NATIONAL RENEWABLE ENERGY LABORATORY

Feasibility Study of Economics and Performance of Solar Photovoltaics at the Atlas Industrial Park in Duluth, Minnesota

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 Environmental Protection Agency (EPA) by the National Renewable Energy Laboratory (NREL) under Interagency Agreement IAG-08-0719 and Task No. WFD3.1002.

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-7A40-56772
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List of Acronyms

AC	alternating current
a-Si	amorphous silicon
BOS	balance of system
CBI	capacity-based incentive
CREB	clean renewable energy bond
DC	direct current
DEDA	Duluth Economic Development Authority
EPA	U.S. Environmental Protection Agency
FTE	full-time equivalent
JEDI	Jobs and Economic Development Impact
kW	kilowatt
kWh	kilowatt-hour
kV	kilovolt
LCOE	levelized cost of energy
MP	Minnesota Power
M-RETS	Midwest Renewable Energy Tracking System
MW	megawatt
MWh	megawatt-hour
NREL	National Renewable Energy Laboratory
O&M	operations and maintenance
PAH	polyaromatic hydrocarbons
PBI	production-based incentive
PCB	polychlorinated biphenyls
PPA	power purchase agreement
PV	photovoltaic
QCEB	qualified conservation energy bond
REC	renewable energy certificate
RES	renewable energy standard
SAM	System Advisor Model
SPE	special purpose entity
SSA	Solar Services Agreement
UAC	Universal Atlas Cement Company
VNM	virtual net metering
W	watt

Executive Summary

The U.S. Environmental Protection Agency (EPA) Region 5, in accordance with the RE-Powering America's Land initiative, selected the Atlas Industrial Park in Duluth, Minnesota, 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 a feasibility study of solar renewable energy generation at the Atlas Industrial Park. 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 study is to assess the site for a possible PV installation and estimate the cost, performance, and site impacts of different PV configurations. In addition, the study evaluates financing options that could assist in the implementation of a PV system at the site.

The feasibility of a PV project 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.

The Atlas Industrial Park is a 62-acre brownfield site currently undergoing remediation and redevelopment. The Duluth Economic Development Authority (DEDA), which owns the property, is considering a 2-acre parcel for a PV installation as part of its redevelopment plan. Based on an assessment of the site conditions, the Atlas Industrial Park is suitable for deployment of a large- or small-scale PV system; however, the economics specific to the area currently limit the financial viability of a PV installation. Table ES-1 summarizes the performance and economics of the different PV systems and the development/financing options evaluated in this study. The table shows the annual energy output, the levelized cost of energy (LCOE), and the PPA price along with the payback period and cost of each system.

Table ES-1. Atlas Industrial Park PV System Summary

PV System Type	System Scale	System Size[a]	Array Tilt	Annual Output	Number of Houses Powered[b]
		(kW)	(deg)	(kWh/year)	
Crystalline Silicon (Fixed Tilt)	Commercial	348	20.0	423,073	38
Crystalline Silicon (Fixed Tilt)	Residential	10	20.0	12,157	1.1
Crystalline Silicon (Fixed Tilt)	Residential	8	20.0	9,726	0.9

Development Scenario	System Scale - Size	System Cost	LCOE Real	LCOE Nominal	Payback Period
			($/kWh)	($/kWh)	or PPA Price
DEDA Purchase	Commercial - 348 kW	$ 2,014,920	0.34	0.44	>25 years
Private Purchase	Commercial - 348 kW	$ 2,014,920	0.15	0.19	>25 years
Private Purchase with PPA	Commercial - 348 kW	$ 2,014,920	0.31	0.40	$0.31/kWh
DEDA Purchase	Residential - 8 kW	$ 58,880	0.30	0.39	>25 years
Private Purchase	Residential - 10 kW	$ 73,600	0.13	0.16	>25 years

a Data assume a maximum usable area of 2 acres.

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

As indicated in Table ES-1, each system configuration is expected to have an LCOE significantly greater than $0.05/kWh, the average commercial electricity rate in Duluth. These results include the current cost of energy, expected installation cost, site solar resource, and existing incentives for a PV system. The economic feasibility of a PV installation at the Atlas Industrial Park is primarily limited by lower-than-average electricity rates but also by available incentives that are based on system capacity and have a relatively low cap of $20,000. The current incentive structure favors smaller residential-scale systems reflected in a lower LCOE; however, the feasibility of these systems is constrained by higher module costs resulting from reduced economies of scale. The most cost-competitive scenario is for a privately owned system without a PPA. This scenario represents a PV configuration designed to offset on-site energy use, whereas the purpose of a PPA is to sell energy to another entity.

If DEDA wishes to further pursue a PV installation at the Atlas Industrial Park, development options different from the ones evaluated in this study should be explored. A public-private partnership between DEDA and Minnesota Power, an energy services company, or a current/future site developer to create a demonstration project could be one way to successfully implement a PV project at the site. The results of this study indicate that a privately owned residential-scale PV installation, such as a rooftop system for future site-occupying businesses, is currently the lowest-cost option for the Atlas Industrial Park; however, further increases in electric rates combined with decreases in module costs and changes to incentive structures could make a PV system at the site cost-competitive in the future.

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1 Study and Site Background

The U.S. Environmental Protection Agency (EPA) Region 5, in accordance with the RE-Powering America's Land initiative, selected the Atlas Industrial Park in Duluth, Minnesota, 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 a feasibility study of solar renewable energy generation at the Atlas Industrial Park. 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 study is to assess the site for a possible PV installation and estimate the cost, performance, and site impacts of different PV configurations. In addition, the study evaluates financing options that could assist in the implementation of a PV system at the site.

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The Atlas Industrial Park is approximately 62 acres and is located at the corner of Commonwealth and Grand Avenues along the St. Louis River corridor in southern Duluth. The City of Duluth has a population of 86,265[1] and is served by the investor-owned utility Minnesota Power (MP). MP is required to follow the state's renewable energy standard (RES), which mandates that 25% of retail electricity sales come from renewable sources by 2025. The utility currently offers capacity-based incentives (CBI) up to $20,000 for solar electric systems through its SolarSense program. In 2012 the budget for the SolarSense program was $300,000 with all funds committed by June 4.

The Atlas Industrial Park was part of a local industrial manufacturing hub along the St. Louis River and was operated by the Universal Atlas Cement Company (UAC), which produced Portland cement from 1915 to the mid-1970s. UAC, a subsidiary of U.S. Steel Corporation, used slag by-products from the nearby Duluth Works steel plant as a raw material in the manufacturing process. The Duluth Works plant was also closed in the 1970s and is now a state and federal Superfund site covering approximately 500 acres. Following closure of the UAC plant, many of the structures were demolished and the debris spread across the site, which created fill depths up to 13 feet. This resulted in unstable soils and contamination, including high pH soils, polyaromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), metals (arsenic and lead), and likely presence of asbestos and petroleum.

The Atlas Industrial Park is a state brownfield owned by the Duluth Economic Development Authority (DEDA), which acquired the land from UAC following its closure. The land is zoned General Industrial and the southwestern 11 acres have been

[1] U.S. Census Quickfacts. Accessed August 2012: http://quickfacts.census.gov/qfd/states/27/2717000.html.

remediated and redeveloped into a warehouse and manufacturing facility for the IKONICS Corporation, an imaging technology company headquartered in Duluth. DEDA plans to develop the southeastern corner of the site to provide IKONICS with a 4-acre expansion and create a 5-acre model site. The remaining 42 acres are undergoing remediation and redevelopment, including road, stormwater, sewer, and electric infrastructure, which are anticipated to be completed in December 2012. The revitalization of the Saint Louis River Corridor is a key part of the city's community-supported comprehensive plan,[2] and DEDA believes that a solar project at the Atlas site would contribute to the growth of the area.

Feasibility assessment team members from NREL, DEDA, and the EPA conducted a site visit on April 17, 2012, to gather information integral to this feasibility study. The team considered information, including solar resource, transmission availability, community acceptance, and ground conditions. The site has un-shaded open areas, is generally flat, has electric infrastructure in place, and is close to transmission and distribution lines, making it a potential candidate for a PV installation.

