Customer Advanced Technologies Program

Solar Powered Lighting Systems

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Customer Advanced Technologies Program

SMUD's Customer Advanced Technologies (C.A.T.) program works with customers to evaluate new or underutilized technologies. The program provides funding for customers in exchange for monitoring rights. Completed demonstration projects include lighting technologies, light emitting diodes (LEDs), residential building shell construction, geothermal heat pumps, indirect / direct evaporative cooling, non-chemical water treatment, solar powered lighting systems and a wide variety of other technologies.

For more program information, please visit: http://www.smud.org/community/cat/

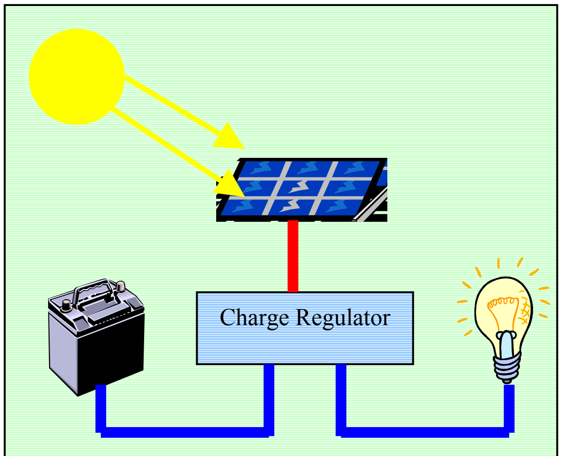
Introduction

For centuries, mankind has been looking for new ways to harness the power of the sun. Today, we successfully use the sun's energy to provide space heating, lighting, hot water and electric power. But how do you use the sun's energy to provide power for systems that operate only in the middle of the night?

This evaluation report focuses on photovoltaic (PV) powered exterior lighting systems and attempts to address the following questions: How do these systems work? Are they economical? What are some of the challenges associated with using this technology?

Technology Description: How Do They Work?

The basic concept is simple: during the day, the photovoltaic panels (a.k.a. solar panels) convert the sun's light into electrical energy that is used to charge long-life, rechargeable batteries. At night the batteries supply power to the lights. In the morning, the solar panels recharge the batteries and thus the cycle repeats itself. The end result: the energy of the sun is harnessed to supply power at night.



Basic PV lighting system.

In reality, these types of systems are somewhat complex. They require solar panels, large-capacity rechargeable batteries, sophisticated charge regulators, inverter ballasts, heavy-duty poles and careful design. Let's take a closer look at some of the system components

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Solar Panels

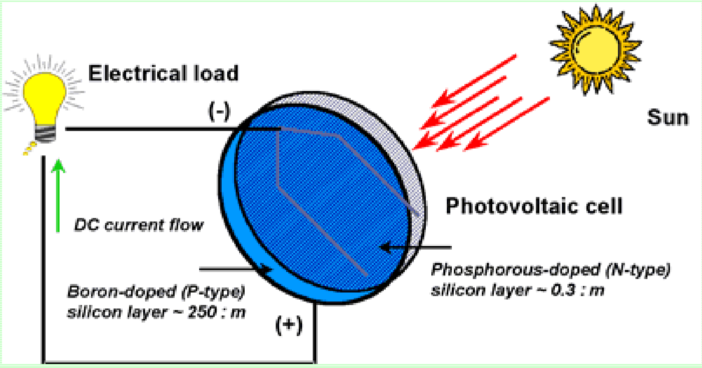
The basic component of the solar panel is the *photovoltaic* or *solar cell*. These cells are semiconductor devices that convert sunlight into electricity in the form of direct current (DC). Groups of PV cells are electrically integrated to form solar *modules*. These modules are combined into assembled, pre-wired photovoltaic *panels* that are suitable for field installation. Finally, groups of panels and modules can be combined to form *solar arrays* that can be configured to provide power for a wide variety of DC applications including motors, light emitting diodes (LEDs) and battery chargers. Solar arrays can also be used for conventional appliances but require power conversion equipment to convert the DC into alternating current (AC). For an in-depth explanation of PV technology, please visit: http://fsec.ucf.edu/pvt/pvbasics/index.htm

The power output of a PV cell depends on the materials used, the amount of surface area and the efficiency of the cell. However, the most important factor is the intensity of the sunlight striking the surface of the cell. The output of a solar cell is directly proportional to the intensity of the sunlight. Stated simply: more sunlight produces more power. Consequently, it is very important to ensure that the solar panels are mounted at the optimal angle and orientation. For locations in the northern hemisphere, the preferred orientation is +/- °20 of due south. For most locations, the tilt angle should be about 45 degrees. This tilt angle is different from conventional solar systems because the system must able to provide power for the lighting during the winter. Customers should check with solar manufacturers or their local utility for additional guidance.

