FIELD TEST DELTA

Demonstration and Evaluation of Lighting Technologies and Applications

POST-TOP PHOTOVOLTAIC PATHWAY LUMINAIRE

Field Test Issue 4

POST-TOP PHOTOVOLTAIC PATHWAY LUMINAIRE

Lighting Research Center

Project Profile

DELTA field-tested 24 post-top photovoltaic-powered (PV) luminaires with LEDs (light-emitting diodes). The luminaires were installed at three public, outdoor sites in the Catskill Mountains region of upstate New York.

Field Test Objectives

DELTA tested the photovoltaic post-top luminaire in the field to:

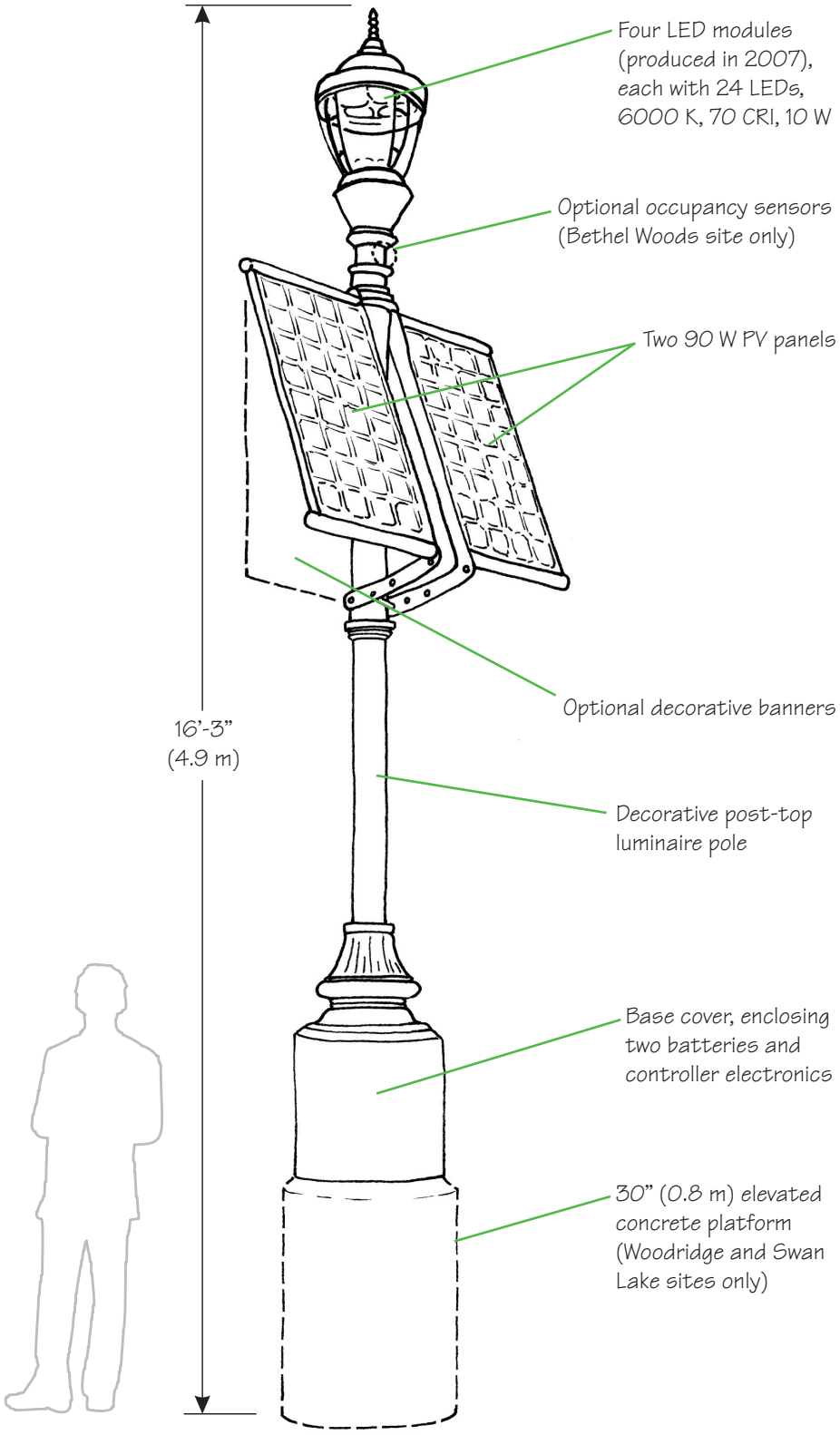
- Verify system performance
- Evaluate people's acceptance of the system
- Quantify photometric performance
- Quantify energy savings

Luminaire Features

In 2007, Philips Hadco Lighting and SolarOne® Solutions collaborated in the design and production of the Renaissance luminaire. This post-top luminaire has a decorative, traditional appearance but operates LED modules powered by photovoltaic (PV) panels (see right).

