US Environmental Protection Agency

Solar Screening Study of Properly Closed Municipal Solid Waste Landfills - Siting Solar Photovoltaics in Ulster County, New York

A screening study prepared by the Environmental Protection Agency, Region 2 for Siting Renewable Energy on Closed Landfills

Team Consisting of:
Environmental Protection Agency, Region 2 - Vince Pitruzzello, Fernando Rosado, Abbey States, and Daniel Moore (SUNY Geneseo Intern) and Department of Energy/National Renewable Energy Lab (NREL).

Acknowledgment:
We would like to thank Timothy B. Rose, P.E. - Executive Director, Ulster County Resource Recovery Agency (UCRRA), Michelle Bergkamp - Director of Recycling, UCRRA, and Amanda LaValle - Coordinator, Ulster County Department of the Environment for their help and assistance with the site visits and facilitating with the County of Ulster.

This report is to be used for screening purposes only.

Additional evaluations will need to be conducted to fully characterize the feasibility and economics of the Ulster County landfills for PV installation. Third party solar developers and local utility companies may have technical and financial interests to pursue potential solar renewable energy projects and perform additional solar assessments to determine if projects are economically viable.

This study does not assess the environmental conditions at the site.

I. Background

On June 20, 2014, the U.S. Environmental Protection Agency, Region 2 (EPA), in cooperation with the Ulster County Resource Recovery Agency and Ulster County Department of the Environment visited and screened three closed landfills in Ulster County, New York for potential solar photovoltaic (PV) renewable energy generation. These three landfills are the Lloyd Transfer Station landfill located in the Town of Lloyd, the New Paltz Landfill located in the Town of New Paltz, and the Ulster County Landfill located in the Town of Ulster.

In 1986, the Ulster County Legislature obtained authorization from the State Legislature for the creation of the **Ulster County Resource Recovery Agency** (UCRRA), a public benefit corporation which was formed for the purpose of developing, financing, and implementing a comprehensive County wide solid waste management program. In the mid-1980's, after new initiatives to close non-complying existing landfills were undertaken by the New York State Department of Energy Conservation (NYSDEC) and strict requirements for the siting, construction, and operation of new disposal facilities were enacted, many communities found it beyond their financial and managerial capability to continue to dispose of waste in traditional ways. Consequently, many of the local municipalities in Ulster County requested that the Ulster County government assumed the responsibility for solid waste management, and the Agency was created by the New York State Legislature pursuant to Chapter 936 of the Public Authorities Law approved December of 1986. UCRRA now owns and operates the three landfills mentioned above.

In general, due to the presence of suspected or known contaminants, landfills have limited redevelopment potential and solar PV installations can be a viable reuse. Many MSW landfills are particularly well-suited for solar development because they are often:

- Located near critical infrastructure including electric transmission lines and roads;
- Located near areas with high energy demand (e.g., large population bases);
- Constructed with large areas of minimal grade (0-2 percent) needed for optimal siting of solar photovoltaic (PV) structures;
- Offered at lower land costs when compared to open space; and may be adequately zoned for renewable energy;
- May have environmental conditions that are not well suited for commercial or residential redevelopment;
- Can provide job opportunities in urban and rural communities;
- Able to accommodate net metered or utility scale projects; and
- May reduce the environmental impacts of energy systems (e.g., reduce greenhouse gas emissions).

However, each solar PV system represents a standalone system that can be sized to use an entire available site area. The feasibility of PV solar systems on landfills is highly impacted by the available area for an array, solar resource, operating status, landfill cap status, distance to transmission lines, and distance to major roads, economic viability, and community support.

This solar screening study report will provide critical information for each landfill to assist Ulster County officials in determining the site's solar PV potential. In addition, the report will outline various financial incentives that could assist in financing the implementation of a solar PV system including incentives offered by New York State Energy Resource and Development Authority[1], (NYSERDA).

[1] http://www.nyserda.ny.gov/

According to NYSERDA, solar PV generation offers the following key benefits:

- PV systems are gentle on the environment. In contrast with electricity generated by fossil fuels, PV-generated electricity creates no noise, and air or water pollution,
- Provides long-term stabilization of electrical costs,
- When combined with a battery backup system, a PV unit can provide power when utility power is not available,
- NYSERDA provides incentives that can reduce the customer's out of pocket cost, and
- Additional federal and state tax credits may apply.

In New York State, another benefit to implementing a renewable energy system is Net Metering/Remote Net Metering[2]. Net Metering/Remote Net Metering is allowed for non-residential solar PV generation systems less than 2 MWs in size. In a conventional net metering situation, a customer-sited renewable energy system is connected to the utility grid through a customer's utility meter. This is known as "behind-the-meter generation." At any given moment, if the site is using more electricity than the system is producing, all the electricity produced by the system is used on-site and the site's electricity needs are supplemented from the grid. If the site is using less electricity than the system is producing, the excess electricity is exported to the grid and the customer receives a credit. This is typically recorded as negative use and is commonly referred to as the "meter spinning backwards." At the end of the billing cycle, the grid-supplied electricity and the credits for any exported electricity are reconciled, and any surplus credits can be carried forward to the next billing cycle. The specifics of net metering are dependent on the customer's service classification. Customers who are eligible for Remote Net Metering may apply those credits to other accounts. It is highly recommended that the electric distribution company (EDC or "utility") serving the Ulster County landfills be contacted about these potential solar on landfill projects and explore net metering opportunities. The EDC serving the area is Central Hudson Gas and Electric.

While the findings of this report do not recommend how a solar array at a landfill be financed, if the municipality decides that they do not want to invest their own funds to build the solar site, they can consider entering into a Power Purchase Agreement (PPA) with a solar developer who would assume the cost of development. Regardless of how the project is structured financially, the electric distribution company needs to be consulted early in the planning stages so that it can inform the municipality of any potential interconnection issues that might exist or upgrades that might be necessary to facilitate the project.

II. PV Ground Mount Systems

The solar array has to be secured and oriented optimally to maximize system output. The structure holding the modules is referred to as the mounting system. The mounting systems can be ground-mounted utilizing a ballast system on top of a landfill cap where there are commonly large unshaded areas. For ground mount 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 range 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.