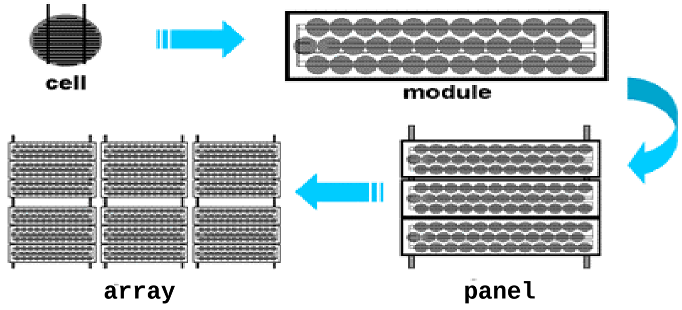
How PV Cells Work

A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon. An electrical field is created near the top surface of the cell where these two materials are in contact, called the P-N junction. When sunlight strikes the surface of a PV cell, this electrical field provides momentum and direction to light-stimulated electrons, resulting in a flow of current when the solar cell is connected to an electrical load

Diagram of photovoltaic cell



Photovoltaic cells, modules, panels and arrays



Source: Florida Solar Energy Center
http://www.fsec.ucf.edu/pvt/pvbasics/index.htm

Higher quality photovoltaic modules have a projected service lifetime of 20 to 30 years. In fact, most of the major manufacturers now warranty the power output of their products for twenty years or more.

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Charge Regulators

The charge regulators are the "brains" of the system. These controllers, which are often proprietary, regulate the flow of electricity from the panels to the batteries and from the batteries to the lights. They also protect the batteries from damage caused by overcharging and over discharging. Since several different types of chargers exist, it is important to match the charger to the type of batteries being used.

Batteries

The electricity generated from the PV panels during the day is stored in rechargeable, high-capacity batteries until it is needed. Presently, there are two main types of batteries commonly used for PV system applications:

1) Open (or flooded) lead-acid batteries

2) Sealed (maintenance free) lead-acid batteries

As the name implies, both of these battery types contain lead plates submerged in a sulfuric-acid electrolytic solution. Lead-acid batteries are commonly used for solar applications because they are relatively inexpensive, widely available, and can be easily recharged (please refer to the insert "Operation of Lead-Acid Batteries" to learn more about how these batteries work).

Operation of Lead-Acid Batteries

Lead -acid batteries convert electrical energy into chemical energy and vice-versa. These batteries usually have six cells that contain positive and negative plates that are submerged in a strong sulfuric acid electrolyte. The positive plates consist of a lead grate that is covered in a paste of lead-oxide. The negative plates are covered in a lead paste. Since each of the cells has a potential of 2 volts D.C., the total six-cell battery has a potential of 12 volts D.C.

When a lead/acid battery is connected to an electrical load, the lead-oxide of the positive plates and the lead of the negative plate react with the sulfuric acid to form lead-sulfate and produce electrical current. The battery will continue to provide electricity until the chemical reaction reaches equilibrium

One of the key benefits of the lead acid battery is the ability to recharge it. By connecting the battery to the proper current, the lead and lead dioxide reform on the plates. However, repeated deep discharges may eventually result in the formation of crystals that cannot be reverted during recharging. This causes the capacity of the battery to diminish.

Characteristics of Open (or flooded) Batteries

This type of battery uses water to dilute the sulfuric acid solution and has the following characteristics:

- ☐ Usually less expensive to purchase than sealed or maintenance free batteries
- ☐ Must remain in an upright position to avoid possible leakage
- ☐ During recharging, some of the water is converted into hydrogen and oxygen and must be replenished on a regular basis, to prevent the plates from becoming dry
- ☐ Deep discharge (below 50% of capacity) can eventually result in the formation of crystals. Generally speaking, these crystals cannot be reverted during recharging, so the capacity of the battery will be diminished.