In this prototype product, four white LED modules (40 W total) are mounted in the post-top luminaire and are oriented to face downward. Photometric software characterizes the luminaire's IESNA classification as a Type III, very short, "cutoff" distribution.

The system is powered by two deep-cell batteries which are charged by two 5.9 sq. ft. (0.5 m²) photovoltaic panels, each with a peak power rating of 90 W. Panels are mounted at 20° from vertical and face south. Battery charging (daytime) and discharging (night) are controlled by a system controller located in the base of the pole. In this prototype, a second controller determines LED output and duration; the system is typically programmed to operate for six hours after sunset at full output, then reduce output to approximately 30% for the remainder of the night. Luminaires are programmed wirelessly using a remote control device. The luminaire confirms settings using a series of flashes.



Renaissance luminaire detail

The controller shuts off the lights when the battery voltage dips below a programmed level (either 11.5 V or 10.5 V). Dimming of the LEDs is achieved using pulse width modulation (PWM), a rapid modulation of light output that creates the perception of a dimmed output. PWM is commonly used as an LED dimming strategy because it allows for continuous dimming down to low light levels.

Field Test Sites

In 2007-2008, twenty-four prototype Renaissance units were installed at three sites in the Catskill Mountains: Swan Lake Park, Bethel Woods Center for the Arts, and the Village of Woodridge. Swan Lake, N.Y., used six Renaissance luminaires to illuminate a new wooden boardwalk next to a small lake (see cover photo). The Bethel Woods site (Bethel, N.Y.) used six Renaissance luminaires to illuminate the parking area and monument commemorating the site of the 1969 Woodstock concert festival (right photo, below); two luminaires adjacent to the parking lot were equipped with occupancy sensors to dim the lights to a low level when unoccupied. The Village of Woodridge, N.Y., replaced eight conventionally powered, 150 W high-pressure sodium (HPS) post-top luminaires with 12 Renaissance luminaires along the main street through the village (left photo, below).

DELTA visited the three sites to perform photometric measurements, to survey residents and visitors, and to install and retrieve monitoring equipment. The results of the field test are summarized in this publication.[1,2]

Results of Field Test

Occupant feedback

In the summer of 2008, DELTA met and surveyed visitors to the Bethel Woods site and residents of Swan Lake and Woodridge. The survey asked questions about visual comfort, lighting quality, and perception of safety. Additionally,

"The lights are a plus to the village and look beautiful; maybe a little more bright." –Woodridge Resident

"Wonderfully laid-out park: lighting is adequate and has a soft hue." –Swan Lake Resident

"Light is very soothing to the eye." –Bethel Woods visitor

"Could be a little more bright." –Bethel Woods visitor

"The lack of glare is particularly pleasing compared to most fixtures. The subtleness is much more fitting for such a rural area." –Bethel Woods visitor

"The solar lights are not only functional but beautiful… I filled out this survey and wrote my comments by the light of the solar lamp! Perfect!" –Bethel Woods visitor

Woodridge residents were surveyed about the existing HPS lighting before the installation of the new PV LED luminaires.