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[2] http://www.cenhud.com/dg/net_metering.html
Attachment #2 for definition of Net Metering and NY regulations.

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 landfill sites. Fixed-tilt systems have lower maintenance costs but generate less energy (kWh) per unit power (kW) of capacity than tracking systems.

Tracking systems rotate the PV modules so they follow the sun as it moves across the sky. This increases energy output but also increases maintenance and equipment costs slightly. Single-axis tracking, in which PV is rotated on a single axis, can increase energy output up to 25% or more.

The selection of mounting type is dependent on many factors including installation size, electricity rates, government incentives, land constraints, soil conditions, alignment and latitude requirements, and local weather. 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. 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.

Major System Components

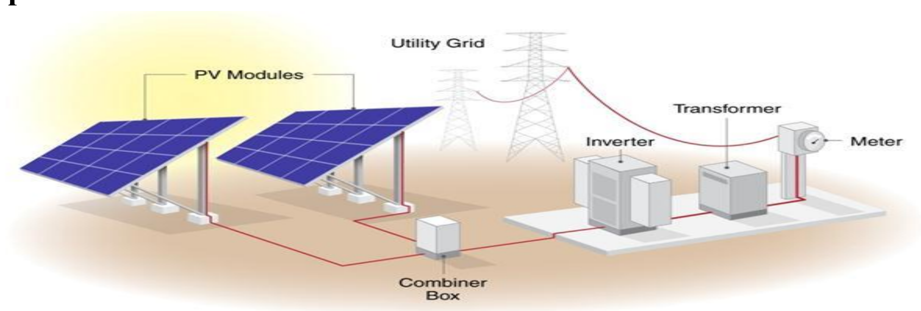


Figure 1. Ground mount array diagram Source: NREL

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

- PV modules
- Inverter
- Balance-of-system components - includes mounting racks, hardware for the panels, and 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 the arrays to inverters and inverters to point of interconnection is generally run as direct burial through trenches. In landfill site applications, this wiring may be required to run through above-ground conduits 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. See attachment #2 for additional information on PV Systems Overview.

A number of landfills that are municipally owned and operated have expressed interest in potential revenue flows from PV systems. In some cases, revenue can be generated by the use of PV on a landfill site pending actual site conditions, financial incentives, economic conditions, and support from the utility companies. **While the Ulster County landfills have been screened for solar PV, the findings of this solar screening study should not be the sole basis for determining if a PV system at the sites are optimal.**

For landfill site applications, the county may need to obtain the approval from NYSDEC. This approval process is necessary in order to ensure that the integrity of the protective measures put in place to cap the site is maintained.

The following sections (III and IV) of the report are separated into respective parts for each of the three previously discussed landfills located in Ulster County. These sections will discuss information specific for each site regarding the feasibility of developing solar photovoltaic systems.

Part 1

Section III. Lloyd Transfer Station Landfill PV System/Siting Considerations

The **Town of Lloyd** is located in the eastern part of Ulster County. U.S. Route 9W runs north and south in the eastern part of the town. The concurrent U.S. Route 44 and NY 55 pass through the southeast corner of the town and NY 299 also runs east-west across the town. The Lloyd Transfer Station Landfill entrance is located on Lily Lake Road north of Oak Crest Drive. According to the 2010 census, the Town of Lloyd has a population of approximately 10,863. The following photos show various views of the landfill.

Figure 2. Views of the feasible area for PV at the Lloyd Transfer Station Landfill
Photos Credits: EPA

Northern View - Electrical Transmission Lines running along the north.

Southern View - Gas vent pipe at the south central portion of the landfill.

Eastern View - Gas vent pipe at the east central portion of the landfill.

Western View – Leachate collection tank located near the center of the Landfill.

Useable Landfill Acreage:

The total feasible area for PV on the Lloyd Transfer Station landfill is approximately 6.25 acres. Figure 3 below shows the landfill image taken from Google Earth; the feasible area for PV is in shaded area determined by the topography of the land. In general, the available landfill area will impact the potential PV system size and the cost of PV systems. The economics of the PV system which will also vary according to the entities developing solar PV at the sites (municipally funded system or a power purchase agreement funded system).

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.

Figure 3 - Aerial view of the feasible for PV at the Lloyd Transfer Station Landfill

Taken with Google Earth Pro

Transmission/Utility Resources:

According to the UCRRA officials, the closest substation is approximately 2 miles from the landfill along Highway 299. Electrical transmission lines run along the northern portion of the landfill (see northern view of the landfill above) and electric power ***feeds into the transfer station located on the site***. A detailed interconnection study may have to be performed through the local electric utility to determine the feasibility of utilizing a tie-in point for a PV system. If the system will be grid-connected and the distance to transmission is more than 1/2 mile, solar PV may not be viable due to the additional cost associated with connecting the system to the nearest grid tie-in.

IV. Solar Assessment:

The EPA solar assessment team used a Solmetric SunEye[3] 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, it can determine if the area is appropriate for solar panels.

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. 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. By finding the solar access, it can be determined if the area is appropriate for solar power generation.

The assessment team collected multiple Solmetric SunEye data points at the center and along perimeter of the landfill and found the annual solar access average to be 97%. The SunEye annual solar access summary for each landfill is available in **Attachment #1**. The following key and site related information was collected to aid in this solar assessment for Lloyd Transfer Station Landfill:

Table 1 – Landfill Information

Landfill/Site Name	Lloyd Transfer Station Landfill
Landfill Physical Address	Lily Lake Rd. Highland, NY, 12528
Landfill Site Operator/Owner	Ulster County Resource Recovery Agency
County Official Contacts	Timothy B. Rose, P.E. - Executive Director, UCRRA, tros@ucrra.org, (845) 336-0600 Amanda LaValle, Coordinator, Ulster County Department of the Environment alav@co.ulster.ny.us, (845) 338-7455
Landfill Closure Date	March, 1998
Annual Post Closure Monitoring/Maintenance	May 22, 2013
Final Landfill Closure Plan	**ftp://ftp.dec.state.ny.us/dshm/SWMF/Info/Ulster%20County%20Landfills%20-%20Closure%20Reports/**
Landfill Physical Characteristics:	
Landfill Size	18 Acres. Inactive.
Landfill Cap Type:	Geomembrane, vegetative, gentle slope
Potential Usable LF Area for Solar PV	6.25 acres (see aerial image on page 6.)
Landfill Orientation:	The potential usable area (6.25 acres) appears overall level with a gentle downward slope towards the North. Significant Slope on **Southern end of the landfill.**
Physical Conditions	Landfill surface heavily vegetated with grass and dirt. Mowing is performed once a year.
Landfill Shading Concerns	No Structures on the landfill. Open area with trees along the perimeter (see aerial image).
LF Settlement/Floodplains/Wetlands Concerns	None.
Existing LF Treatment Systems:	Leachate collection system/piezometer/venting.
Landfill Contour Maps or other site maps	See the Annual Post Closure Monitoring/Maintenance Report link above.
Utility Information:	
Utility Company serving the Area (contacts)	Central Hudson Gas and Electric **http://www.cenhud.com/dg/** Email - distributedgeneration@cenhud.com
Nearby major highways	North of Highway 299/East of NY Thruway I-87/West of US Rt. 9W
Distance to Electrical Transmission Lines	Electrical transmission lines are located along northern portion of the landfill.
Location of the Substations	Approximately 2 miles away along Route 299
Landfill Electrical Load/Classification	Verification needed with the Ulster County Officials.

[3] More information on this tool can be found at: http://www.solmetric.com/

Other	
Any on-going remediation at the site? Any private parties associated with the LF?	Not applicable.
Any existing site liens/bankruptcy status?	Not applicable.
Additional Information	System Capacity for Fixed PV System – 1.48 MW based on 5.74 acres per MW System Capacity for Single Axis PV System – 1.22 MW based on 6.96 acres per MW

PV Watts 2 Site Identification:

The predicted array performance was found using PV Watts Version 2[4] for the Lloyd Transfer Station landfill. NREL's PVWatts™ calculator determines the energy production and cost savings of grid-connected photovoltaic (PV) energy systems throughout the world. It allows homeowners, installers, manufacturers, and researchers to easily develop estimates of the performance of hypothetical PV installations. The PVWatts calculator works by creating hour-by-hour performance simulations that provide estimated monthly and annual energy production in kilowatts and energy value. Users can select a location and choose to use default values or their own system parameters for size, electric cost, array type, tilt angle, and azimuth angle.

The PVWatts Grid Data Calculator, Version 2 is another NREL tool which was utilized to calculate estimates of kWh and MWh energy performance for the system based on the number of acres available. Table #2 below shows the station identification information, PV system specifications, and energy specifications for the site.

Table # 2 - PV Watts2 Site Identification Information and Specifications

Station Identification		
Cell ID:	**268368**	
State:	**New York**	
Latitude:	**41.6 ° N**	
Longitude:	**74.1 ° W**	
PV System Specifications		
	Fixed Axis	**Single Axis**
DC Rating:	**1088 kW**	**898.0 kW**
DC to AC Derate Factor:	**0.8**	**0.8**
AC Rating:	**870.4 kW**	**718.4 kW**
Array Type:	**Fixed Tilt**	**1-Axis Tracking**
Array Tilt:	**20 °**	**20 °**
Array Azimuth:	**180° South**	**180° South**
Energy Specifications		
Average (Regional) Cost of Electricity:	**14.8 ¢/kWh**	

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

Table # 3 - shows the performance results for a 20-degree, 1088 kW fixed-tilt PV system and 898 kW single-tilt PV system at the Lloyd Transfer Station landfill as **calculated by PV Watts 2.**

Performance Results - Fixed Axis PV system					Performance Results – Single Axis PV system		
Month	**Solar Radiation ($kWh/m^2/day$)**	**AC Energy (kWh)**	**Energy Value ($)**		**Solar Radiation ($kWh/m^2/day$)**	**AC Energy (kWh)**	**Energy Value ($)**
1	2.62	72,856	10,795.8		3.15	74,605	11,054.97
2	3.47	87,101	12,906.63		4.24	89,546	13,268.93
3	4.66	125,643	18,617.78		5.83	131,668	19,510.56
4	5.06	128,774	19,081.73		6.22	132,370	19,614.59
5	5.85	147,649	21,878.63		7.19	151,322	22,422.89
6	6.1	146,172	21,659.77		7.4	148,243	21,966.65
7	5.94	145,584	21,572.64		7.24	147,761	21,895.22
8	5.54	135,332	20,053.50		6.81	139,200	20,626.66
9	4.86	117,053	17,344.91		6	120,959	17,923.70
10	3.89	100,670	14,917.28		4.82	104,846	15,536.08
11	2.61	66,848	9,905.54		3.15	68,019	10,079.06
12	2.33	62,753	9,298.74		2.75	63,114	9,352.23
Year	**4.42**	**1,336,434**	**198,032.80**		**5.41**	**1,371,651**	**203,251.20**

V. Forecasted Economics and Performance:

Installed System Costs:
In addition to the solar modules and inverter, a solar PV system consists of other parts called balance-of-system components, which include:

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

These prices include the PV array and the balance of system (BOS) components for each system, including the inverter and electrical equipment, as well as the installation cost. This includes estimated taxes and a national-average labor rate, but does not include land cost. The economics of grid-tied PV depend on incentives, the cost of electricity, the solar resource, and panel tilt and orientation. For the purposes of this analysis, the project is expected to have a 25 year life, although the systems can be reasonably expected to continue operation past this point.

The cost of a PV system depends on the system size and other factors such as geographic location, mounting structure, type of PV module, etc. For this analysis, the installed cost of fixed-tilt ground ballasted system was assumed to be $3/W and the installed cost of single-axis ballasted tracking was assumed to be $3.5/W system. These costs represent plausible scenarios for purchase price on landfills.

