Federal Technology Alert

A publication series designed to speed the adoption of energy-efficient and renewable technologies in the Federal sector

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Photovoltaics

A proven technology for providing electricity in remote and difficult-to-access locations

The Executive Office has put a high priority on ensuring U.S. buildings are energy efficient and environmentally sustainable. The action plan includes improving Federal procurement of energy-efficient technology, such as photovoltaics. This commitment spearheads the President's Million Solar Roofs Initiative, which aims at installing 1 million solar energy systems on residential, commercial, and public sector buildings by 2010. The Federal sector's portion of that goal is 20,000 facilities. FEMP plays a leading role in meeting this commitment by encouraging and facilitating the use of photovoltaics.

Photovoltaics (PV) is a well-proven and reliable technology that is used increasingly in Federal facilities to provide power in remote or difficult-to-access locations. It uses semiconductor devices to convert sunlight directly to electricity. Because PV systems have no moving parts and require no fuel other than sunlight, they require very little operation and maintenance effort. They also operate silently and have no exhausts or emissions. This *Federal Technology Alert* of the Federal Energy Management Program is one of a series on new energy-efficient and renewable energy technologies. It describes the various types of PV systems, the situations in which PV is likely to be cost effective, equipment selection guidelines, procurement information, and a method for calculating life-cycle costs.

PV systems are most often cost effective in areas with abundant sunlight, as the size and cost of the PV array for any application are directly related to the availability of the solar resource. The only major drawback of PV systems is their high initial cost for capital equipment. However, life-cycle cost analysis often favors PV in comparison to other alternatives such as engine generators and long utility line extensions because of PV's low maintenance and repair costs. Also, PV systems run cleanly and quietly, and can be installed with much less disruption to the environment.


Lawrence Berkeley Lab/PIX01056

Application

PV systems can be designed to power any electrical load regardless of size or location as long as sunlight is available. The primary reason more PV systems are not used is cost. The economic feasibility of using a PV system to power a specific load is determined by the size and nature of the load, the availability of the solar resource, and the cost of power alternatives.

The size and nature of an electric load must be well understood to properly select a packaged PV system or to design and specify a custom system. Whether the system selection/design function is being performed by Federal facility personnel, PV design contractors, or PV system suppliers, the load's power and energy requirements, and its daily and yearly schedule of operation, must be properly assessed.

The magnitude of the load (power and energy) is often difficult to pin down, especially for larger applications that are composed of multiple loads with variable operation schedules (such as residences and ranger stations). For any application, both the maximum power needed at any one time (watts) and the maximum daily energy requirement (kilowatt-hours) must be known. The maximum power requirement determines the size of inverter needed for AC applications and the system wire sizes.

The daily energy requirement and the availability of the solar resource during each season of use determine the size of the required PV array. The daily energy requirement is simply the load's instantaneous power requirement in watts multiplied by the number of hours it operates each day. (Load watts x hours = load watt-hours.) The daily energy requirement, the required availability of the load and the nature of local weather patterns (typical number of days without sunshine) determine the size of the battery bank.

Another factor that influences the size of the array (and the cost of the system) is availability of the solar resource. Although cost-effective PV systems are being installed everywhere in the United States, they are economically feasible most often where there is an abundance of sunshine. PV modules convert sunlight to electricity, so fewer PV modules are required when more light energy is available.

The solar resource also varies by time of year, so PV systems for year-round applications must be sized to provide enough energy during the time of lowest insolation (typically December in the continental United States). If an application is used only during the warmer months (such as for campground host trailers and livestock watering pumps), a smaller PV system is required.

The third factor that determines the economic feasibility of PV power is the cost of the power alternatives. In most cases, the first choice for power is a utility line connection. When utility power is not an option because of high line construction costs, PV systems and other sources of power such as engine generators become more economical in comparison. The actual cost for a line extension to a particular load can be obtained from the local utility company. Many utilities also offer PV service as an alternative to uneconomical line extensions and may be able to provide cost estimates for PV systems.