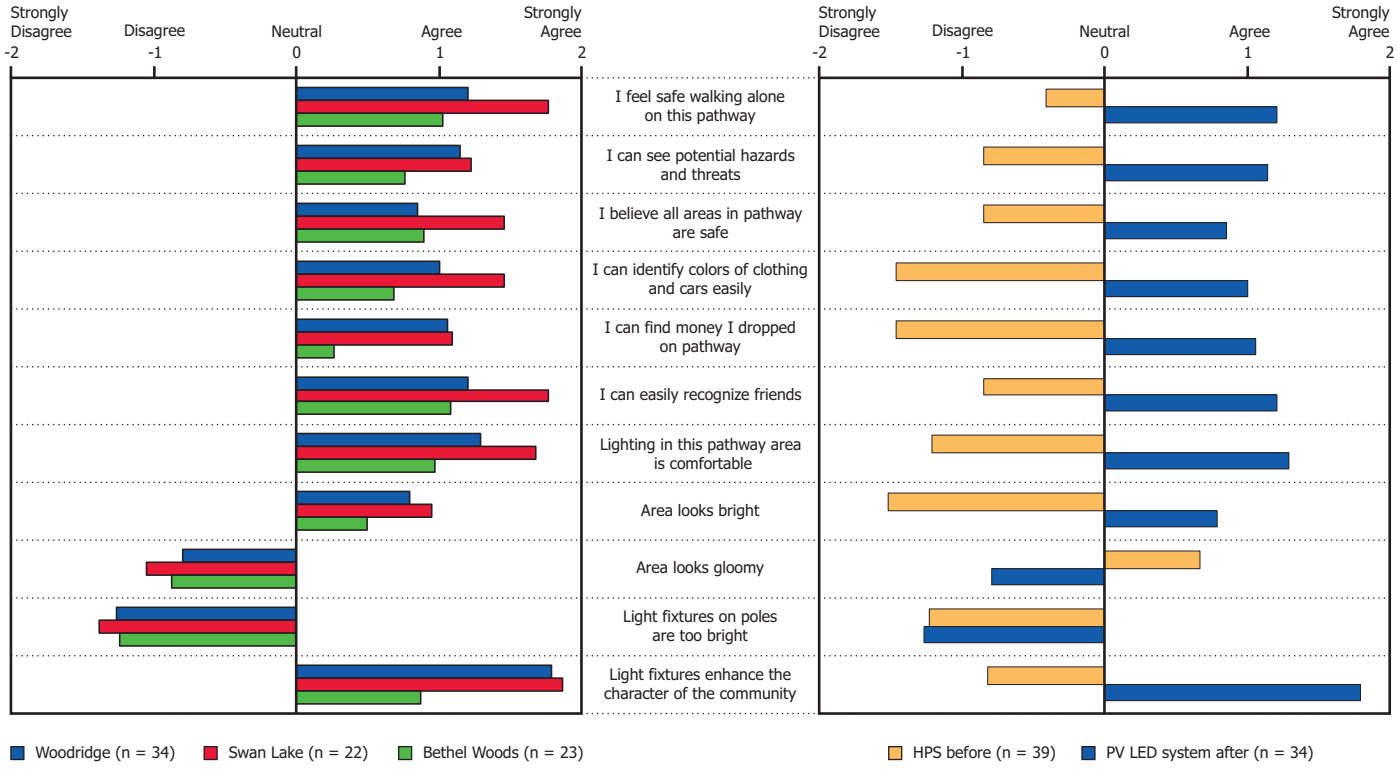
Survey results from the three sites (figure on next page) show that feedback from residents and visitors was clearly positive at all three installations, both in terms of illumination and appearance of the luminaires. Impressions from the Bethel Woods site were slightly less positive than the two other sites.

While most people found the illumination comfortable at these rural sites, a few found it too dim. Illumination from the Renaissance luminaires was greatly preferred to the previous HPS lanterns at the Woodridge site (figure on next page).

Village of Woodridge installation (left) and Bethel Woods installation, site of the 1969 Woodstock concert festival (right)

1 Extensive details are listed in the project report, available upon request from the Lighting Research Center.

2 Frering, D., J. Brons, and C. Emery. 2009. Demonstration and evaluation of sustainable, photovoltaic powered LED street lighting. *Solar 2009: Proceedings of the 38thAnnual Conference, 34th National Passive Solar Conference, and 4th Policy and Marketing Conference,* Buffalo/Niagara, N.Y., May 11-16, 2009, American Solar Energy Society.



Survey results at all three sites

Before and after survey comparison at the Woodridge site

Photometric Results

Field measurements showed that the luminaires provided a low-level illuminance at the three sites that in most areas was consistent with IESNA recommendations for pedestrian walkways.[3] The table below summarizes the measurements.