[2] 2006 City of Duluth Comprehensive Plan. Accessed September 2012: http://www.duluthmn.gov/planning/comp_plan/index.cfm.

2 Development of a PV System on Brownfields

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

- Can be developed in place of limited greenfields, preserving the land carbon sink
- May 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
- 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 on a site that would otherwise go unused. For many brownfields, 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 by other similar sites demonstrates the potential for PV system development.

Although brownfields can potentially present unique challenges for installing PV systems, in many ways brownfields can be ideal locations for renewable energy projects offering a productive use of unproductive land. PV systems have been successfully installed on a variety of brownfields in many parts of the country. For example, in Chicago, Illinois, a 41-acre site within the West Pullman industrial redevelopment area was used to install a 10-MW PV system in 2010. The project was the result of a partnership between the City of Chicago and the Excelon Corporation, a local utility that developed the site that had been home to numerous manufacturing facilities since the 1800s.[3]

The Atlas Industrial Park has potential to be used for other functions beyond the solar PV systems proposed in this report. Any potential use should align with the community vision for the site and should work to enhance the overall utility of the property. Some examples of other functions for the site include:

- Renewable-energy-powered remediation
- Business park with sustainable site features
- Habitat restoration/open space.

[3] See http://www.exeloncorp.com/assets/energy/powerplants/docs/pdf_ExelonCitySolarFact.pdf for a description of the project.

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

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

3 PV Systems

3.1 PV Overview

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

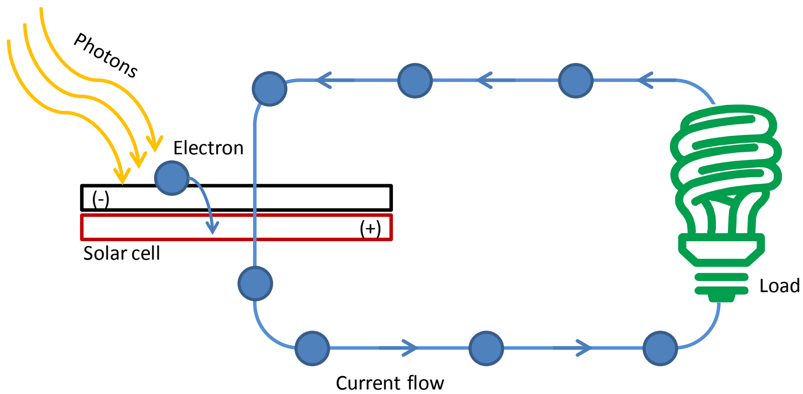

Figure 1. Generation of electricity from a PV cell

Source: EPA

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

3.2 Major System Components

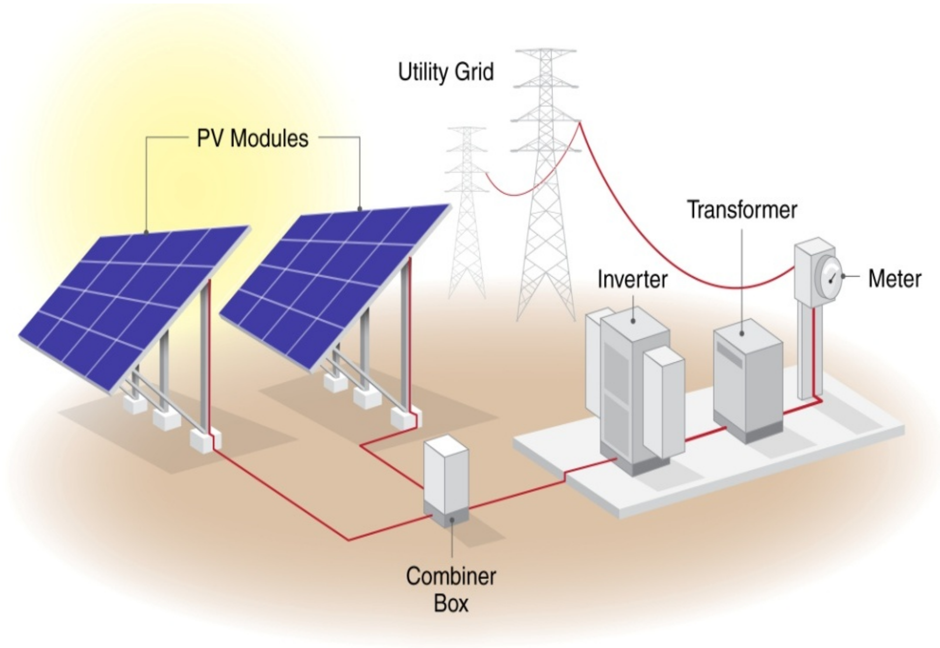

Figure 2. Ground-mounted array diagram

Source: NREL

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

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

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

3.2.1 PV Module

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

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

3.2.1.1 Crystalline Silicon

Traditional solar cells are made from silicon. Silicon is quite abundant and nontoxic. It builds on a strong industry on both 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 25–30-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 is controlled by raw material selection and manufacturing technique. Crystalline silicon panels are widely used based on deployments worldwide.

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

Source: SunPower, NREL PIX 23816 *Source: NREL PIX 13823*

Figure 3. Mono- and multi-crystalline solar panels

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 6%–8% for a-Si and 11%–12% for CdTe. Figure 4 shows thin-film solar panels.

Source: Republic Services, NREL PIX 23817 *Source: NREL PIX 14726* *Source: NREL PIX 17395*

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

3.2.2 Inverter

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

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

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

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

Micro-inverters are dedicated to the conversion of a single PV module's power output. The AC output from each module is connected in parallel to create the array. This technology is relatively new to the market and in limited use in larger systems due to the 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. Instead, it impacts only that shaded panel if micro-inverters are used. Figure 5 shows a string inverter.

Figure 5. String inverter

Source: NREL PIX 07985

3.2.3 *Balance-of-System Components*

In addition to the modules and inverter, a 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

An 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 brownfields, mounting system designs will be primarily driven by these considerations coupled with settlement concerns.

Typical ground-mounted systems can be categorized as fixed tilt or tracking. Fixed-tilt mounting structures consist of panels installed at a set angle, typically based on site latitude and wind conditions, to increase exposure to solar radiation throughout the year. Fixed-tilt systems are used at many brownfield sites and have lower maintenance costs but generate less energy (kWh) per unit power (kW) of capacity than tracking systems. However, energy density is often greater for fixed-tilt systems, which require less area per module and are less prone to "self-shading" than tracking systems, although self-shading does increase with panel-tilt for fixed-tilt systems requiring additional spacing between rows.

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

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 by 25% or more. With dual-axis tracking, the module is able to directly face the sun all day, potentially increasing energy output by 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.

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

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

3.2.3.2 Wiring for Electrical Connections

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

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

3.2.3.3 PV System Monitoring

Monitoring PV systems can be essential for reliable functioning and maximum yield of a system. It can be as simple as reading values, such as produced AC power, daily kilowatt-hours, and cumulative kilowatt-hours, locally on an LCD display on the inverter. For more sophisticated monitoring and control purposes, environmental data, such as module temperature, ambient temperature, solar radiation, and wind speed, can be collected.

Remote control and monitoring can be performed by various remote connections. Systems can send alerts and status messages to the control center or user. Data can be stored in the inverter's memory or in external data loggers for further system analysis. Collection of this basic information is standard for PV 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, 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.

3.2.4 Operation and Maintenance

PV panels typically have a 25-year performance warranty. The inverters, which come standard with a 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. The system should expect a replacement of system inverters in year 15 at a cost of $0.25/W, which has been amortized over the first 15 years of operation.

3.3 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 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, available incentives, and utility policy.

4 Proposed Installation Location Information

This section summarizes the findings of the NREL solar assessment site visit at the Atlas Industrial Park on April 17, 2012.