Technology Selection

When PV systems were less available than they are today, most installed systems were custom designed and specified for each application. The PV array was typically mounted on the roof if there was a convenient structure on site, and the batteries and other components were housed indoors or in a custom-built enclosure. This approach ensures that the PV system exactly suits the needs of the application, but the time and effort required for each custom design adds to the cost of the system. Installation is also more complicated when the system needs to be assembled and wired on site and integrated into a structure.

This approach is still important for very large applications, applications with nontypical loads, or systems that need to be integrated into structures for aesthetics, but prepackaged systems are available today to meet the needs of most applications. These systems are typically pre-assembled and pre-wired with all components except the array housed in a weatherproof enclosure. The array is usually mounted either on the enclosure or on a pole or rack adjacent to it. Packaged systems for specific applications such as outdoor lighting or water pumping also include the load (lamp and luminaire or water pump).

Because system manufacturers have experience integrating, assembling, and wiring their standard packaged systems, they are more likely to have any "bugs" worked out. And because the packaged systems are sold as a complete product, the manufacturers are usually willing to warranty the function of the entire system instead of passing through component warranties.

Case Studies

Three case studies are presented to provide detailed examples of various PV applications and ways to estimate cost savings and life-cycle costs. The first is a PV/engine generator hybrid system installed at Pinnacles National Monument near Salinas, California. It provides power for a cluster of park facilities on an isolated mini-grid. Originally powered by two diesel generators, the park converted to a PV hybrid system with a propane generator to save on fuel and maintenance costs and to eliminate the possibility of a diesel fuel spill.

The second case study is an example of a PV–powered system that pumps water for the Meadows Group and Buffalo Creek Campgrounds in Pike's Peak National Forest near Denver, Colorado. The new system replaced a generator-powered pumping system to save on operating labor and maintenance.

The third study is an overhead glazing system that is the first model for demonstrating the integration of PV into a Federal building. The system is mounted on the skylighted entryway of the Thoreau Center for Sustainability at Presidio National Park in San Francisco, California. PV cells that produce electricity and form an element in the shading and daylighting design are laminated to the skylight glass.

Benefits

- Lower life-cycle cost
- Zero emissions from PV
- Silent
- Increased siting flexibility
- Decreased installation lead time
- Installations cause fewer disruptions
- Improved aesthetics
- Increased reliability from redundant supply
- Portability
- Progressive "green" image
- Modular; can grow with load.

Implementation Barriers

One of the largest perceived barriers is the initial cost of PV systems. PV systems generally have higher initial installation costs than alternatives such as engine generators, but they are much less expensive to operate and maintain. FEMP was established to fund viable renewable energy and energy and water conservation projects undertaken by Federal agencies.

Another barrier is lack of familiarity with PV by designers and operating staff; related to this is uncertainty with PV's performance record. Technical training for design and maintenance staff can help them understand PV technology with its advantages and limitations. Training can also help staff recognize potentially cost-effective PV applications and provide sources for obtaining equipment, services, and assistance. The PV Systems Assistance Center at Sandia National Laboratories can provide PV training and identify classes and workshops.

Other perceived barriers include vandalism, visual quality concerns, conflicts with historical resource context, adverse climate, procurement restrictions and problems, and inability to locate contractors.

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Abstract

The Executive Office has put a high priority on ensuring U.S. buildings are energy efficient and environmentally sustainable. The action plan includes improving Federal procurement of energy-efficient technology, such as photovoltaics. This commitment spearheads the President's Million Solar Roofs Initiative, which aims at installing 1 million solar energy systems on residential, commercial, and public sector buildings by 2010. The Federal sector's portion of that goal is 20,000 facilities. FEMP plays a leading role in meeting this commitment by encouraging and facilitating the use of photovoltaics.