Measured Horizontal Illuminances along Pathway
(excluding foliage shadows)

	Before		After	
	Range (min-max)	Average	Range (min-max)	Average
Woodridge	0.6 - 17.3 lx	4.2 lx	0.8 - 14.8 lx	5.7 lx
Swan Lake	NA	NA	3.2 - 19.7 lx	11.3 lx
Bethel Woods	NA	NA	0.5 - 10.0 lx	3.2 lx

1 footcandle (fc) = 10.76 lux (lx)

At the Woodridge site, measured illuminances were similar before and after retrofit of the Renaissance luminaires. However, occupant feedback was clearly more positive after the retrofit. This may be because of the spectral characteristics of LED light sources compared with the previous HPS system. Because of greater human sensitivity to light with a "white" appearance than a "yellowish" appearance at low light levels, it is possible to predict improved visibility using "unified luminance" calculations.[4] DELTA used the photometric information above to calculate unified luminance at the Woodridge site before and after installation of the Renaissance luminaires. In the parking area, for instance, average photopic illuminance was slightly (1.4 times) higher with the LED system, but unified luminance was estimated to be 2.9 times higher.[5] This is consistent with the occupants' higher visibility ratings of the LED system compared with the previous HPS system.

Other photometric conditions were notable. Because the Renaissance PV panels are located beneath the light source, they cast shadows on the ground; however, there were no complaints about shadows from the panels. Trees and shrubs also caused some obstruction of electric light; comments were made about foliage shadows on occupant surveys.

Installation/Maintenance

DELTA interviewed the site personnel in charge of installation and/or maintenance of the Renaissance luminaires. These personnel characterized the installation of the Renaissance luminaires as easy; installers did, however, suggest improved, locking wire connectors. They commented that neither clean-

3 IESNA. 1999. Lighting for Exterior Environments, RP-33-99. Publication recommends an average 5 lx horizontal and 10:1 uniformity ratio for pedestrian walkways distant from roadways.

4 Rea, M.S., J.D. Bullough, J.P. Freyssinier-Nova, and A. Bierman. 2004. A proposed unified system of photometry. *Lighting Research and Technology*. 36(2): 85-111.

5 Extensive details are listed in the project report, available upon request from the LRC.

ing nor snow-shoveling of PV panels was necessary in the winter.

One luminaire at Swan Lake experienced water ingress that damaged its electronic controllers; the controller housing has subsequently been redesigned. There also were reports of three failed PV mounting brackets; improved brackets have been installed for all 24 luminaires.

Operation

The Renaissance luminaires are designed to turn on at dusk and operate per programmed settings until morning. To verify actual operation patterns, DELTA installed monitoring equipment in the summer of 2008, as well as during the fall and winter of 2008-2009.[6] The monitoring data showed that on-times were similar for the luminaires within a site; when the weather was dark, the units turned on earlier as a group. Units dimmed down (as intended) to a lower light output after a scheduled period of time. Off-times varied; the data indicate that some units occasionally remained on unnecessarily after sunrise.

The data show that during the first summer of operation, four out of the 24 Renaissance luminaires occasionally turned off before morning. This occurred at all three sites and may have been caused by the protective low voltage disconnect feature, which is necessary when battery voltage drops below the programmed criteria.

While most of the winter saw normal operation, in 13 out of 14 luminaires that DELTA monitored, there was at least one instance in which the luminaires turned off prematurely, or did not turn on at all. This occurred for about a week in both November and December. This infrequent but widespread pattern of inactivity is evidence of insufficient battery voltage, which would trigger the low voltage disconnect protective feature. Insufficient battery voltage may have been caused by reduced solar collection, reduced battery capacity due to cold temperatures, and/or excessive discharge (when luminaires stayed on after sunrise). Specifiers of PV-powered systems should consider whether reliable illumination is expected and necessary. In many locations where Renaissance may be used, reliable illumination may not be critically important (and would have a cost implication).

Monitoring data confirmed that occupancy sensors dimmed lights repeatedly at the Bethel Woods parking lot; however, it is unclear whether they were responsive to actual human occupancy. DELTA researchers observed that the luminaires dimmed down while the space was occupied and did not seem to respond to body movement. The data indicate that the sensors increased the light output back to full output repeatedly throughout the night, even in the snowy winter months when the site was unlikely to be visited. The occupancy sensor therefore may not have been working as intended.