The installed system cost assumptions are summarized as follows:

Table 4 - Installed System Cost Assumptions

System Type	Fixed-Tilt ($/Wdc)	Single-Axis Tracking ($/Wdc)
Baseline system	2.40	2.8
With ballast (+25%)	0.60	0.70
Total installed cost	3.00	3.5

Table 6 provides a gross estimate for the proposed PV systems without the potential dollar offsets based on the available PV useable area, proposed on the system size, and the installation costs assumed for both the fixed-tilt system or a single-axis tracking system (indicated above).

Table 6 - Estimated PV System Size and Costs

Mounting System Type	Estimated Acres/MW	Estimated System Size	Estimated System Cost
Fixed Axis	5.74 acres	1.088 MW*	$3,264,000
Single Axis	6.96 acres	0.898 MW**	$3,143,000

- Assumes 6.25 acres of solar PV usable area for the Lloyd Landfill.
- *5.74 acres/MW for Fixed Axis based on historical data provided by NREL.
- **6.96 acres/MW for Single Axis based on historical data provided by NREL.
- Assumes $3/W for Fixed-Tilt and $3.5/W for Single-Axis Tracking for the estimated system costs.

Part 2:

Section III. New Paltz Landfill PV System/Siting Considerations

New Paltz is located in the southeastern section of Ulster County. Interstate-87 runs north and south just east of the landfill. NY Route 32 runs north and south just west of the landfill and Horsenden Road runs east-west just south of the landfill. The entrance to the New Paltz Landfill is located at the end of Clearwater Road. According to the 2010 census, the Town of New Paltz has a population of approximately 7,034. The following photos show various views of landfill.

Figure 2. Views of the feasible area for PV at the New Paltz Landfill
Photos Credits: EPA

View of the northern portion of the landfill.

View of the southern portion of the landfill.

View of the eastern portion of the landfill.

View of the western portion of the landfill. Transmission lines running along the west side of the landfill.

Useable Landfill Acreage:

The total feasible area for PV on the New Paltz landfill is approximately 8.5 acres. Figure 3 below shows the landfill image taken from Google Earth; the feasible area for PV is in shaded area determined by the topography of the land. In general, the available landfill area will impact the potential PV system size and the cost of PV systems. The economics of the PV system which will also vary according to the entities developing solar PV at the sites (municipally funded system or a power purchase agreement funded system).

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.

Figure 3 - Aerial view of the feasible for PV at the New Paltz Landfill

Taken with Google Earth Pro

Transmission/Utility Resources:

The electrical transmission lines run along the west portion (see photo above) and north portion of the landfill. The electrical power is being fed into the transfer stations, recycling store, and the pumps (leachate collection system) along the northern section of the landfill. In general, having an electrical substation and transmission lines close to the site makes it ideal for connecting into a PV system. However, a detailed interconnection study will have to be performed through the local electric utility, to determine the feasibility of utilizing tie-in point for a PV system.

IV. Solar Assessment:

The EPA solar assessment team used a Solmetric SunEye[5] 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, it can determine if the area is appropriate for solar panels.

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. 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. By finding the solar access, it can determine if the area is appropriate for solar power generation.

The assessment team collected multiple Solmetric SunEye data points at the center and along perimeter of the landfill and found the annual solar access average to be 98%. The SunEye annual solar access summary for each landfill is available in **Attachment #1**. The following key and site related information was collected to aid in this solar assessment for the New Paltz Landfill:

Table 1 – Landfill Information

Landfill/Site Name	New Paltz Landfill
Landfill Address/County	Located off Clearwater Rd. New Paltz, NY
Landfill Operator/Ownership	Ulster County Resource Recovery Agency
Point of Contact/Email	Timothy B. Rose, P.E. - Executive Director, UCRRA–tros@ucrra.org (845) 336-0600 Amanda LaValle, Coordinator, Ulster County Department of the Environment – alav@co.ulster.ny.us (845) 338-7455
Landfill Closure Date	February 2, 1998
Annual Post Closure Monitoring/Maintenance Report	June 14, 2013
Final Landfill Closure Plan	ftp://ftp.dec.state.ny.us/dshm/SWMF/Info/Ulster%20County%20Landfills%20-%20Closure%20Reports/
Landfill Physical Characteristics:	
Landfill Size	19 Acres
Useable Landfill Area for PV Solar	8.5 Acres
Landfill Contour Maps	See attached landfill closure report.
Landfill Cap Type	Geomembrane
Landfill Orientation	Gentle downward slope towards the North with significant slope toward East and West borders
Physical Condition	Landfill surface is grassy with a vegetation cover. Mowing is performed once per year.
Landfill southern slope/shading concerns	No shading concerns are relevant at the site.
Settlement/Floodplains/Wetlands Concerns	None
Existing Treatment Systems	Leachate collection system, venting
Utility Information:	
Utility Company Serving the Area	Central Hudson Gas and Electric **http://www.cenhud.com/dg/**Email - distributedgeneration@cenhud.com
Distance from Landfill to Transmission Lines	Transmission lines run through the Northern boundary of the site.
Distance from Landfill to Substations	Unknown.
Nearby major highways	East of US Route 32/West of NY Thruway I-87

[5] More information on this tool can be found at: http://www.solmetric.com/

Other:	
Any on-going remediation at the site? PRPs associated with the LF	Not applicable.
Any existing site liens/bankruptcy status?	Not applicable.
Additional Information	System Capacity for Fixed PV System – 1.48 MW based on 5.74 acres per MW System Capacity for Single Axis PV System – 1.22 MW based on 6.96 acres per MW

PV Watts 2 Site Identification:

The predicted array performance was found using PV Watts Version 2[6] for the New Paltz landfill. NREL's PVWatts™ calculator determines the energy production and cost savings of grid-connected photovoltaic (PV) energy systems throughout the world. It allows homeowners, installers, manufacturers, and researchers to easily develop estimates of the performance of hypothetical PV installations. The PVWatts calculator works by creating hour-by-hour performance simulations that provide estimated monthly and annual energy production in kilowatts and energy value. Users can select a location and choose to use default values or their own system parameters for size, electric cost, array type, tilt angle, and azimuth angle.