Photovoltaics (PV) or solar electricity is a well-proven and reliable technology used increasingly by Federal facilities to provide power in remote or difficult-to-access locations.

PV systems are used throughout the United States, but they are cost effective most often in areas with abundant sunlight, as the size and cost of the PV array for any application are directly related to the availability of the solar resource. The only major drawback of PV systems is the high initial cost for capital equipment. However, when the life-cycle costs (LCCs) of PV systems are compared to alternatives such as engine generators or long utility line extensions, PV is often the most economical option.

This *Federal Technology Alert* discusses on- and off-grid PV applications and provides Federal facility managers with the detailed information they require to evaluate potential PV applications. Descriptions of PV system components and technological methods are included, along with installation and maintenance requirements and suggestions for where to apply the technology and what to avoid. Also provided are PV equipment selection guidelines, procurement information, and a method for calculating LCCs.

Three case studies are presented to provide detailed examples of various PV applications and ways to estimate cost savings and LCCs.

Southern California Edison/PIX04041

A portable PV/propane hybrid system provides electricity for the California State University Desert Research Center in Southern California.

Contents

About the Technology

Photovoltaics (PV) is a descriptive name for a technology in which radiant light energy (photo) is converted to electricity (voltaic) by semiconductor devices. It is used worldwide to provide electricity, especially in remote or difficult-to-access locations. Unlike solar thermal technologies that provide heat, PV converts sunlight to direct current (DC) electricity.

The PV modules that perform this conversion have no moving parts, emit no exhausts, are completely silent, and require only sunlight as fuel. They are also very durable and reliable, and last at least 20–30 years. PV modules power virtually all satellites and have been important to the space program since 1958, when the first PV system went into orbit with the Vanguard I satellite.

PV systems can generate electricity anywhere the sun shines (even in space), but their cost usually limits their applications to remote or difficult-to-access locations where line-tied utility power is either unavailable or too expensive to install. Some line-tied PV systems are currently being used for high-value applications such as utility distribution line support demonstration projects and peak load shaving for buildings (see Technology Outlook section for details) but they are, for the most part, not cost effective at this time.

As new, less expensive PV technologies are commercialized and electricity costs increase, line-tied PV systems will become more economically feasible. In fact, plans are under way to construct a PV and solar thermal power plant in Nevada that will sell power for less than $0.10 per kilowatt-hour (kWh) by the year 1999; however, the PV systems that are cost effective today serve off-grid applications.

These applications include livestock water pumping; outdoor area and sign lighting (see Figure 1); off-grid power for homes, cabins, and trailers; telecommunications; remote monitoring stations; cathodic protection; traffic warning signals; air traffic safety beacons; and many more. This Federal Technology Alert discusses on- and off-grid PV applications that are cost effective for Federal facilities.

Sandia National Laboratories/PIX02063

Figure 1. PV lighting system at Roosevelt Lake in Phoenix, Arizona.

Application Domain

PV has been used increasingly in the Federal government since it was first used in the space program. As the cost of PV modules dropped from more than $100 per watt (W) in the mid-1970s to less than $6/W today, more and more government agencies have found cost-effective applications for this versatile technology. PV systems are presently in use in almost every sector of the Federal government, but the agencies that use PV the most typically contend with remote regions of the country and vast tracts of land. They include the National Park Service (NPS), the Bureau of Land Management (BLM), the Forest Service, the Coast Guard, and all branches of the Department of Defense (DOD).

The total number of PV systems used in the Federal sector is not known, but Sandia National Laboratories (Sandia) has recently conducted studies of PV systems used in three of these agencies. The results of these studies were published in a series of documents titled *Renew the Parks, Renew the Public Lands,* and *Renew the Forests.*

Renew the Parks reveals that more than 600 PV systems are used in the national parks. Most are used for resource monitoring (31%) and communications (27%). As part of the study, parks were requested to identify future PV projects. The results totaled 643 future projects in 125 parks.