IMPORTANT SAFETY NOTE: Lead-acid batteries produce explosive gases. Care must be taken to ensure that areas used for recharging and storing lead-acid batteries are well ventilated.

Sealed or Maintenance Free Batteries

Gel cells and Absorbed Glass Mat (AGM) batteries use thickening agents and glass mats to immobilize the electrolyte. Although they are initially more expensive then flooded cell batteries, they offer several advantages:

- ☐ Maintenance free; since these types of batteries are sealed and operate under pressure, the oxygen and hydrogen produced during the charge process are recombined back into the electrolytic solution.

- ☐ Higher discharge rates allows the use of fewer batteries to power the same load

- ☐ Can be mounted sideways

Life Expectancy

The reduction in performance of a battery over time is unavoidable. Generally speaking, the useful life expectancy of lead-acid batteries used for solar applications is five to seven years. However, the actual life expectancy strongly depends on the number of discharges, depth of discharge, manner of recharging, and proper maintenance. Totally discharging a battery will dramatically shorten its life.

Note: lead-acid batteries are classified as chemical waste and must be disposed of by taking them to an approved waste depot or collection point. The batteries are recycled and the materials are used in new batteries.

Lighting Fixtures and Lamps

Solar lighting manufacturers offer a wide variety of lighting fixtures including area lights, floodlights, streetlights (aka cobra heads) 'shoe box' lights and decorative fixtures. However, lamp choices are primarily limited to low wattage (<42 watts) compact fluorescent and low-pressure sodium lamps. The main reason for this limitation is the size and cost of PV panels (and batteries). Consider the following example:

Given: Four 42-watt compact fluorescent fixtures to be operated 12 hours / day in Sacramento, CA (roughly the lighting equivalent of using one conventional 200-watt metal halide system) System will be mounted on one pole and will be used to provide year-round lighting for a parking lot.

Find: Required number of solar panels and batteries to provide adequate power

Formulas: Because this system will be operated on a year-round basis, the solar power assembly (PV panels and batteries) must be adequately sized to provide sufficient power to operate the lights under the worst conditions (winter). Some manufacturers suggest selecting an assembly with enough capacity to withstand five consecutive days of operation with little or no sunlight.

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Since the capacity of batteries is rated in amp-hours, solar lighting power assemblies are also rated in a similar fashion. Therefore, we must determine the amount of amp-hours required to power the lighting system for five days without recharging. To do this, we will use the following formulas:

Fixture Amps = [(fixture watts / volts) x ballast factor)]

Daily Capacity required = (# of fixtures) x (amps / fixture) x (hours / day)

Total System Capacity = (Daily Capacity) x (5 days)

Solution: Fixture Amps = (42 watts / 12 volts) x 0.81 ballast factor)] = **2.84 amps / fixture**

Daily Capacity = (4 fixtures) x (2.84 amps / fixture) x (12 hours / day) = **136.3 amp-hours / day**

Total System Capacity = (136 amp-hours / day) x (5 days) = **681.6 amp-hours**

Next, we will use manufacturer's data[1] (below) to select a power assembly. Keep in mind that these ratings include the unavoidable losses associated with using batteries and converting power from DC to AC.

Power Assembly Sizes(in watts)	Number of Solar Panels and Watts	Charge Current Produced in Full Sun	# of Batteries & Total Amp Hours Stored	Daily Amp Hours Produced in the Winter-5 Hrs.*
SELS10	1-10 Watt	.61 Amps	1@36 A. Hrs.	3.05 Amp Hours
SELS18	1-18 Watt	1.1 Amps	1@36 A. Hrs	5.5 Amp Hours
SELS36	1-36 Watt	2.2 Amps	1@82 A. Hrs.	11 Amp Hours
SELS50	1-50 Watt	3.15 Amps	1@82 A. Hrs.	15.8 Amp Hours
SELS75	1-75 Watt	4.4 Amps	1@82 A. Hrs.	22 Amp Hours
SELS100	2-50 Watt	6.3 Amps	1@112 A. Hrs.	31.5 Amp Hours
SELS150	3-50 Watt	9.45 Amps	2@164 A. Hrs.	47.2 Amp Hours
SELS200	4-50 Watt	12.6 Amps	2@224 A. Hrs.	63 Amp Hours
SELS250	5-50 Watt	15.75 Amps	2@223 A. Hrs	78.8 Amp Hours