4.1 Atlas Industrial Park PV System

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. If there are structures, fences, vegetation, or electrical poles that can be removed, the un-shaded area can be increased to incorporate more PV panels. From the information collected during the site visit, the team concluded that 80% of the entire site could accommodate a PV system and the remaining 20% would be unusable due to roads, topography, vegetation, or other restrictions.

Typically, a minimum of 2 useable acres is recommended to site PV systems. Useable acreage is typically characterized as "flat to gently sloping," southern exposures that are free from obstructions and get full sun for at least a 6-hour period each day. For example, eligible space for PV includes 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.

Figure 6 shows an aerial view of the Atlas Industrial Park taken from Google Earth showing the total feasible area (highlighted in orange) and electrical tie-in point for a PV system. As shown, there are large expanses of relatively flat, un-shaded land, which makes it a suitable candidate for a PV system. The total area of the site that appears feasible for PV is 23.3 acres (1,016,969 ft^2), which could support a 4-MW fixed-tilt system or a 3.3-MW single-axis tracking system.

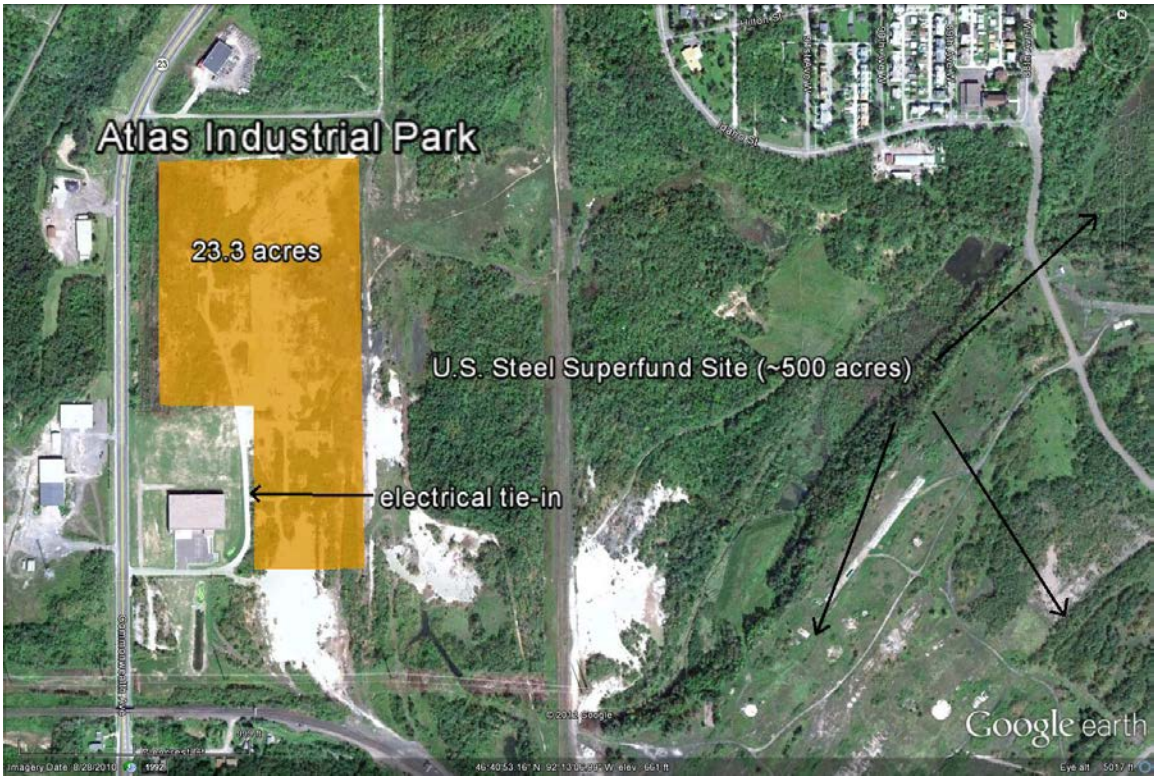

Figure 6. Aerial view of the feasible area for PV at the Atlas Industrial Park

Illustration made in Google Earth

Based on current development plans it is unlikely that the entire site will be utilized for a PV system. Instead, a smaller 2-acre parcel, which was formerly the location of the Atlas Cement silos, is being considered. This site is shown in Figure 7 and could support a 348-kW fixed-tilt or 287-kW single-axis tracking PV system. The difference in system size is due to the need for additional space to prevent self-shading between modules with tracking systems, which also becomes more pronounced at higher tilt angles for fixed-tilt systems. In addition, if the existing vegetation could be removed along Commonwealth Avenue, the available acreage and visibility could be increased.

Figure 7. Aerial view of the 2-acre silo site for PV at the Atlas Industrial Park

Illustration made in Google Earth

PV systems are suitable for Duluth, Minnesota, where the average global horizontal annual solar resource—the total solar radiation for a given location, including direct, diffuse, and ground-reflected radiation—is 4.33 kWh/m^2/day. For comparison, Seattle, Washington, receives 3.67 kWh/m^2/day and Tucson, Arizona, receives 6.13 kWh/m^2/day.[4] Figures 8–11 show various views of the Atlas Industrial Park site taken during the site visit.

[4] PVWatts Viewer. Accessed August 2012: http://gisatnrel.nrel.gov/PVWatts_Viewer/index.html.

Figure 8. Northwest view of the Atlas Industrial Park

Photo by Lars Lisell, NREL

Figure 9. East view of the Atlas Industrial Park

Photo by Lars Lisell, NREL

Figure 10. Southeast view of the Atlas Industrial Park

Photo by Lars Lisell, NREL

Figure 11. West view (near silo site) of the Atlas Industrial Park

Photo by Lars Lisell, NREL

4.2 Utility-Resource Considerations

When considering a ground-mounted system, an electrical tie-in location should be identified to determine how it would be connected to the grid or on-site facilities. The existing infrastructure at the Atlas Industrial Park is well suited for installation of a PV system. The expected electrical tie-in and inverter location for the PV system at the Atlas Industrial Park is located at the MP electrical box east of the IKONICS building along the road into the site. The proposed additional electric infrastructure might also be used as an alternative tie-in and inverter location and could add flexibility to the location of a PV system. Additionally, there are transmission and distribution lines crossing the southern portion of the property that could carry surplus electricity off-site. The electrical tie-in point was not evaluated specifically for compatibility with a PV system and for the purposes of this analysis the site was assumed to need no additional infrastructure. Before moving forward with a solar project, however, a grid integration study should be performed in order to determine definitively whether or not additional infrastructure will be needed to accommodate a PV system. The expected electrical tie-in point is shown in Figure 12.

Figure 12. Potential electrical tie-in point for the PV system at the Atlas Industrial Park showing the IKONICS building and meter in the background

Photo by Lars Lisell, NREL

4.3 PV Site Solar Resource

The Atlas Industrial Park site has been evaluated to determine the adequacy of the solar resource available using both on-site data and industry tools. The assessment team for this feasibility study collected multiple Solmetric SunEye data points and found an annual solar access of 95% and estimated solar resource of 4.19 kWh/m^2/day. The data gathered using this tool is available in Appendix A.

The predicted array performance was found using PVWatts Version 2[5] for Duluth, Minnesota. 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 Duluth, Minnesota, as calculated by PVWatts. The monthly results for each system type are available in Appendix B.

Table 2. Performance Results for 1-kW PV Systems in Duluth, Minnesota

System Type	AC Energy (kWh/yr)	Increase from Fixed 20° Tilt
Fixed Tilt, 20° Tilt	1,216	0%
Fixed Tilt, 46.8° Tilt (latitude)	1,271	4.5%
Single-Axis Tracking	1,427	17.3%
Double-Axis Tracking	1,714	41.0%

4.4 Atlas Industrial Park Energy Usage

Understanding the energy use of a site will enable a full analysis of whether or not energy produced would need to be sold or if it could offset on-site energy use. Currently the Atlas Industrial Park does not have any energy-consuming infrastructure in place. However, a PV system could be used to offset adjacent facilities, such as the IKONICS building, or on-site energy use from future development.

