215	18.06
7	8.79	188	15.79
8	8.13	176	14.78
9	8.00	170	14.28
10	6.83	156	13.10
11	5.52	126	10.58
12	4.41	106	8.90
Year	**7.53**	**1,997**	**167.75**

Table C-5. Performance Results for Single-Axis Tracking PV System

Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	7.08	167	14.03
2	7.54	158	13.27
3	8.79	202	16.97
4	10.00	219	18.40
5	10.70	234	19.66
6	10.83	224	18.82
7	9.05	193	16.21
8	8.54	184	15.46
9	8.90	187	15.71
10	8.38	187	15.71
11	7.64	170	14.28
12	6.50	153	12.85
Year	**8.66**	**2,279**	**191.44**

Appendix D. 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.

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 owner/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; 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 the owners'/operators' assets and equity in the project. In addition, private entities can utilize any of the 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.

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 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 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 either receiving competitively priced electricity from the project via the PPA or via land lease revenues for making the site available to the solar developer via 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. For public entities, this arrangement allows them to utilize the benefits of the tax credits (lower PPA price, higher lease payment) while not directly receiving them. The term of a PPA typically varies from 20–25 years.

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 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 not within the first 5 years). Next, 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 investors' return is met.

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.

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 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. A number of business models have emerged as a way to address to this issue.

In the SSA, 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 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 may purchase the services in annual installments. The municipality may buyout 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.

Sale/Leaseback

In this widely accepted 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, they 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.

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 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 sites, or do not want to install solar systems on their facilities. Customer pro-rated shares of solar projects are acquired through a long-term transferrable lease of one or more panels or through subscription to a share of the project in terms of a specific level of energy output or a set amount of energy output capacity.

Under the customer lease option, customers receive billing credits for the number of kilowatt-hours their pro-rated shares of the solar project produces each month; it 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 from 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 may be a joint venture between the utility and a third-party developer leading to eventual utility ownership 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 (production incentive) and Utah (state income tax credit). Community solar is known as "Solar Gardens" in some locations (e.g., Colorado).

Appendix E. SAM Results

Table E-1. SAM Results

Municipal Purchase		Private Purchase/PPA	
Net Annual Energy	*site specific*	Net Annual Energy	*site specific*
LCOE Nominal	14.92 ¢/kWh	PPA Price	4.75 ¢/kWh
LCOE Real	11.48 ¢/kWh	LCOE Nominal	5.36 ¢/kWh
First-Year Revenue Without System	$0	LCOE Real	4.25 ¢/kWh
First-Year Revenue With System	$0	After-Tax IRR	0%
First-Year Net Revenue	$0	Pre-Tax Min DSCR	0.15
After-Tax NPV	*site specific*	After-Tax NPV	*site specific*
Payback Period	15	PPA Price Escalation	1.5%
Capacity Factor	19.3	Debt Fraction	63%
First Year kWh_{DC}/kW_{AC}	1,694	Capacity Factor	19.3
		First Year kWh_{DC}/kW_{AC}	1,694

Appendix F. Results of the JEDI Model

Table F-1. Estimated Economic Impact of a PV System at the Vincent Mullins Landfill

Photovoltaic - Project Data Summary Based on Model Default Values	
Project Location	Arizona
Year of Construction or Installation	2013
Average System Size - DC Nameplate Capacity (kW)	4,300
Number of Systems Installed	1
Total Project Size - DC Nameplate Capacity (kW)	4,300
System Application	Utility
Solar Cell/Module Material	Crystalline Silicon
System Tracking	Fixed Mount
Base Installed System Cost ($/kW DC)	$3,630
Annual Direct O&M Cost ($/kW)	$26.00
Money Value - Current or Constant (Dollar Year)	2012
Project Construction or Installation Cost	$15,609,000
Local Spending	$7,209,558
Total Annual Operational Expenses	$1,922,444
Direct Operating and Maintenance Costs	$111,800
Local Spending	$102,856
Other Annual Costs	$1,810,644
Local Spending	$0
Debt Payments	$0
Property Taxes	$0

Local Economic Impacts - Summary Results	**Jobs**	**Earnings**	**Output**
During Construction and Installation Period		**$000 (2012)**	**$000 (2012)**
Project Development and Onsite Labor Impacts			
Construction and Installation Labor	22.0	$1,422.30	
Construction and Installation Related Services	33.9	$1,149.80	
Subtotal	55.9	$2,572.10	$4,335.60
Module and Supply Chain Impacts			
Manufacturing	0.0	$0.0	$0.0
Trade (Wholesale and Retail)	5.2	$292.10	$848.10
Finance, Insurance, and Real Estate	0.0	$0.0	$0.0
Professional Services	9.2	$364.70	$1,213.40
Other Services	14.1	$924.60	$3,001.50
Other Sectors	15.0	$167.80	$515.60
Subtotal	43.5	$1,749.20	$5,578.50
Induced Impacts	31.8	$1,180.80	$3,897.80
Total Impacts	**131.3**	**$5,502.10**	**$13,811.90**

During Operating Years	Annual Jobs	Annual Earnings $000 (2012)	Annual Output $000 (2012)
Onsite Labor Impacts			
PV Project Labor Only	1.0	$62.30	$62.30
Local Revenue and Supply Chain Impacts	0.4	$18.90	$60.10
Induced Impacts	0.3	$11.60	$38.10
Total Impacts	**1.7**	**$92.80**	**$160.50**

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.

Detailed PV Project Data Costs

Installation Costs	Cost	Purchased Locally (%)	Manufactured Locally (Y or N)
Materials & Equipment			
Mounting (rails, clamps, fittings, etc.)	$569,226	100%	N
Modules	$6,251,493	100%	N
Electrical (wire, connectors, breakers, etc.)	$649,014	100%	N
Inverter	$929,709	100%	N
Subtotal	$8,399,442		
Labor			
Installation	$1,422,264	100%	
Subtotal	$1,422,264		
Subtotal	$9,821,706		
Other Costs			
Permitting	$65,721	100%	
Other Costs	$1,452,432	100%	
Business Overhead	$4,269,141	100%	
Subtotal	$5,787,294		
Subtotal	$15,609,000		
Sales Tax (Materials & equipment purchases)	$0	100%	
Total	$15,609,000		

PV System Annual O&M Costs	Cost	Local Share
Labor		
Technicians	$67,080	100%
Subtotal	$67,080	
Materials and Services		

Materials & Equipment	$44,720	100%
Services	$0	100%
Subtotal	$44,720	
Sales Tax (Materials & Equipment Purchases)	$0	100%
Average Annual Payment (Interest and Principal)	$1,810,644	0%
Property Taxes	$0	100%
Total	$1,922,444	
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)	100%	
Local Property Taxes	$0	100%
Local Sales Tax Rate	6.60%	100%
Sales Tax Exemption (percent of local taxes)	100.00%	
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%