***Note: The amount of Power Shown uses 5 Hours of Full Power Sun as a Worst cast Scenario. Consult your local Solar Insolation/Sun Tables or the SEPCO™ factory if your are unsure of how many sun hours there are in your location. The 5 hours that is used is a value consistent with a moderately sunny location. Also Note: If your fixture consumption is slightly over one of the Power Assemblies, and a timer is used, the operating time could be reduced slightly to lower the amount of fixture**

As you can see, our example would require three SELS200 assemblies (twelve 50-watt solar panels and six batteries) to withstand five days without recharging. Since each solar panel measures 13" x 48," twelve panels would require 52 square feet! Needless to say, mounting twelve panels on a single pole would be far too impractical (and expensive) to be a viable option for this application.

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[1] Source: SEPCO www.sepconet.com

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Lighting Controllers

Manufacturers offer a wide variety of lighting controllers ranging from simple photoelectric controls (aka dusk-to-dawn) to elaborate programmable electronic, multi-event time clocks. These controllers regulate the number of hours that the lighting is used. The key is to choose a controller that meets the needs of the application yet is still easy to use.

System Design Considerations

They are a number of factors that must be carefully evaluated when considering using solar powered lighting systems:

- ☐ **Lighting application requirements:** as discussed earlier, solar powered lighting systems are limited to lower wattage compact fluorescent and low-pressure sodium lamps. If the application requires moderate to high illumination levels, or is currently illuminated by metal-halide or high-pressure sodium lamps, PV is probably not a viable option.

- ☐ **Poles:** when selecting poles, pay close attention to the equivalent-projected-surface-area and weight of the solar panels, lighting fixtures and batteries, as well as the local wind conditions. Reinforced direct burial fiberglass poles may be a viable option for certain applications, but should be carefully selected. If the solar-powered lighting systems are going to be installed in a parking lot, be sure to provide adequate protection to prevent damage from accidental vehicle collisions. It may be necessary to install raised concrete foundations, bollards or other barriers to adequately protect the poles.

- ☐ **Batteries:** consider the amp-hour capacity ratings, accessibility, safety, maintenance, and disposal requirements associated with each battery type (e.g. flooded-cell, gel cell or AGM).

- ☐ **Solar Panels**: consider power output ratings, certifications, mounting options, orientation, aesthetics, weight, vulnerability to vandalism and warranty terms when choosing solar panels.

- ☐ **Charge regulators / lighting controllers:** ensure that regulators are compatible with the solar panels and batteries. Consider features, testing procedures and ease of use.

- ☐ **General considerations:** consider the total system cost, warranty terms, and the manufacturer's reputation. Ask for references and then follow up by contacting them.

Note: manufacturers are often willing to assist customers in selecting appropriate equipment to meet their application needs. Some companies, such as the Solar Electric Power Company (SEPCO), offer online design tools that provide useful information (refer to the Design Guide at www.sepconet.com).

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Are Solar Powered Lighting Systems Economical?

When evaluating the cost effectiveness of solar powered lighting systems (versus conventional grid-connected systems) it is important to consider all of the factors that are associated with each type of system on a project-by-project basis. The table below lists some of these factors:

Description	***Solar Powered Systems***	***Conventional Systems (grid-connected)***
Poles	Yes, may need stronger poles	Yes
Lighting fixtures	Same for both	Same for both
Trenching, cabling and conduit	None	Yes
Concrete or asphalt repairs	None	Yes (retrofit only)
Solar panels & batteries	Yes	None
Lighting controllers	Yes	Yes
Energy bills	None	Yes
Battery replacements	Every 5 to 7 years	None
Lamp replacements	Same for both	Same for both
Utility panel or electric service	None	Yes

The cost effectiveness of solar powered lighting systems will vary greatly depending on the specific requirements associated with any given project. They may be a very attractive option for:

- Locations or areas where access to the electric grid would require extensive trenching or establishing a new electric utility account
- Areas with high electric rates. Simply put: the higher the energy rates the more cost effective solar powered lighting systems will be
- Lighting for temporary parking lots or special events-especially if used instead of gasoline or diesel powered lighting systems