4.4.1 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[6]:

[5] NREL: Renewable Resource Data Center – PVWatts. Accessed September 2012: http://www.nrel.gov/rredc/pvwatts/.

[6] Energy Policy Act of 2005, Title XII—Electricity, Subtitle E—Amendments to PURPA, Section 1251—Net Metering and Additional Standards. Accessed January 9, 2013: http://www.gpo.gov/fdsys/pkg/PLAW-109publ58/pdf/PLAW-109publ58.pdf.

> (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.

Minnesota's net-metering law,[7] which took effect in 1983, requires utilities to offer net metering to all customers with solar and wind-energy systems up to 40 kW.

Renewable energy certificates (RECs), also known as green certificates, green tags, or tradable renewable certificates, are tradable commodities in the United States that represent proof of electric energy generation from eligible renewable energy resources (renewable electricity). The RECs that are associated with the electricity produced and are used on-site remain with the customer-generator. If, however, the customer chooses to receive financial compensation for the net electricity generation remaining after a 12-month period, the utility will be granted the RECs associated with only that surplus they purchase. Minnesota currently participates in the Midwest Renewable Energy Tracking System (M-RETS), which uses production data from participating generators to create RECs in the form of digital tradable certificates for each megawatt-hour.[8]

4.4.2 Virtual Net Metering

Some states and utilities allow for virtual net metering (VNM), often referred to as community solar or solar gardens. 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. Currently neither MP nor the State of Minnesota offer VNM.

[7] For the full text of this bill, see http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=MN01R&re=0&ee=0.

[8] Midwest Renewable Energy Tracking System. Accessed August 2012: www.mrets.net.

5 Economics and Performance

The economics and performance of a PV system installed on the 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. In particular, this study used the NREL System Advisor Model (SAM).[9]

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

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

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

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

5.1 Assumptions and Input Data for Analysis

Cost of a PV system depends on the system size and other factors, such as geographic location, mounting structure, and type of PV module. Based on significant cost reductions seen in recent years, the average cost for utility-scale ground-mounted systems have declined from \$4.80/W in the first quarter (Q1) of 2010 to \$2.90/W in Q1 2012. Costs for smaller commercial and residential-scale systems have also declined steadily to \$4.63/W and \$5.89/W, respectively. The lower cost of utility-scale systems reflects increased economies of scale, which allows fixed costs to be spread over a larger project budget. With an increasing demand and supply, the potential for further cost reduction is expected as market conditions evolve. Figure 13 shows the cost per watt of PV systems from 2010 to 2012 for residential, commercial (non-residential), and utility-scale installations.

[9] For additional information on SAM, see https://sam.nrel.gov/cost.

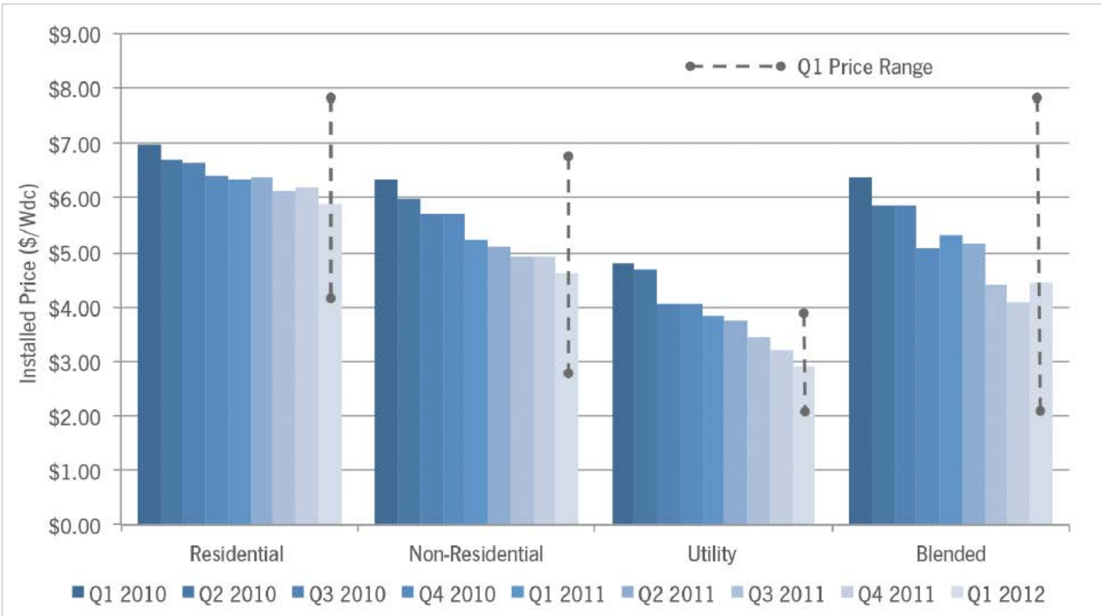

Figure 13. Solar market insight Q1 2012 national weighted average system prices[10]

Credit: Solar Energy Industries Association

For this analysis, the installed cost of fixed-tilt ground-mounted commercial- and residential-scale systems was assumed to be $5.79/W and $7.36/W, respectively. The increased cost is because of 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 for commercial- and residential-scale systems are summarized in Table 3.

Table 3. Installed Fixed-Tilt System Cost Assumptions

System Size	Commercial ($/W)	Residential ($/W)
Baseline system	4.63	5.89
With ballast	1.16	1.47
Total installed cost	5.79	7.36

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,

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

and panel tilt and orientation. For this analysis, the cost of electricity was assumed to be $0.05/kWh, an average of MP's commercial rates.[11]

It was assumed for this analysis that relevant federal incentives are received. 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 federal tax credits and accelerated depreciation on the PV system, which can be worth about 15% of the initial capital investment. 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.

MP's current solar electric incentive program, SolarSense, uses a CBI structure with a cap of $20,000. The program budget for 2012 has been fully committed and the utility is currently evaluating the results for next year's program. Due to the uncertainty of next year's incentive structure, this analysis limited the incentive to the base level. Table 4 shows the incentive levels for the SolarSense program.

Table 4. Minnesota Power's 2012 SolarSense Program Incentive Levels

Incentive	Level ($/kW)
Base incentive	2,000
Non-profit/tax exempt owner	500
Minnesota-made modules	1,000
NABCEP certified installers	250

For the purposes of this analysis, three development scenarios were considered for installing a PV system at the site:

1. DEDA purchase
2. Private purchase and use
3. Private development with a PPA.

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 system DC-to-AC 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 O&M expenses are estimated to be $30/kW/year during the first 15 years and then $20/kW/year for years 16–25. A fixed 20°-tilt system was used as a baseline for evaluating the economics of PV at the site. The exact system design is beyond the scope of this study and will depend on additional site-specific analysis and input from stakeholders. The assumptions and inputs for each scenario are included in Table 5 with the differences highlighted.

[11] Minnesota Power commercial rates. Accessed August 2012: http://www.mnpower.com/customer_service/your_bill/documents/Final_4961a.pdf.

Table 5. SAM Inputs and Assumptions

Parameter	DEDA Purchase	Private Purchase/PPA
Analysis period (years)	25	25
Inflation	2.50%	2.50%
Real discount rate	3.00%	5.85%
Federal tax rate	0	35.00%
State tax rate	0	9.80%
Insurance (% of installed cost)	0.50%	0.50%
Property tax	0.00%	0.00%
Construction loan	0.00%	0.00%
Loan term (years)	25	15
Loan rate	6.00%	6.00%
Debt fraction	100.00%	50.00%
Minimum IRR	n/a	n/a / 15.00%
PPA escalation rate	n/a	n/a / 1.50%
Federal depreciation	n/a	Custom 5-year MACRS[a]
State depreciation	n/a	n/a
Federal ITC	n/a	30.00%
Capacity-based incentive	$2.50/kW	$2.00/kW
Degradation	0.50%	0.50%
Operational availability	100.00%	100.00%
Cost - fixed axis per kW	$5.79	$5.79
Grid interconnection cost	0	0
O&M	$30/kW/yr for years 1-15 & $20/kW/yr for years 16-25	
DC-AC derate factor	80.00%	80.00%
Tilt	20°	20°

[a] Modified Accelerated Cost Recovery System

The PVWatts calculation engine within SAM was used to calculate expected energy performance for the system based on system size, configuration, and solar resource. System size was calculated from the available land area; this analysis was restricted to the 2-acre silo site and determined to be 348 kW for a fixed-tilt system and 287 kW for a single-axis tracking system. Additionally, this study evaluated smaller residential-scale systems, which are favored by the current incentive structure from MP.