The PVWatts Grid Data Calculator, Version 2 is another NREL tool which was utilized to calculate estimates of kWh and MWh energy performance for the system based on the number of acres available. Table #2 below shows the station identification information, PV system specifications, and energy specifications for the site.

Table # 2 - PV Watts2 Site Identification Information and Specifications

Station Identification		
Cell ID:	**268368**	
State:	**New York**	
Latitude:	**41.6 ° N**	
Longitude:	**74.1 ° W**	
PV System Specifications		
	Fixed Axis	**Single Axis**
DC Rating:	**1480 kW**	**1220 kW**
DC to AC Derate Factor:	**0.8**	**0.8**
AC Rating:	**1184 kW**	**976 kW**
Array Type:	**Fixed Tilt**	**1-Axis Tracking**
Array Tilt:	**20 °**	**20 °**
Array Azimuth:	**180° South**	**180° South**
Energy Specifications		
Average (Regional) Cost of Electricity:	**14.8 ¢/kWh**	

Table # 3 - shows the performance results for a 20-degree, 1480 kW fixed-tilt PV system and 1220 kW single-tilt PV system in the New Paltz landfill as **calculated by PV Watts 2.**

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

Performance Results - Fixed Axis PV system				Performance Results – Single Axis PV system		
Month	**Solar Radiation ($kWh/m^2/day$)**	**AC Energy (kWh)**	**Energy Value ($)**	**Solar Radiation ($kWh/m^2/day$)**	**AC Energy (kWh)**	**Energy Value ($)**
1	2.62	99,106	14,685.53	3.15	101,356	15,018.93
2	3.47	118,483	17,556.81	4.24	121,655	18,026.84
3	4.66	170,911	25,325.59	5.83	178,880	26,506.44
4	5.06	175,171	25,956.84	6.22	179,835	26,647.95
5	5.85	200,846	29,761.36	7.19	205,583	30,463.29
6	6.1	198,837	29,463.67	7.4	201,399	29,843.30
7	5.94	198,038	29,345.27	7.24	200,744	29,746.25
8	5.54	184,091	27,278.60	6.81	189,114	28,022.91
9	4.86	159,226	23,594.11	6	164,331	24,350.57
10	3.89	136,941	20,291.92	4.82	142,441	21,106.91
11	2.61	90,932	13,474.30	3.15	92,408	13,693.02
12	2.33	85,363	12,649.09	2.75	85,744	12,705.55
Year	**4.42**	**1,817,944**	**269,382.94**	**5.41**	**1,863,490**	**276,131.95**

IV. Forecasted Economics and Performance:

Installed System Costs:
In addition to the solar modules and inverter, a solar PV system consists of other parts called balance-of-system components, which include:

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

These prices include the PV array and the base of system (BOS) components for each system, including the inverter and electrical equipment, as well as the installation cost. This includes estimated taxes and a national-average labor rate, but does not include land cost. The economics of grid-tied PV depend on incentives, the cost of electricity, the solar resource, and panel tilt and orientation. For the purposes of this analysis, the project is expected to have a 25 year life, although the systems can be reasonably expected to continue operation past this point.

The cost of a PV system depends on the system size and other factors such as geographic location, mounting structure, type of PV module, etc. For this analysis, the installed cost of fixed-tilt ground ballasted system was assumed to be $3/W and the installed cost of single-axis ballasted tracking was assumed to be $3.5/W system. These costs represent plausible scenarios for purchase price on landfills.

The installed system cost assumptions are summarized as follows:

Table 4 - Installed System Cost Assumptions

System Type	Fixed-Tilt ($/Wdc)	Single-Axis Tracking ($/Wdc)
Baseline system	2.40	2.8
With ballast (+25%)	0.60	0.70
Total installed cost	3.00	3.5

These prices include the PV array and the base operating system (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. Although the economics of grid-tied PV will depend on NYS financial incentives, available federal tax credit, the regional cost of electricity, the solar resource, and panel tilt and orientation, the following represents a gross estimated costs for the proposed PV systems without the potential dollar offsets:

Mounting System	Estimated Acres/MW	Estimated System Size	Estimated System Cost
Fixed Axis	5.74 acres	1.48 MW*	$4,440,000
Single Axis	6.96 acres	1.22 MW**	$4,270,000

- Based on the physical assessment of the landfill, approximately 8.5 acres of usable area for the New Paltz Landfill is recommended for a solar PV system.
- *5.74 acres/MW for Fixed Axis based on historical data provided by NREL.
- **6.96 acres/MW for Single Axis based on historical data provided by NREL.
- Assumes $3/W for Fixed-Tilt and $3.5/W for Single-Axis Tracking for the estimated system costs.

Part 3.

Section III. Town of Ulster Landfill PV System/Siting Considerations

The **Town of Ulster** is located in the eastern part of Ulster County. U.S. Route 9W runs north and south in the center of the town. Interstate-87 and NY 32 also run north-south in the western and eastern portion of the town, respectively. U.S. 209 also runs east-west across the center of the town. The entrance to the Town of Ulster Landfill is located on Frank Sottile Boulevard at the intersection of Miron Lane. According to the 2010 census, the Town of Ulster has a population of approximately 12,327. The following photos show various views of landfill.

Figure 2. Views of the feasible area for PV at the Town of Ulster Landfill
Photos Credits: EPA

Northern portion of the landfill looking northeast. Electrical transmission lines running along the northern portion of the site.

Southern portion looking northwest to the road.

Eastern portion of the landfill.

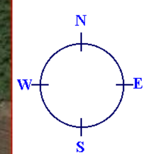
Western portion of the landfill.

Useable Landfill Acreage:

The total feasible area for PV on the Town of Ulster landfill is approximately 9.5 acres. Figure 3 below shows the landfill image taken from Google Earth; the feasible area for PV is in shaded area determined by the topography of the land. In general, the available landfill area will impact the potential PV system size and the cost of PV systems. The economics of the PV system which will also vary according to the entities developing solar PV at the sites (municipally funded system or a power purchase agreement funded system).

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.