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Showcase Project

Project: **California State University of Sacramento (CSUS)**
South Overflow Parking Lot
6000 J Street
Sacramento, CA 95819

Basecase: (hypothetical design alternative)

- Description: eighteen 36-watt compact fluorescent fixtures mounted on 20 foot poles **(grid connected)**
- Electrical demand = 0.648 kW (calculated)
- Expected hours of operation
  - 9 fixtures @ 2,555 hrs. per year (max 7 hrs/night)
  - 9 fixtures @ 4,380 hrs. per year (average 12 hrs/night)
- Energy consumption = 2,247 kWh per year (calculated)
- Total estimated project cost: $46,000
- Energy costs = $180 per year (calculated)

New System:

- Description: eighteen 36-watt compact fluorescent fixtures mounted on 20 foot poles **(solar powered)**
- Electrical demand = **none**
- Expected hours of operation
  - 9 fixtures @ 2,555 hours per year (max 7 hrs/night)
  - 9 fixtures @ 4,380 hrs. per year (average 12 hrs/night)
- Energy consumption = **none**
- Total project cost = $94,160
- Customer Advanced Technologies Program grant = $20,000
- Net total project cost = $74,160

Results:

- Electrical demand reduction = 0.648 kW (calculated)
- Annual energy savings = 2,247 kWh (calculated)
- Electrical cost savings = $180 per year (calculated)
- Net project cost (Basecase – New System) = $28,160
- Reduction in CO_2 and N_{OX} emissions (powered by solar energy instead of power plants)

Comments:

"We chose to install solar-powered lighting systems as part of our continued commitment to energy efficiency and the environment. Although these types of systems are initially more expensive, they will provide long term benefits to our students."

- Linda Hafar, Director, Facilities and Utilities, CSUS

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Showcase Project

Project: **Sacramento Men's Senior Baseball League**
Dan McAuliffe Memorial Ballpark
3228 Jed Smith Dr.
Sacramento, CA 95825

Basecase: (hypothetical design alternative)

- Description: eight 32-watt compact fluorescent fixtures mounted on four 20-foot direct burial fiberglass poles **(grid connected)**
- Electrical demand = 0.256 kW (calculated)
- Expected hours of operation = 1,000 hours per year
- Energy consumption = 256 kWh per year (calculated)
- Installation costs: $12,215 (estimated)
- Material costs: $5,340 (estimated)
- Total project cost[1]: $17,555 (estimated)
- Energy costs = $25 per year (calculated)

New System:

- Description: eight 32-watt compact fluorescent fixtures mounted on four 20-foot direct burial fiberglass poles **(solar powered)**
- Electrical demand = **none**
- Expected hours of operation = 1,000 hours per year
- Energy consumption = **none**
- Total project cost = $21,276

Results:

- Electrical demand reduction = 0.256 kW (calculated)
- Annual energy savings = 256 kWh (calculated)
- Electrical cost savings = $25 per year (calculated)
- **Net project cost (Basecase – New System) = $3,720**
- Simple payback = 15 years
- Reduction in CO_2 and N_{OX} emissions (powered by solar energy instead of power plants)

[1] Includes costs for trenching and subsequent repairs for existing asphalt parking lot

Comments:

"SMUD developed, designed and implemented a state-of-the-art, renewable energy lighting project that will save energy dollars and provide our community baseball complex with needed security and safety. We really appreciate SMUD's efforts."

-Steve Croockewit, Sacramento Men's Senior Baseball League

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Conclusions

Market Potential and Barriers

Although the environmental benefits provided by this technology are attractive, the market potential is presently limited to applications requiring low to moderate illumination levels. Furthermore, the local average installed cost for these systems is still relatively high (~$5,200 / system). However, despite the high cost, significant opportunities exist for remote locations or applications where access to the electrical grid is costly.

Technology Transfer and Recommendations

As further advances are made in the areas of lighting, photovoltaic panels and battery technology, these systems may become more viable and be able to compete head to head with ‘conventional’ grid connected systems. Until then, utilities should continue to actively participate in the development of solar-powered lighting systems.

In particular, utilities should explore the potential benefits of purchasing system components (solar panels, poles, racks, batteries etc) from manufacturers in bulk (instead of making purchases on a project-by-project basis) and using in-house or contracted labor to assemble and install the systems. This may result in lower per unit costs, but more demonstration projects will be needed to test this premise.

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