5.2 SAM Forecasted Economic Performance

Using the inputs and assumptions summarized above, the SAM tool predicts the levelized cost of energy (LCOE), payback period, and PPA price for a PV system at the Atlas Industrial Park. Table 6 summarizes the results of the economic analysis for the system configurations and development scenarios considered in this study. The entire results are available in Appendix C.

Table 6. Atlas Industrial Park PV System Summary

PV System Type	System Scale	System Size[a] (kW)	Array Tilt (deg)	Annual Output (kWh/year)	Number of Houses Powered[b]
Crystalline Silicon (Fixed Tilt)	Commercial	348	20.0	423,073	38
Crystalline Silicon (Fixed Tilt)	Residential	10	20.0	12,157	1.1
Crystalline Silicon (Fixed Tilt)	Residential	8	20.0	9,726	0.9

Development Scenario	System Scale - Size	System Cost	LCOE Real ($/kWh)	LCOE Nominal ($/kWh)	Payback Period or PPA Price
DEDA Purchase	Commercial - 348 kW	$ 2,014,920	0.34	0.44	>25 years
Private Purchase	Commercial - 348 kW	$ 2,014,920	0.15	0.19	>25 years
Private Purchase with PPA	Commercial - 348 kW	$ 2,014,920	0.31	0.40	$0.31/kWh
DEDA Purchase	Residential - 8 kW	$ 58,880	0.30	0.39	>25 years
Private Purchase	Residential - 10 kW	$ 73,600	0.13	0.16	>25 years

a Data assume a maximum usable area of 2 acres.

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

In each case the results indicate that the LCOE and PPA price would be significantly higher than the retail commercial rate of $0.05/kWh. Although the current CBI and incentive cap favor smaller residential-scale systems, the increased cost per watt compared to larger commercial-scale systems also limits the economic feasibility of these systems.

Figures 14 and 15 show the optimal size for a residential-scale PV system based on current base-level CBIs. The inputs and assumptions were kept the same as the commercial-scale system; however, the module cost was increased to $7.36/W, reflecting current market data for residential systems. Again, the LCOE for each scenario was found to be significantly higher than the current retail commercial electricity rate. The optimal system size is 8 kW for the DEDA purchase scenario and 10 kW for the private purchase scenario. In each case, adding CBIs would decrease the optimal system size by reaching the incentive cap with a smaller system.

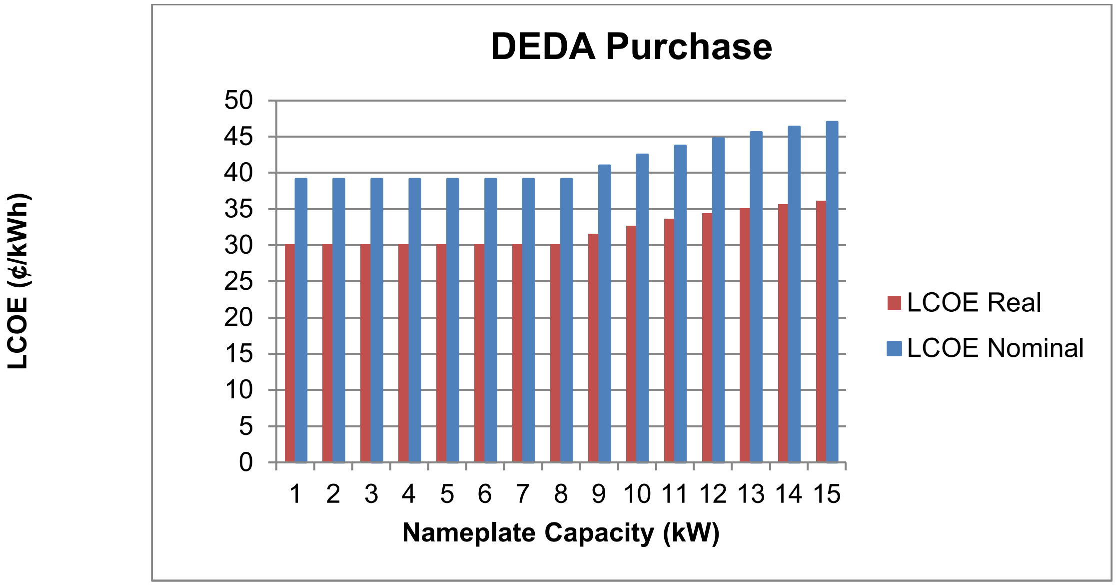

Figure 14. Optimal system size for a DEDA-purchased residential-scale system

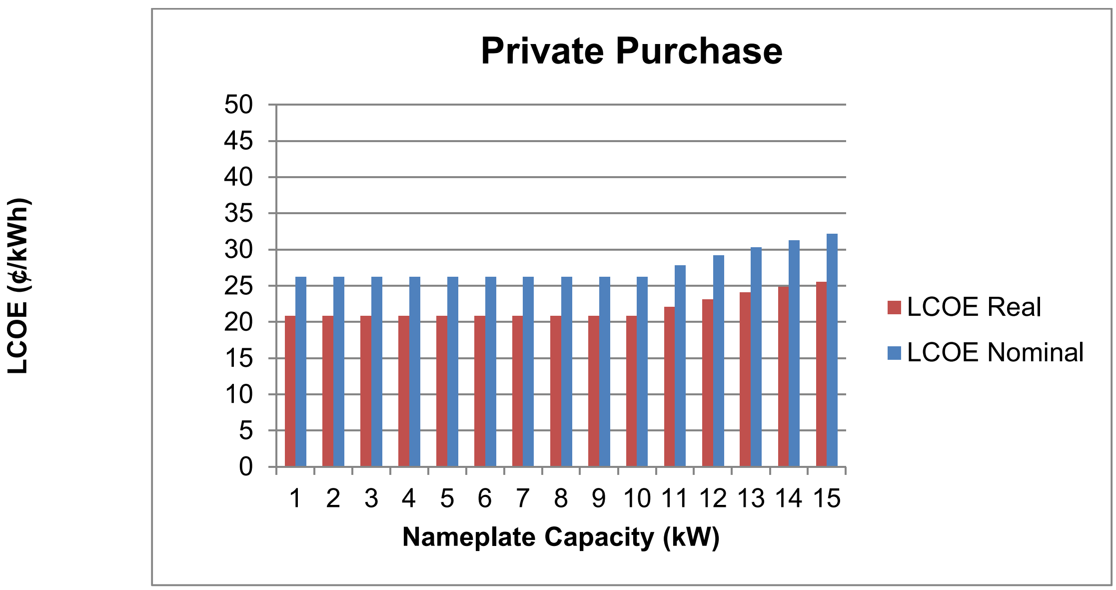

Figure 15. Optimal system size for a privately purchased residential-scale system

Due to the uncertainty of future incentives and high LCOE for PV in Duluth, this study evaluated grid-parity—the point at which PV might become cost-competitive with grid-purchased electricity. Table 7 summarizes the result of the grid-parity analysis showing the module cost at which the real LCOE (without incentives) becomes cost-competitive with the current price of electricity. The results indicate that significant decreases in module costs would be necessary to compete with grid-purchased electricity. Grid parity could occur in Duluth as module costs continue to decline and incentives for PV evolve in the coming years. The entire results of this analysis are available in Appendix C.