According to *Renew the Public Lands*, approximately 690 PV systems are used by the BLM. Most (61%) are used for remote automated weather stations. Another 123 future PV projects were identified. In *Renew the Forests*, the numbers given for the Forest Service are 500 PV systems and 200 identified future projects. Most of the current systems (62%) are used for communications. Figure 2 shows the distribution of PV applications for these agencies.

PV applications included in the "Other" category on Figure 2 include lake aerating, water disinfecting, ventilation systems, battery chargers, security systems, interpretive displays, traffic counters, automatic gates, navigation aids, and wastewater management.

Sandia published a paper in 1996 titled "Photovoltaics in the Department of Defense" that documents the history of PV use in DOD. According to this paper, the U.S. military had installed approximately 2,000 small remote systems with about 2 megawatts (MW) of PV power by 1992. After 1992, DOD shifted its emphasis to developing and implementing larger-scale

PV applications. Since then, another 124 systems with 2.1 MW of PV power have been installed. There are about 50,000 more potential PV applications in the U.S. military with about 50 MW of PV.

Most of these systems are used in remote locations, but many applications are cost effective in urban environments. They typically involve small loads that do not justify constructing a utility line extension or are in difficult-to-access locations where line construction would be very costly. Such locations include street and highway median strips, areas with no utility easements, municipalities with restrictive building regulations, and areas across from streets, intersections, and railways. Examples of cost-effective urban applications include:

- Emergency telephones for roadways, bike paths, parks, and parking lots
- Lighting for signs, billboards, and flagpoles
- Traffic counters
- Traffic hazard warning flashers
- School crossing flashers
- Security lighting for parks, playgrounds, parking lots, paths, outdoor stairways, and equipment yards
- Irrigation controls for ball fields, median strips, and landscaping.

PV systems are also very popular for portable and temporary applications because they can be designed for easy transportation. These include road construction sign boards and warning flashers, portable power packs, and livestock water-pumping systems that are moved from pasture to pasture to follow stock rotations. PV is also widely used in small portable appliances such as watches and calculators.

These expanding markets have caused the U.S. PV industry to grow rapidly to keep pace with the increasing demand in the United States and abroad. In 1996, U.S. PV module shipments grew by 26% to 41 MW (45% of the world market share). Virtually every U.S. module manufacturer either just completed or is now in the midst of a major expansion in module production capacity.

The 1997 Solar Energy Industries Association membership directory lists no fewer than 22 manufacturers of PV modules and 29 suppliers of complete PV systems (see Manufacturers section for listings). PV systems are easily procured by Federal agencies via General Services Administration (GSA) schedules that cover most major makes of PV system components and complete systems. In addition, PV systems can be obtained from many electric utility companies that offer PV service programs to satisfy their customers' remote-power needs.

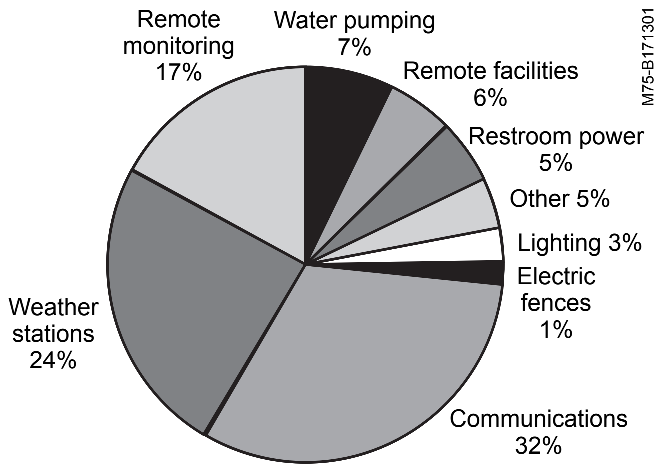


Figure 2. Distribution of current PV applications in NPS, Forest Service, and BLM.