Figure 3 - Aerial view of the feasible for PV at the Town of Ulster Landfill



Taken with Google Earth Pro

Transmission/Utility Resources:

The electrical transmission lines run along the northern portion (see photo above) of the landfill. In general, having an electrical substation and transmission lines close to the site makes it ideal for connecting into a PV system. However, a detailed interconnection study will have to be performed through the local electric utility, to determine the feasibility of utilizing tie-in point for a PV system.

IV. Solar Assessment:

The EPA solar assessment team used a Solmetric SunEye[7] 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, it can determine if the area is appropriate for solar panels.

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. 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. By finding the solar access, it can be determined if the area is appropriate for solar power generation.

The assessment team collected multiple Solmetric SunEye data points at the center and along perimeter of the landfill and found the annual solar access average to be 96%. The SunEye annual solar access summary for each landfill is available in **Attachment #1**. The following key and site related information was collected to aid in this solar assessment for the Town of Ulster Landfill:

Table 1 – Landfill Information

Landfill/Site Name	Town of Ulster Landfill
Landfill Address/County	Located off Frank Sottile Blvd, Ulster, NY
Landfill Operator/Ownership	Ulster County Resource Recovery Agency
Point of Contact/Email	Timothy B. Rose, P.E.. - Executive Director, UCRRA – tros@ucrra.org (845) 336-0600 Amanda LaValle, Coordinator, Ulster County Department of the Environment – alav@co.ulster.ny.us (845) 338-7455
Landfill Closure Date	1/23/1998
Annual Post Closure Monitoring/Maintenance Report	5/29/2013
Final Landfill Closure Plan	ftp://ftp.dec.state.ny.us/dshm/SWMF/Info/Ulster%20County%20Landfills%20-%20Closure%20Reports/
Landfill Physical Characteristics:	
Total Landfill Size	29 Acres
Useable Landfill Area for PV Solar	9.5 Acres
Landfill Contour Maps	See Annual Post Closure Monitoring/Maintenance Report link above.
Landfill Cap Type	Geomembrane
Landfill Orientation	Gentle downward slope toward the North
Physical Condition	Landfill surface is grassy with a vegetation cover. Mowing is performed once per year.
Landfill southern slope/shading concerns	None
Settlement/Floodplains/Wetlands Concerns	None
Existing Treatment Systems	Leachate collection, venting
Utility Information:	
Utility Company Serving the Area	Central Hudson Gas and Electric **http://www.cenhud.com/dg/** **Email - distributedgeneration@cenhud.com**
Distance from Landfill to Transmission Lines	Transmission lines run through the Northern boundary of the site.
Distance from Landfill to Substations	
Nearby major highways	West of NY Route 32/East of US Route 9W/South of US Route 199

[7] More information on this tool can be found at: http://www.solmetric.com/

Other:	
Community vision for reuse and development at the site? Is there municipality support?	
Any on-going remediation at the site? PRPs associated with the LF	Not applicable.
Any existing site liens/bankruptcy status?	Not applicable.
Additional Information	System Capacity for Fixed PV System – 1.48 MW based on 5.74 acres per MW System Capacity for Single Axis PV System – 1.22 MW based on 6.96 acres per MW

PV Watts 2 Site Identification:

The predicted array performance was found using PV Watts Version 2[8] for the Town of Ulster landfill. NREL's PVWatts^{TM} calculator determines the energy production and cost savings of grid-connected photovoltaic (PV) energy systems throughout the world. It allows homeowners, installers, manufacturers, and researchers to easily develop estimates of the performance of hypothetical PV installations. The PVWatts calculator works by creating hour-by-hour performance simulations that provide estimated monthly and annual energy production in kilowatts and energy value. Users can select a location and choose to use default values or their own system parameters for size, electric cost, array type, tilt angle, and azimuth angle.

The PVWatts Grid Data Calculator, Version 2 is another NREL tool which was utilized to calculate estimates of kWh and MWh energy performance for the system based on the number of acres available. Table #2 below shows the station identification information, PV system specifications, and energy specifications for the site.

Table # 2 - PV Watts2 Site Identification Information and Specifications

Station Identification		
Cell ID:	**268368**	
State:	**New York**	
Latitude:	**41.6 ° N**	
Longitude:	**74.1 ° W**	
PV System Specifications		
	Fixed Axis	**Single Axis**
DC Rating:	**1655 kW**	**1365 kW**
DC to AC Derate Factor:	**0.8**	**0.8**
AC Rating:	**1324 kW**	**1092 kW**
Array Type:	**Fixed Tilt**	**1-Axis Tracking**
Array Tilt:	**20 °**	**20 °**
Array Azimuth:	**180° South**	**180° South**
Energy Specifications		
Average (Regional) Cost of Electricity:	**14.8 ¢/kWh**	

8 http://www.nrel.gov/rredc/pvwatts/

Table # 3 - shows the performance results for a 20-degree, 1655 kW fixed-tilt PV system and 1365 kW single-tilt PV system in the Ulster County landfill as **calculated by PV Watts 2.**

Performance Results - Fixed Axis PV system					Performance Results – Single Axis PV system		
Month	**Solar Radiation ($kWh/m^2/day$)**	**AC Energy (kWh)**	**Energy Value ($)**		**Solar Radiation ($kWh/m^2/day$)**	**AC Energy (kWh)**	**Energy Value ($)**
1	2.62	110,825	16,422.05		3.15	113,403	16,804.06
2	3.47	132,492	19,632.66		4.24	136,114	20,169.37
3	4.66	191,120	28,320.16		5.83	200,141	29,656.89
4	5.06	195,884	29,026.09		6.22	201,208	29,815
5	5.85	224,595	33,280.49		7.19	230,017	34,083.92
6	6.1	222,348	32,947.53		7.4	225,336	33,390.29
7	5.94	221,454	32,815.05		7.24	224,603	33,281.67
8	5.54	205,859	30,504.19		6.81	211,590	31,353.41
9	4.86	178,053	26,383.89		6	183,862	27,244.67
10	3.89	153,133	22,691.25		4.82	159,370	23,615.45
11	2.61	101,684	15,067.53		3.15	103,392	15,320.63
12	2.33	95,456	14,144.67		2.75	95,935	14,215.65
Year	**4.42**	**2,032,904**	**301,235.71**		**5.41**	**2,084,971**	**308,951**

V. Forecasted Economics and Performance:

Installed System Costs:
In addition to the solar modules and inverter, a solar PV system consists of other parts called balance-of-system components, which include:

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

These prices include the PV array and the base of system (BOS) components for each system, including the inverter and electrical equipment, as well as the installation cost. This includes estimated taxes and a national-average labor rate, but does not include land cost. The economics of grid-tied PV depend on incentives, the cost of electricity, the solar resource, and panel tilt and orientation. For the purposes of this analysis, the project is expected to have a 25 year life, although the systems can be reasonably expected to continue operation past this point.