Table 7. Predicted Real Module Cost for Grid Parity ($0.05/kWh)

	Module Cost ($/kW)
DEDA Purchase	0.60
Private Purchase	1.10
Private PPA	0.40

5.3 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.[12] 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.

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. Table 8 shows the assumed values for the Atlas Industrial Park.

Table 8. JEDI Analysis Assumptions

Input	Assumed Value Residential	Assumed Value Commercial
Capacity	9 kW	348 kW
Year Placed In Service	2013	2013
Installed System Cost	$7.36/W	$5.79/W
Location	Duluth, MN	Duluth, MN

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.

[12] 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 JEDI tool, see http://www.nrel.gov/analysis/jedi/about_jedi.html.

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 one person working 40 hours per week for the duration of a year. Construction period jobs are considered short-term positions that exist only during the procurement and construction periods. Table 9 summarizes the results from the JEDI model analysis. The full results are provided in Appendix D.

Table 9. JEDI Summary Results

	Residential System	Commercial System
Jobs during construction	0.7	18.9
Wages paid to workers	$13,600	$935,500
Economic output during construction	$24,100	$2,326,000
Jobs during operating years	0.0	0.1
Earnings per year	$200	$7,700
Economic output per year	$300	$13,500

5.4 Financing Opportunities

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

5.4.1 Owner and Operator Financing

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

For public entities that choose to finance, own, and operate a solar project, funding can be raised as part of a larger, general obligation bond; as a standalone tax credit bond; through a tax-exempt lease structure, bank financing, grant and incentive programs, or internal cash; or some combination of the above. Federal qualified energy conservation bonds (QECBs)[13] can also be used to finance renewable energy as well as energy efficiency projects. Certain structures are more common than others and grant programs for solar programs are on the decline. Regardless, as tax-exempt entities, public entities

[13] Department of Energy, Solution Center: Qualified Energy Conservation Bonds. Accessed January 10, 2013: http://www1.eere.energy.gov/wip/solutioncenter/financialproducts/qecb.html.

are unable to benefit directly from the various tax-credit-based incentives available to private companies. This has given way to the now common use of third-party financing structures, such as the PPA.

5.4.2 Third-Party Developers with Power Purchase Agreements

Because many project site hosts do not have the financial or technical capabilities to develop a capital intensive project, many times they turn to third-party developers (and/or their investors). In exchange for access to a site through a lease or easement arrangement, third-party developers will finance, develop, own, and operate solar projects utilizing their own expertise and sources of tax equity financing and debt capital. Once the system is installed, the third-party developer will sell the electricity to the site host 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 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 (low PPA price, higher lease payment) while not directly receiving them. The term of PPAs typically varies from 20–25 years.

5.4.3 Third-Party "Flip" Agreements

The most common use of a third-party "flip" agreement 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). After the flip, the site host would have the option to buy out all or most of the tax investors' 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 investors' return is met.

5.4.4 Hybrid Financial Structures

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

5.4.5 Solar Services Agreement and Operating Lease

The Solar Services Agreement (SSA) and operating lease business models have been predominately used in the municipal and cooperative utility markets due to its 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 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 buy out the system once the third-party has accrued the tax credits, but because of 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."

5.4.6 Sale/Leaseback

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

5.4.7 Community Solar Gardens/Solar

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, which 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 PV 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, the customer receives a billing credit for the number of kilowatt-hours their pro-rated share of the solar project produces each month; it is also known as VNM. Under the customer subscription option, the customers typically pay a set price for a block of solar energy (i.e., 100 kWh per month blocks) from the community solar project. Other models include monthly energy outputs from a specific investment dollar amount or a specific number of panels.

Community solar garden and customer subscription-based projects can be owned solely by the utility, owned solely by third-party developers with facilitation of billing provided by the utility, or 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). Solar gardens are not currently offered in Minnesota, but if approved by the Minnesota public utility commission could be an effective way to make the Atlas site a sustainable office park.

6 Conclusions and Recommendations

From a technical standpoint, the Atlas Industrial Park is a suitable area in which to implement a PV project with an adequate land area and solar resource. However, the existing economics specific to Duluth currently limit the feasibility of a PV system there. As summarized in Section 5, the economic analysis completed using SAM predicts an LCOE significantly higher than the current retail rate, which is approximately half the national average.[14] Additionally, MP's current incentive structure favors smaller systems by using a capacity-based approach with a relatively low incentive cap. Based on current economics, the most cost-competitive scenario is a privately owned residential-scale system used to offset on-site energy use, with larger systems also predicted to have lower LCOEs than either the DEDA purchase or PPA scenarios.

Future changes to electric rates, module costs, and incentives may make PV in Duluth cost-competitive with grid-purchased electricity. Continued increases in electric rates combined with decreases in module costs will reduce the gap between grid-purchased electricity and distributed generation. In addition, changes to MP's current incentive structure or the addition of incentives from the state could further reduce the LCOE of PV systems in the future if, for example, a performance-based incentive (PBI) was offered. The structure of PBIs typically produces cash flows for the project on an annual basis rather than a one-time payment during the construction year, as is the case with CBIs. For comparison, Massachusetts, many parts of which have a solar resource similar to Duluth, offers a PBI of $0.55/kWh.[15] If a similar incentive was available in Duluth, either from the state or utility, the LCOE for PV systems would become more competitive with retail electric rates. Table 10 shows the predicted economics for PV systems in Duluth using PBIs from Massachusetts.

Table 10. Predicted Real Levelized Cost of Energy Using a Performance-Based Incentive in Duluth

Development Scenario	System Scale – Size	Real LCOE ($/kWh)	Payback Period or PPA price	Debt Fraction
DEDA Purchase	Commercial - 348 kW	0.098	9.8 years	100%
Private Purchase	Commercial - 348 kW	0.028	6.6 years	10%
Private Purchase with PPA	Commercial - 348 kW	0.018	$0.021/kWh	40%
DEDA Purchase	Residential - 8 kW	0.186	>25 years	100%
Private Purchase	Residential - 10 kW	0.022	8.6 years	50%

[14] In 2011 the average retail electricity price for commercial customers was $0.103/kWh. Energy Information Administration, Factors Affecting Electricity Prices. Accessed August 2012: www.eia.gov/energyexplained/index.cfm?page=electricity_factors_affecting_prices.

[15] For a complete description of incentives available in Massachusetts, see http://www.dsireusa.org/incentives/index.cfm?re=0&ee=0&spv=0&st=0&srp=1&state=MA.

Although the existing economics currently limit the feasibility of PV in Duluth, financing options separate from the ones considered in this study may provide DEDA with a viable means to implement a PV system at the Atlas Industrial Park. Future site developers may in fact be able to install a small or large PV system at a price comparable to retail electric rates with a creative financial model and changes to existing economics. Additionally, DEDA may be able to facilitate the development of a standalone system using alternative financing. For example, a public-private partnership with MP, an energy services company, or current/future site developers to create a solar demonstration project could be a beneficial arrangement to all stakeholders. By leasing the land for a nominal fee, DEDA could provide a developer with a highly visible site to build a large commercial-scale ground-mounted PV system. The energy from a PV system could be fed directly into MP's electric grid to satisfy the state's RES and/or used on-site by IKONICS or other site developers. In addition, if VNM becomes an option, a solar garden approach could be used whereby off-site electric customers could purchase a stake in the system on a per-kilowatt-hour or module basis.[16]

It is recommended that DEDA further pursue opportunities for a PV installation at the Atlas Industrial Park. A renewable energy project aligns closely with Duluth's vision for the redevelopment of the St. Louis River corridor, and the Atlas Industrial Park in particular could provide a valuable opportunity for a highly visible demonstration project for the city and solar developer to gain experience with large PV systems. Although this report finds that traditional financing opportunities are not economically feasible at this time due to existing incentives and low electricity rates, creative partnerships and financing may facilitate a PV installation at the Atlas Industrial Park in the short term. Additionally, changes in electric rates, incentives, and module costs could make a PV system more cost-competitive with grid-purchased electricity in the years to come.