How PV Systems Work

Unlike energy-saving technologies such as solar water heating, compact fluorescent lightbulbs, and energy-efficient appliances, PV systems reduce costs and mitigate environmental pollution not by saving energy but by serving new and current electric loads more cost effectively. This is possible when the traditional method of providing electricity, a utility line extension, becomes too expensive to install, maintain, or repair.

To gain a perspective on when PV systems are cost effective for new loads, compare the length of a line extension to costs of PV systems in Figure 3.

As this figure shows, whether a PV system is more cost effective than a line extension depends on the length of the line and the cost per mile of line construction. Construction costs of $30,000/mile are typical for buried underground line. Investor-owned utilities charge about $15,000/mile for overhead line, and rural electric cooperatives and other public utilities sometimes construct overhead lines for as little as $10,000/mile.

Table 1 provides some average costs for typical PV systems. Any application with a PV system cost that falls below the applicable line on the chart has a good potential for economic feasibility.

The cost-per-mile lines do not appear to start at zero dollars because an additional cost for a transformer is assumed whenever

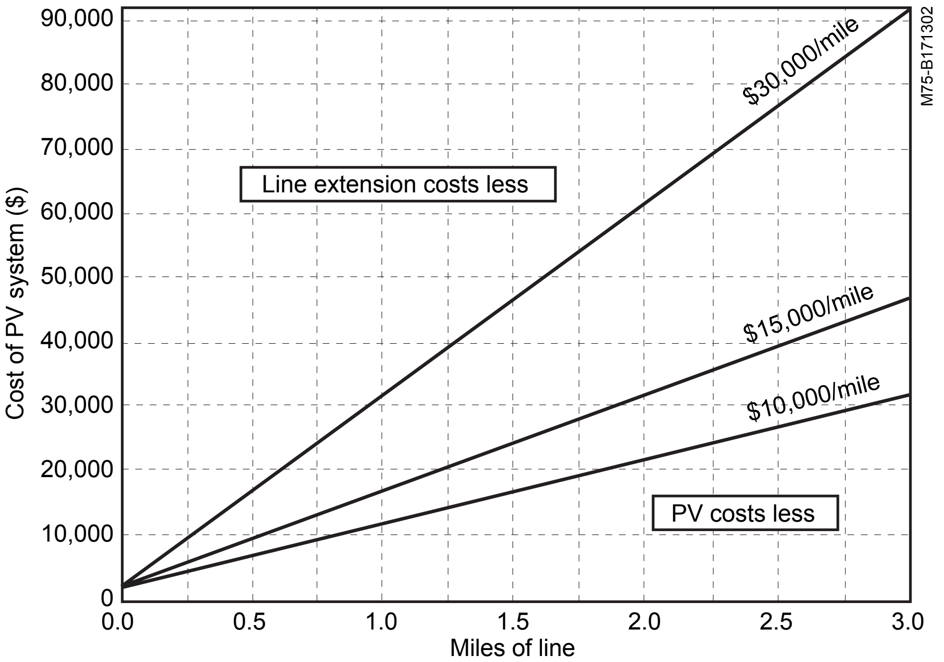


Figure 3. Cost of PV versus line extensions.

Table 1. Typical PV system costs

Packaged PV power supply that provides annual average of **1/2 kWh AC/day**	–	$ 5,000
Packaged PV power supply that provides annual average of **3 kWh AC/day**	–	$19,000
Packaged PV power supply that provides annual average of **8 kWh AC/day**	–	$38,000
PV pumping system that provides **1,000 GPD @ 50 feet** of vertical lift in summer	–	$ 2,000
PV pumping system that provides **3,000 GPD @ 200 feet** of vertical lift in summer	–	$12,000
Parking lot light that operates all night (36-W compact fluorescent)	–	$ 3,500

(All systems sized for Boulder, Colorado)

the line is longer than 200 feet. The average value of $2,000 was used for this cost.