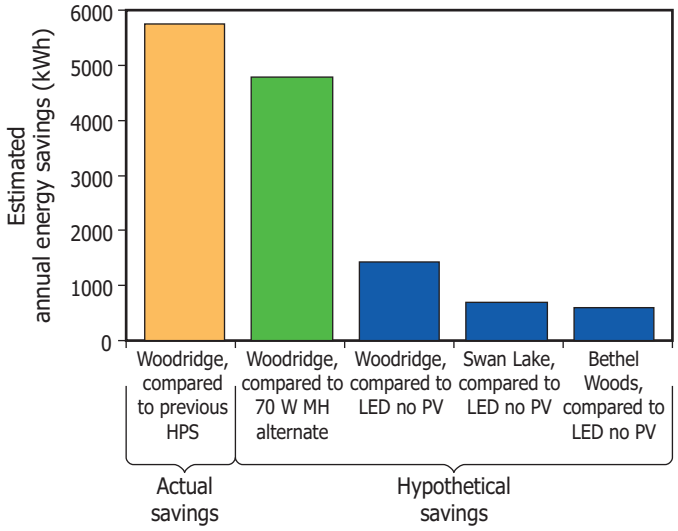
6 Extensive details are listed in the project report, available upon request from the LRC.

DELTA observed one instance in which a new floodlight prevented one Renaissance unit from turning on; when the floodlight was disconnected, the PV unit turned back on as expected.

Calculations: Energy, Life-cycle Costs, Air Pollution, Light Pollution

Energy Calculations

The Renaissance luminaires save energy by avoiding conventional utility power. For Woodridge,[7] it is possible to calculate energy savings compared with the actual previous lighting system, as well as two hypothetical conditions: an alternate metal halide (MH) solution designed by Hadco Lighting, and the LED Renaissance luminaire without solar power. The figure below extends this energy savings comparison to Swan Lake[8] and Bethel Woods.[9]



Calculated (actual) and estimated (hypothetical) energy savings of the PV LED Renaissance luminaire over several lighting and power scenarios at the three sites.

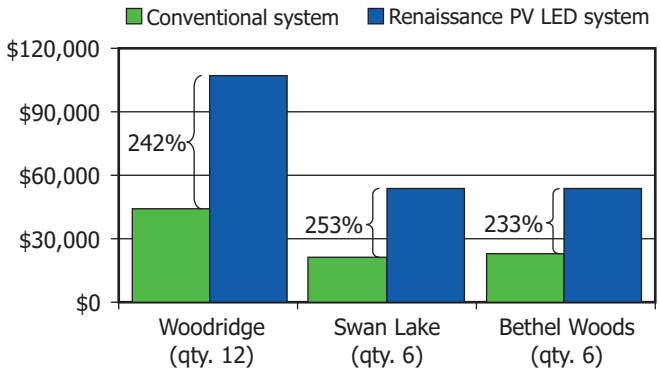
7 Woodridge—*HPS comparison, 8 heads*: Per electric utility assumptions, calculated 171 W for 11.5 hours per night; illuminances of old/depreciated system similar to new LED system. *MH comparison, per Hadco's 70 W metal halide alternate solution, 12 heads*: Assumes 95 W per MH head, including ballast losses, operated for 11.5 hours per night, as per local utility assumptions. (Note that this solution would produce higher illuminances than the other Woodridge solutions.) *LED, no PV*: Assumes 12 luminaires operated for 6 hours at full output (40 W) for 365 nights per year; assumes another 6 hours per night at a dimmed state of 30% of full output, approximately 14 W.

8 Swan Lake—*LED, no PV*: Assumes five luminaires programmed for 6 hours per night full output (40 W), and one luminaire at 4 hours per night full output. All six assumed to operate for total of 12 hours per night, on average, for 365 days/year; operation time may be longer than 12 hours since off-times are unclear. Remainder of night assumed to operate at a dimmed state of 30% of full output, approximately 14 W.

9 Bethel Woods—*LED, no PV*: Assumes six luminaires programmed for 4 hours per night full output (40 W), not including savings from occupancy sensors, since off-time data is unclear. All six assumed to operate for a total of 12 hours per night on average. Dimmed state assumed to be 14 W.

Life-cycle Cost Estimates

DELTA estimated cost of ownership of the PV-powered LED Renaissance luminaires, compared with conventionally powered luminaires in the same decorative family operating 70 W metal halide lamps.[10] DELTA estimates that the PV-powered LED luminaires at these sites are two times more expensive to own and operate over the ten-year period analyzed than the conventional system. This is due mainly to the significantly higher initial cost of the PV-powered Rennaissance luminaires. This cost difference would have been less if the systems had been located further from the electric grid, making it more expensive to bring power to each location. For example, DELTA estimates that if utility power were located 0.75 miles (1.2 km) from either the Swan Lake or Bethel Woods locations, the life-cycle costs of the PV-powered system would have been comparable with the grid-connected alternatives.