[16] For a list of solar gardens by state, see www.solargardens.org/.

Appendix A. Solar Access Measurements

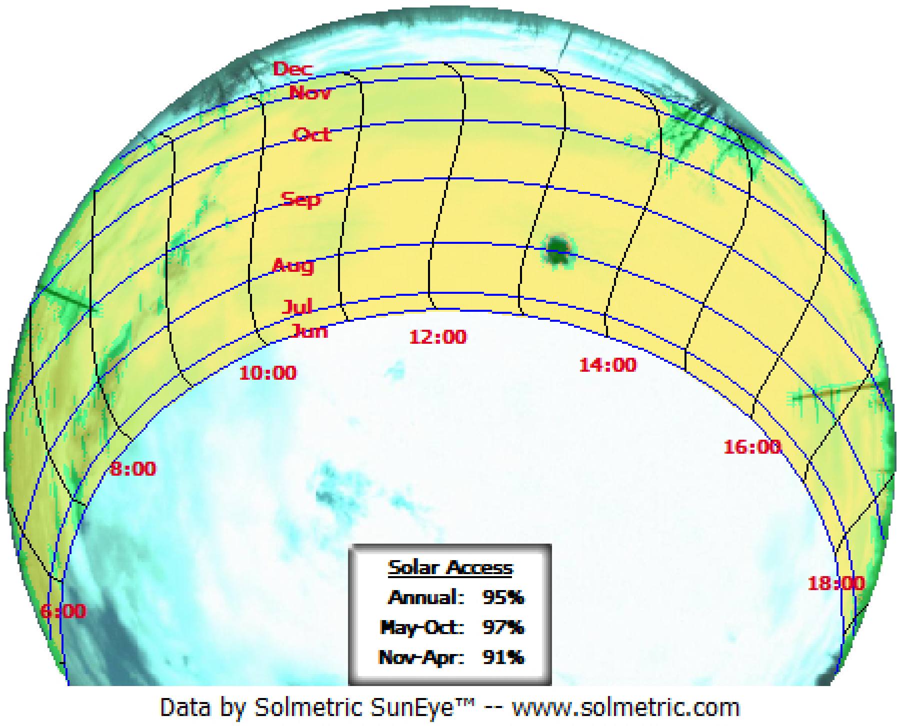

Figure A-1. Solar access measurements for the Atlas Industrial Park PV site

Appendix B. Results from PVWatts

Table B-1. PVWatts Inputs

Station Identification	
Cell ID	14913
State	Minnesota
Latitude	46.83° N
Longitude	92.18° 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	$0.05/kWh

Table B-2. Performance Results for a 20-Degree Tilt System

Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	2.49	67	3.35
2	3.44	83	4.15
3	4.83	126	6.30
4	4.99	120	6.00
5	5.90	140	7.00
6	6.20	139	6.95
7	5.97	135	6.75
8	5.49	126	6.30
9	4.30	99	4.95
10	3.31	80	4.00
11	2.09	50	2.50
12	1.94	50	2.50
Year	4.25	1,216	60.80

Table B-3. Performance Results for a Tilt = Latitude (46.8°) Fixed-Tilt System

Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	3.29	90	4.50
2	4.27	104	5.20
3	5.41	141	7.05
4	4.99	119	5.95
5	5.42	127	6.35
6	5.51	122	6.10
7	5.36	120	6.00
8	5.26	120	6.00
9	4.48	102	5.10
10	3.85	94	4.70
11	2.61	63	3.15
12	2.61	69	3.45
Year	4.42	1,271	63.55

Table B-4. Performance Results for Zero-Degree Single-Axis System

Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	2.37	64	3.20
2	3.51	86	4.30
3	5.38	143	7.15
4	5.79	142	7.10
5	7.44	180	9.00
6	7.99	183	9.15
7	7.65	177	8.85
8	6.65	156	7.80
9	4.91	115	5.75
10	3.47	86	4.30
11	2.03	48	2.40
12	1.80	46	2.30
Year	4.92	1,427	71.35

Table B-5. Performance Results for Zero-Degree Double-Axis System

Month	Solar Radiation (kWh/m^2/day)	AC Energy (kWh)	Energy Value ($)
1	3.98	109	5.45
2	5.16	126	6.30
3	6.67	175	8.75
4	6.48	158	7.90
5	7.96	192	9.60
6	8.46	194	9.70
7	8.10	186	9.30
8	7.25	168	8.40
9	5.70	133	6.65
10	4.62	114	5.70
11	3.08	76	3.80
12	3.14	84	4.20
Year	5.89	1,714	85.70

Appendix C. Results of the SAM Analysis

Table C-1, Table C-2, and Table C-3 are summary output tables from SAM that show the five scenarios analyzed in this study.

Table C-1. DEDA Purchase Scenario

DEDA Purchase - 8 kW		DEDA Purchase - 348 kW	
Net Annual Energy	9,726 kWh	Net Annual Energy	423,073 kWh
LCOE Nominal	39.15 ¢/kWh	LCOE Nominal	44.16 ¢/kWh
LCOE Real	30.12 ¢/kWh	LCOE Real	33.98 ¢/kWh
First-Year Revenue without system	$0	First-Year Revenue without system	$0
First-Year Revenue with System	$0	First-Year Revenue with System	$0
First-Year Net Revenue	$0	First-Year Net Revenue	$0
After-Tax Net Present Value	-$48,432	After-Tax NPV	-$2,376,681
Payback Period	>25 years	Payback Period	>25 years
Capacity Factor	13.9%	Capacity Factor	13.9%
First Year kWh_{AC}/kW_{DC}	1,216	First Year kWh_{AC}/kW_{DC}	1,216

Table C-2. Third-Party Purchase Without PPA

Third Party - 10 kW		Third Party - 348 kW	
Net Annual Energy	12,157 kWh	Net Annual Energy	423,073 kWh
LCOE Nominal	15.88 ¢/kWh	LCOE Nominal	18.80 ¢/kWh
LCOE Real	12.60 ¢/kWh	LCOE Real	14.93 ¢/kWh
First-Year Revenue without system	$0	First-Year Revenue without system	$0
First-Year Revenue with System	$0	First-Year Revenue with System	$0
First-Year Net Revenue	$0	First-Year Net Revenue	$0
After-Tax Net Present Value	-$18,991	After-Tax NPV	-$782,657
Payback Period	>25 years	Payback Period	>25 years
Capacity Factor	13.9%	Capacity Factor	13.9%
First Year kWh_{AC}/kW_{DC}	1,216	First Year kWh_{AC}/kW_{DC}	1,216

Table C-3. Commercial-Scale PPA Scenario

Third Party/PPA - 348 kW	
Net Annual Energy	423,073 kWh
PPA Price	35.15 ¢/kWh
LCOE Nominal	39.67 ¢/kWh
LCOE Real	31.49 ¢/kWh
After-Tax IRR	15%
Pre-Tax Min DSCR[a]	1.25
After-Tax Net Present Value	$185,576
PPA Price Escalation	1.50%
Debt Fraction	50%
Capacity Factor	13.9%
First Year kWh_{DC}/kW_{AC}	1,216