PV System Components

PV systems have individual components that are assembled to serve the needs of a specific load or loads. With certain applications such as outdoor area lighting and water pumping, PV systems may also include the loads (the light or pump) because they are specifically designed to operate with PV systems.

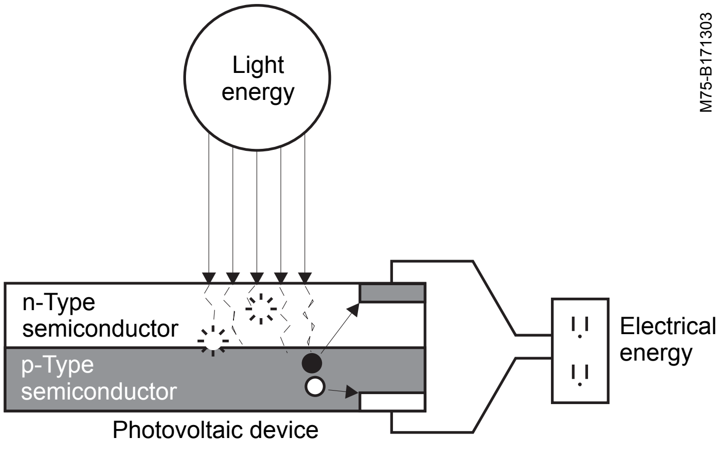
Depending on the nature of the load, each PV system may include:

- PV arrays, which convert light energy to DC electricity
- Batteries, which store electricity for use when the sun is not shining
- Battery charge controllers, which protect the battery by preventing overcharge and over-discharge
- Inverters, which convert DC to alternating current (AC)
- Converters, which convert PV system voltage to a higher or lower voltage
- Solar trackers, which optimize the solar gain of the PV array by tracking the sun

The Photovoltaic Effect

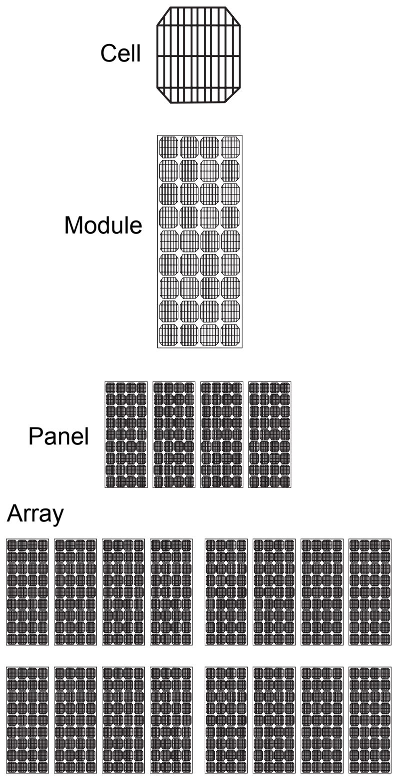
Sunlight is composed of photons—discrete units of light energy. When photons strike a PV cell, some are absorbed by the semiconductor material and the energy is transferred to electrons. With their new-found energy, the electrons can escape from their associated atoms and flow as current in an electrical circuit.

PV arrays require no care other than occasional cleaning of the surfaces if they become soiled or are used in dusty locations. However, they must be kept clear of snow, weeds, and other sources of shading to operate properly. (PV cells are connected in series, so shading even one cell in a module will appreciably decrease the output of the entire module.)



PV Cells

PV cells are the basic building blocks of PV modules. They are made of semiconducting materials, typically silicon, doped with special additives. Approximately 1/2 volt is generated by each silicon PV cell. The amount of current produced is directly proportional to the cell's size, conversion efficiency, and the intensity of light. As shown in the figure below, groups of 36 series-connected PV cells are packaged together into standard modules that provide a nominal 12 volts (or 18 volts @ peak power). PV modules were originally configured in this manner to charge 12-volt batteries. Desired power, voltage, and current can be obtained by connecting individual PV modules in series and parallel combinations in much the same way as batteries. When modules are fixed together in a single mount they are called a panel and when two or more panels are used together, they are called an array. (Single panels are also called arrays.)