The cost of a PV system depends on the system size and other factors such as geographic location, mounting structure, type of PV module, etc. For this analysis, the installed cost of fixed-tilt ground ballasted system was assumed to be $3/W and the installed cost of single-axis ballasted tracking was assumed to be $3.5/W system. These costs represent plausible scenarios for purchase price on landfills.

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Mounting System	Estimated Acres/MW	Estimated System Size	Estimated System Cost
Fixed Axis	5.74 acres	1.655 MW*	$4,965,000
Single Axis	6.96 acres	1.365 MW**	$4,777,500

- Based on the physical assessment of the landfill, approximately 9.5 acres of usable area for the Ulster Landfill is recommended for a solar PV system
- *5.74 acres/MW for Fixed Axis based on historical data provided by NREL.
- **6.96 acres/MW for Single Axis based on historical data provided by NREL.
- Assumes $3/W for Fixed-Tilt and $3.5/W for Single-Axis Tracking for the estimated system costs.

VI. Incentives:

The economics of grid-tied PV will also depend on NYS financial incentives, available federal tax credit, the regional cost of electricity, the solar resource, and panel tilt and orientation. Table 5 provides possible financial incentives that can be considered by Ulster Officials to assist with financing the proposed solar PV systems.

Table 5 - Summary of Applicable Incentives

1. Federal and State Investment Tax Credit	System owners may qualify up to 30% federal and 25% NY State (up to $5,000) tax credits. Always consult with your qualified tax professional or accountant to determine your eligibility for tax credits.
2. NYSERDA New York Sun Competitive PV Program – Program Opportunity Notice (PON) 2956	For non-residential systems over 200 kW. The maximum incentive for an individual project is capped at $3 million. For more information, go to http://www.nyserda.ny.gov/Energy-Efficiency-and-Renewable-Programs/Renewables/Solar-Technologies/Solar-PV-Competitive-Program.aspx
3. Net Metering and Remote Net Metering	For more information regarding net metering and remote net metering, please refer to the following NYSERDA website: http://www.nyserda.ny.gov/Energy-Efficiency-and-Renewable-Programs/Renewables/Net-Metering-Interconnection.aspx
4. Other Incentives	For other applicable incentives, go to the following website: http://www.dsireusa.org/incentives/index.cfm?state=NY

VII. Re-Powering America's Land – Best Practices, Success Stories, Screening Tools, and Feasibility Studies for Renewable Energy on Contaminated Properties and Landfills:

Through the Re-Powering America's Lands Initiative, the U.S. EPA promotes the reuse of potentially contaminated properties, landfills, and mining sites for renewable energy generation. This initiative identifies the renewable energy potential of these sites and provides the useful resources for communities, developers, industry, state and local governments or anyone interested in reusing these sites for renewable energy development. The various Re-Powering resources are summarize below and can be found at **http://www.epa.gov/oswercpa**.

- **Mapping and Screening Tools -** Under the Mapping and Screening tools, EPA's Repowering America's Land team screened more than 11,000 potentially contaminated sites and MSW landfills covering nearly 15 million acres across the United States for suitability to site renewable energy generation facilities, including utility-scale solar. Maps depicting the locations of these EPA tracked sites and their potential for supporting renewable energy generation can be found at **www.epa.gov/oswercpa/mapping_tool.htm.** These maps enable users to view screening results for various renewable energy technologies at each site.

- **Technical Assistance and Support -** As part of the RE-Powering America's Land Initiative, the EPA and the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) are evaluating the feasibility of developing renewable energy production on Superfund, brownfields, and former landfills or mining sites. This project pairs EPA's expertise on contaminated sites with the renewable energy expertise of NREL. A list of feasibility studies for renewable energy production for various technology including solar and can be found at **www.epa.gov/oswercpa/rd_tech_assist.htm.**

- **Redevelopment Tools and Resources –** Under the Redevelopment Tools and Resources, EPA and NREL created the joint publication, "**Best Practices for Siting Solar PV on Municipal Solid Waste Landfills**" to provide assistance in addressing common technical challenges of siting PV on MSW landfills (such as impacts to landfill settlement differentials and the PV solar performance, impacts to other landfill systems, understanding landfill cap integrity/characteristics, and understanding landfill post closure requirements for solar PV design considerations) and find other useful information for solar developers, landfill owners, and federal, state, and local governments. Other documents for stakeholders to consider are "**RE-Powering Finance Fact Sheet, "Handbook on Siting Renewable Energy Projects while Addressing Environmental Issues", and "Revised Bona Fide Prospective Purchaser (BFPP) Provisions Enforcement Guidance for Tenants.**"

- **Fact Sheets and Success Stories -** The Re-Powering Team highlighted numerous successful stories and fact sheets of Renewable Energy projects implemented throughout the United States. The RE-Powering America Team also maintains a list of completed renewable energy installations on contaminated sites and landfills. To date, the RE-Powering Initiative has identified 110 renewable energy installations on 103 contaminated lands, landfills, and mine sites, with a cumulative installed capacity over 709 megawatts (MW) and consistent growth in total installations since the inception of the RE-Powering Initiative.