Ten-year life-cycle cost estimates

Air Pollution Calculations

The energy calculations on page 5 can be translated to pollution avoided. As shown in the table below, DELTA consulted NYSERDA's rates for New York State to translate from annual kilowatt hours saved to pollution averted.[11]

Light Pollution Calculations

Light pollution calculations were favorable for the installation of the Renaissance PV luminaire. DELTA performed outdoor site-lighting performance (OSP) light pollution calculations[12] to compare the Woodridge PV LED installation to a conventional MH luminaire in the Renaissance family. Because the PV LED installation contributed less light to the site, it had less light leaving the site, so it produced less light that may contribute to sky glow and light trespass.

Annual reduced power plant pollution from use of PV-powered LED Renaissance luminaires compared with other lighting and power scenarios

		SO_2		NO_x		CO_2	
Site	**Comparison**	lbs	kg	lbs	kg	lbs	kg
Woodridge	HPS previous system	17.2	7.8	8.6	3.9	6,270	2,850
	MH	14.4	6.5	7.2	3.3	5,225	2,375
	LED no PV	4.3	1.9	2.1	1.0	1,550	704
Swan Lake	LED no PV	2.1	0.9	1.0	0.5	754	343
Bethel Woods	LED no PV	1.8	0.8	0.9	0.4	650	296

Sulfur dioxide (SO_2) is associated with visible pollution (haze) and acid rain. SO_2 is also a direct lung irritant. Nitrogen oxides (NO_x) are a primary cause of ozone production (a main component in smog) and acid rain. Carbon dioxide (CO_2) is a possible contributor to future climate changes, such as global warming.

10 Extensive details are listed in the project report, available upon request from the LRC.

11 As provided by NYSERDA Energy Analysis group.

12 Brons, J.A., J.D. Bullough, and M.S. Rea. 2008. Outdoor site-lighting performance: A comprehensive and quantitative framework for assessing light pollution. *Lighting Research and Technology* 40(3): 201–224.

Lessons Learned

Survey Results

- The Renaissance PV LED luminaires were well-liked by residents, visitors, and maintenance staff at all three sites.
- While most of the people surveyed found the illumination comfortable at these rural sites, a few found it too dim.
- Illumination from the Renaissance luminaires were clearly preferred to the previous HPS lanterns at the Woodridge site.

Photometric Results

- Measurements at the three sites were generally consistent with the illuminances recommended for pedestrian walkways.
- Because the PV panels are located beneath the light source, they cast shadows on the ground. Trees and shrubs also caused some obstruction of electric light.

Installation/Maintenance

- Installation was characterized as easy; installers suggested different wiring connectors.
- No cleaning or snow-shoveling of panels was necessary in the winter.
- Water ingress damaged the electronic controllers in one luminaire; controller housings have subsequently been redesigned.
- PV mounting brackets have been improved and replaced.

Operation

- On-time and dimming operation functioned as expected.
- Off-times varied; some units appeared to remain on unnecessarily after sunrise.
- As with any PV-powered lighting system, specifiers should consider whether reliable illumination is critical year-round:
  - Early shut-offs occurred rarely in the summer, but were more frequent in the winter.
  - Insufficient battery voltage may have triggered the protective low voltage disconnect feature.
- Although occupancy sensors were active at the Bethel Woods parking lot, this optional feature may not be working as intended.

Energy, Life-cycle Cost Calculations

- The Renaissance PV LED luminaires save energy by not requiring utility power. They would also save energy (nearly 6000 kWh) when compared with the previous conventionally powered lighting system at Woodridge.
- Life-cycle costs were estimated to be over two times greater than a conventional 70 W metal halide lighting solution. If the sites were located far from conventional power sources, life-cycle costs would have been lower.

Current Product Status

With refinements brought about from this demonstration, the Renaissance PV LED luminaire is now commercially available.

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Field Test DELTA evaluates new energy-efficient lighting products to independently verify field performance claims and to suggest improvements. A primary goal of the Field Test DELTA program is to facilitate rapid market acceptance of innovative energy-efficient technologies.

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