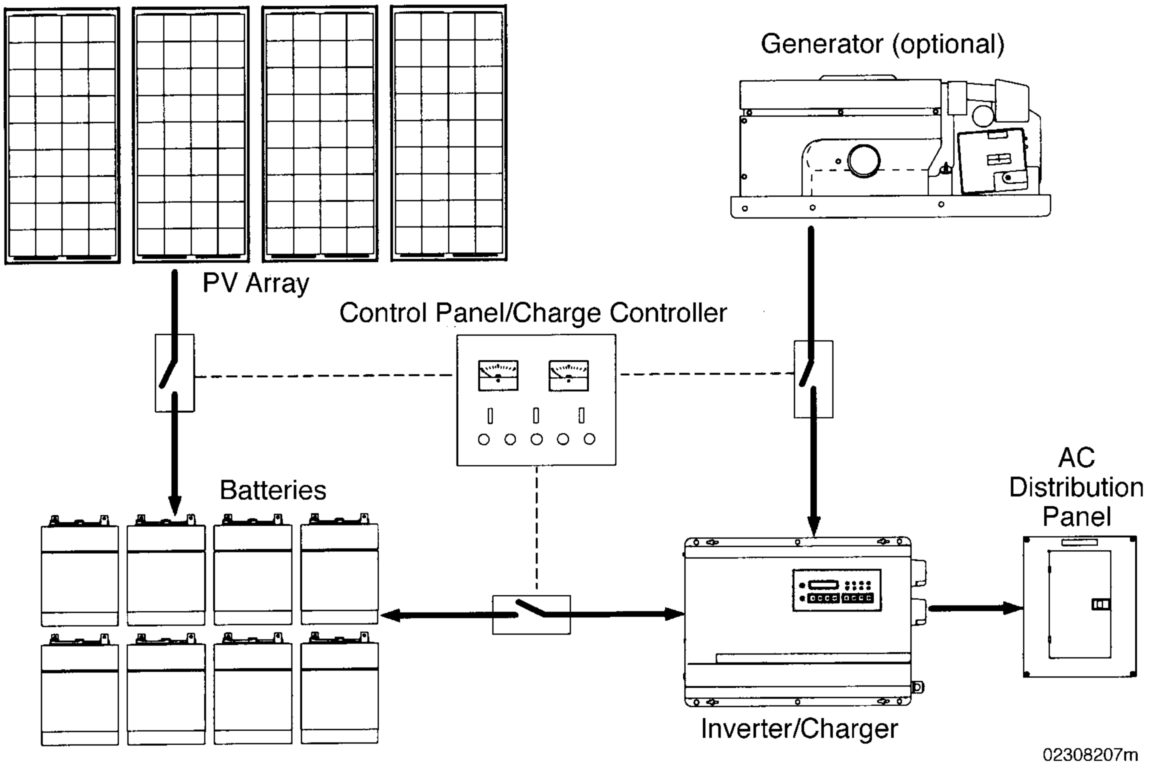


Figure 4. Schematic of a typical stand-alone PV system.

- Engine generators (for hybrid systems), which provide backup power and power for charging batteries.

Figure 4 shows how these components are interconnected in a stand-alone PV system. The function of each component is described below.

PV Array — The primary component of a PV system, it converts sunlight to electrical energy; all other components simply store, condition, or control energy use.