VIII. Conclusions and Recommendations

The Ulster County landfills discussed in this report were screened for viable usable areas and other ideal site conditions to determine the viability of solar PV generation. The Ulster County landfills appear to have favorable site conditions to support solar PV generation and economic viable reuse, especially for locations that have existing transmission capacity, accessible roads, industrial zoning and all other critical infrastructure in place for PV systems**.**

Using obtainable and accessible land that is unavailable for other purposes allows for reuse of land that would not otherwise contribute to productivity. **Based on the screening information collected and assessed for each landfill, EPA supports the potential of solar PV generation for all Ulster County landfills outlined in this report.**

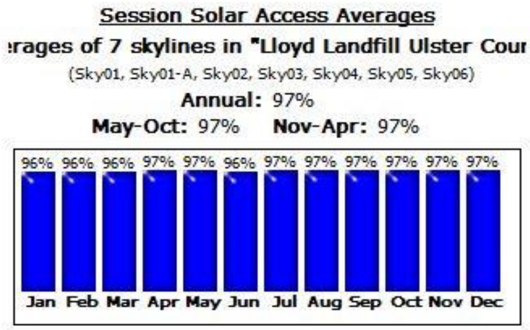
Although this screening study provides the PV system sizes based on proposed usable area, actual system installation will need to factor the availability of funds and the amount of power that can be sold. A third-party developer power purchase agreement (PPA) is another feasible way for a system to be financed for these sites. In exchange for access to a site through a lease arrangement, third-party developers can finance, develop, own, and operated the solar projects utilizing their own expertise and sources of tax equity financing debt capitol. Once the system is installed, the third-party developer can sell the electricity to the site host or local utility via a PPA – a contract to sell electricity at negotiated rate for a fixed period of time. The benefits to the site host will be either receiving competitively priced electricity from the project and/or revenues via a land lease payments from a solar developer. The term of the PPA typically varies from 20 - 25 years.

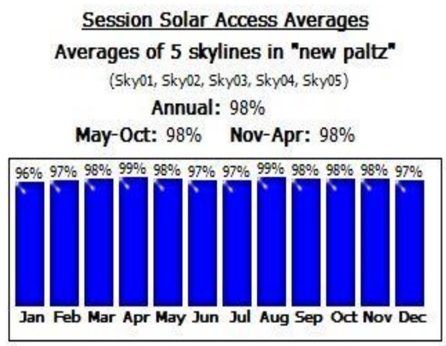
As a reminder, this report is to be used for screening purposes only.

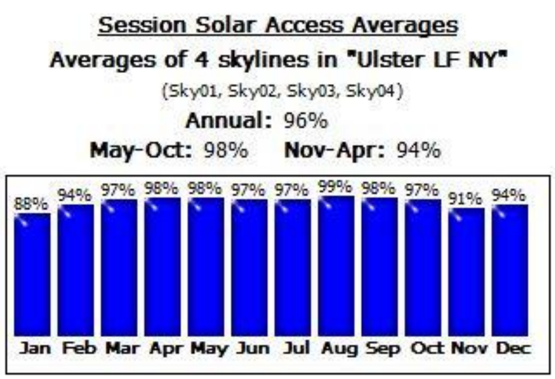
Additional evaluations will need to be conducted to fully characterize the feasibility and economics of the Ulster County landfills for PV installation. Third party solar developers and local utility companies may have technical and financial interests to pursue potential solar renewable energy projects and perform additional solar assessments to determine if projects are economically viable.

This study does not assess the environmental conditions at the site.

Attachment #1 - SunEye Solar Measurements







Attachment #2 - 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 stimulating electrons (negative charges) in a layer in the cell designed to give up electrons easily. The existing electric field in the solar cell pulls these electrons to another layer. By connecting the cell to an external load, this current (movement of charges) can then be used to power the load, e.g., light bulb.

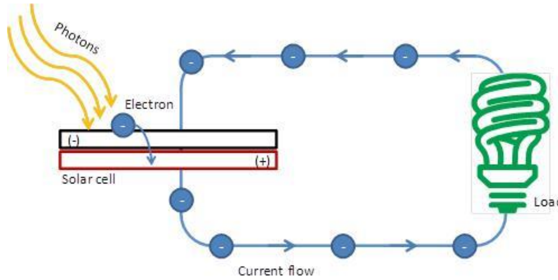


Figure 4. Generation of electricity from a PV cell

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 kilowatts (kW)), commercial (100-500 kW), to large utility scale (10+ megawatts (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.

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. 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.

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

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

Inverters:
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 weakness 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, as well as 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 typically run between 5 and 10 years with 10 years being the current industry standard. On larger units, extended warranties up to 20 years are possible. Given that the expected life of the PV panels is 25-30 years, an operator can expect to replace a string inverter at least one time during the life of the PV system.

Microinverters 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 microinverters range in size between 175 W and 380 W. These inverters can be the most expensive option per watt of capacity. Warranties range from 10 to 20 years. Small projects with irregular modules and shading issues typically benefit from microinverters.

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 - Source: NREL PIX 07985 - **String inverter**

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.

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 (i) the arrays to inverters and (ii) inverters to point of interconnection is generally run as direct burial through trenches. In landfill site applications, this wiring may be required to run through above-ground conduits 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.

Attachment #3 - Glossary or Definition of Terms

Glossary or Definition of Terms	
PV	Photovoltaic Energy
AC	Alternating Current – which can be transmitted over power lines
DC	Direct Current - which cannot be transmitted over power lines
Ballast	A footing on which a Solar Panel can be placed which will not penetrate the landfill cap
Inverter	A machine which takes in Direct Current and converts it to Alternating Current which can then be transmitted to an electrical substation for transmission to a utility company
Energy Density	The number of solar arrays which can be placed in a specific area and is the packing factor – Fixed Axis Panels take up less space, Single Axis Panels take up more space.
kW or kWh	Kilowatt or Kilowatt Hours
MW or MWh	Mega Watt or Mega Watt Hours
ITC	Investment tax credits
LCOE	Levelized Cost of Energy
O&M	Operations and Maintenance
Payback Period	Number of years until the project is paid for
PPA	Power Purchase Agreement - legal contract between an electricity provider and a purchaser that defines all commercial terms for the sale of electricity