[a] Debt service coverage ratio

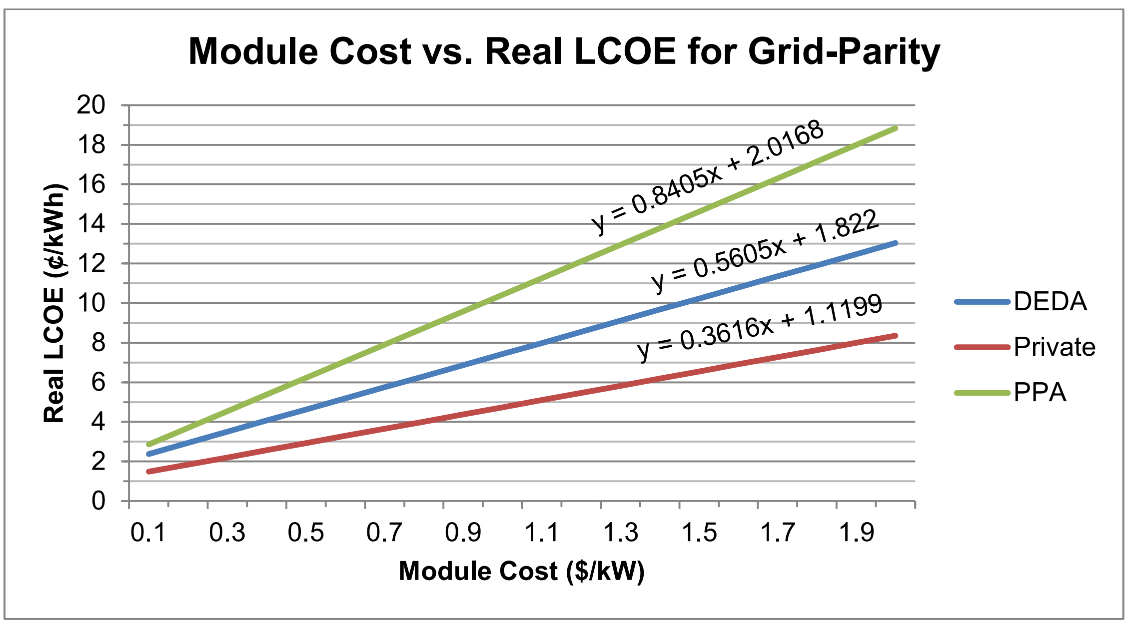

Figure C-1. Module cost versus real levelized cost of energy for grid parity

Appendix D. Results of the JEDI Model

Table D-1 and Table D-2 are output tables from the JEDI PV model for implementing a residential- and commercial-scale PV system in Duluth, Minnesota.

Table D-1. JEDI Results, Residential-Scale System

Photovoltaic - Project Data Summary based on model default values	
Project Location	Minnesota
Year of Construction or Installation	2013
Average System Size - DC Nameplate Capacity (kW)	9
Number of Systems Installed	1
Total Project Size - DC Nameplate Capacity (kW)	9
System Application	Small Commercial
Solar Cell/Module Material	Crystalline Silicon
System Tracking	Fixed Mount
Base Installed System Cost ($/kWDC)	$7,360
Annual Direct Operations and Maintenance Cost ($/kW)	$26.00
Money Value - Current or Constant (Dollar Year)	2012
Project Construction or Installation Cost	$66,240
Local Spending	$42,955
Total Annual Operational Expenses	$7,918
Direct Operating and Maintenance Costs	$234
Local Spending	$213
Other Annual Costs	$7,684
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 On-site Labor Impacts			
Construction and Installation Labor	0.1	$6.0	
Construction and Installation Related Services	0.2	$7.6	
Subtotal	0.2	$13.6	$24.1
Module and Supply Chain Impacts			
Manufacturing	0.0	$0.0	$0.0
Trade (Wholesale and Retail)	0.0	$3.2	$9.2
Finance, Insurance and Real Estate	0.0	$0.0	$0.0
Professional Services	0.1	$2.4	$7.5
Other Services	0.1	$3.8	$12.2

Other Sectors	0.1	$2.5	$6.0
Subtotal	0.2	$12.0	$34.9
Induced Impacts	0.2	$7.5	$24.3
Total Impacts	**0.7**	**$33.1**	**$83.2**

During operating years	**Annual Jobs**	**Annual Earnings $000 (2012)**	**Annual Output $000 (2012)**
On-Site Labor Impacts			
PV Project Labor Only	0.0	$0.1	$0.1
Local Revenue and Supply Chain Impacts	0.0	$0.0	$0.1
Induced Impacts	0.0	$0.0	$0.1
Total Impacts	**0.0**	**$0.2**	**$0.3**

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.)	$2,619	100%	N
Modules	$21,010	100%	N
Electrical (wire, connectors, breakers, etc.)	$1,685	100%	N
Inverter	$3,792	100%	N
Subtotal	$29,106		
Labor			
Installation	$5,972	100%	
Subtotal	$5,972		
Subtotal	$35,078		
Other Costs			
Permitting	$8,378	100%	
Other Costs	$3,420	100%	
Business Overhead	$19,364	100%	
Subtotal	$31,162		
Subtotal	$66,240		
Sales Tax (Materials & Equipment Purchases)	$0	100%	
Total	$66,240		

PV System Annual Operating and Maintenance Costs	Cost	Local Share
Labor		
Technicians	$128	100%
Subtotal	$128	
Materials and Services		
Materials & Equipment	$106	100%
Services	$0	100%
Subtotal	$106	
Sales Tax (Materials & Equipment Purchases)	$0	100%
Average Annual Payment (Interest and Principal)	$7,684	0%
Property Taxes	$0	100%
Total	$7,918	

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	6.88%	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	$23.69	45.6%
O&M Labor		
Technicians	$23.69	45.6%

Table D-2. JEDI Results, Commercial-Scale System

Photovoltaic - Project Data Summary Based on Model Default Values	
Project Location	Minnesota
Year of Construction or Installation	2013
Average System Size - DC Nameplate Capacity (kW)	348
Number of Systems Installed	1
Total Project Size - DC Nameplate Capacity (kW)	348
System Application	Large Commercial
Solar Cell/Module Material	Crystalline Silicon
System Tracking	Fixed Mount
Base Installed System Cost ($/kWDC)	$5,790
Annual Direct Operations and Maintenance Cost ($/kW)	$26.00
Money Value - Current or Constant (Dollar Year)	2012
Project Construction or Installation Cost	$2,014,920
Local Spending	$1,205,084
Total Annual Operational Expenses	$242,779
Direct Operating and Maintenance Costs	$9,048
Local Spending	$8,324
Other Annual Costs	$233,731
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 On-site Labor Impacts			
Construction and Installation Labor	3.0	$191.20	
Construction and Installation Related Services	4.1	$198.10	
Subtotal	7.0	$389.30	$662.40
Module and Supply Chain Impacts			
Manufacturing	0.0	$0.0	$0.0
Trade (Wholesale and Retail)	1.5	$101.40	$289.20
Finance, Insurance, and Real Estate	0.0	$0.0	$0.0
Professional Services	1.3	$63.60	$194.50
Other Services	1.4	$99.00	$317.40
Other Sectors	2.5	$73.50	$185.20
Subtotal	6.7	$337.50	$986.20
Induced Impacts	5.2	$208.70	$677.40
Total Impacts	**18.9**	**$935.50**	**$2,326.00**

During operating years	Annual Jobs	Annual Earnings $000 (2012)	Annual Output $000 (2012)
On-Site Labor Impacts			
PV Project Labor Only	0.1	$5.00	$5.00
Local Revenue and Supply Chain Impacts	0.0	$1.70	$5.10
Induced Impacts	0.0	$1.00	$3.30
Total Impacts	**0.1**	**$7.70**	**$13.50**

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.)	$87,998	100%	N
Modules	$730,706	100%	N
Electrical (wire, connectors, breakers, etc.)	$61,708	100%	N
Inverter	$131,884	100%	N
Subtotal	$1,012,295		
Labor			
Installation	$191,183	100%	
Subtotal	$191,183		
Subtotal	$1,203,478		
Other Costs			
Permitting	$218,164	100%	
Other Costs	$89,047	100%	
Business Overhead	$504,231	100%	
Subtotal	$811,442		
Subtotal	$2,014,920		
Sales Tax (materials and equipment purchases)	$0	100%	
Total	$2,014,920		

PV System Annual Operating and Maintenance Costs	Cost	Local Share
Labor		
Technicians	$5,429	100%
Subtotal	$5,429	
Materials and Services		

Materials & Equipment	$3,619	100%
Services	$0	100%
Subtotal	$3,619	
Sales Tax (materials and equipment purchases)	$0	100%
Average Annual Payment (interest and principal)	$233,731	0%
Property Taxes	$0	100%
Total	$242,779	
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	6.88%	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%