Most PV arrays for stand-alone PV systems (not tied to the utility grid) consist of crystalline silicon PV modules that range in size from 50 to 80 peak watts. (Peak watts are the rated output of PV modules at standard operating conditions of 25°C and insolation of 1,000 W/m^2.) PV modules are the most reliable components in any PV system. They have been engineered to withstand extreme temperatures, severe winds, and impacts from 1-in. hail balls at terminal velocity (55 mph). PV modules have a life expectancy of 20–30 years and manufacturers warranty them against power degradation for 10–20 years. The array is usually the most expensive component of a PV system; it accounts for approximately one-third the cost of a stand-alone system.

Batteries — Because most applications require electricity when the sun is not shining, battery storage of electricity is usually necessary. The batteries used in PV systems are similar to automobile batteries, but are specially constructed to withstand many deep discharge cycles. (Current is provided for extended periods.) Automobile batteries are designed for shallow discharge cycles (to provide large currents for short periods), and are not suitable for PV systems.

The two most common types of batteries used in PV systems are flooded lead acid batteries that require periodic maintenance (addition of distilled water and equalization), and valve-regulated lead acid batteries, which are "maintenance-free." To reduce the maintenance frequency required by flooded batteries, catalytic recombiner caps can be used. These caps recombine the hydrogen and oxygen gases emitted by the battery cell into water that is returned to the battery.

The batteries are usually the second most expensive components in stand-alone PV systems and have the shortest lifetimes (typically 3–7 years). Therefore, battery replacement costs (as well as other component replacement costs) must be carefully accounted for when PV systems are compared to other power alternatives.

PV-powered water pumping is one of the few applications that does not require battery storage. Instead, water is pumped and stored in large tanks for use at night and during periods of little or no sunshine.

Charge Controllers — Just as an automobile uses a voltage regulator to control the charging voltage to the battery, a similar type of controller is used in PV systems to avoid overcharging the batteries. PV charge controllers limit the current from the PV array to the batteries once the batteries reach a full state of charge (at a preset voltage). Most charge controllers also include a feature that disconnects the electrical load from the batteries when they reach a low-voltage set point. This feature is also usually included with inverters.

Inverters — PV arrays and batteries are typically configured to provide 12, 24, or 48 volts of DC power. However, many applications require 120 or 240 volts of AC power. DC is converted to AC with a separate component called an inverter. Inverters enable the operation of commonly used equipment such as household appliances, power tools, computers, office equipment, and motors. The nature of an AC load determines the type of inverter waveform needed. AC loads such as timers, clocks, laser printers, fluorescent lights, and some meters often have difficulty operating on anything less than true sine-wave power. The power quality specifications of sensitive equipment must be well matched to inverter capabilities in type of waveform and in minimum and

PV-Powered Water Pumping

One major application that differs significantly from most others is water pumping. Whether they are for livestock or wildlife watering, potable water supplies or small-scale irrigation, PV systems dedicated to water pumping seldom include batteries or battery charge controllers because water storage is generally more economical than electricity storage. Instead, water is stored in tanks, cisterns, or reservoirs large enough to handle the daily water requirement for 3 to 5 days of poor weather (depending on the location). Eliminating batteries reduces maintenance, system complexity, and the need to purchase replacement batteries and charge controllers. The components in a PV pumping system include a PV array, a pump, and a special pump controller that matches the PV output voltage and current to the needs of the pump (especially during low sunlight conditions).

K.C. Electric/PIX03396

PV-powered water pumping on a Colorado ranch.

maximum acceptable voltage and frequency. Fortunately, most electrical equipment is not too demanding about power quality and will operate with almost any inverter.

In addition to providing AC power for loads, some inverters can also take AC input from an auxiliary power source such as an engine generator and convert it to DC current to charge the batteries. This capability is usually available with the larger, full-featured inverters.

Converters — Occasionally the voltage output of a PV array, battery, or inverter will not match the voltage requirement of the load. When this occurs, converters are used to step the DC voltage up or down to meet the needs of the load.

Trackers — Trackers optimize the energy production of PV modules by facing them toward the sun as it travels across the sky. This increases the effective length of the solar day by about 40% during the summer and decreases the number of PV modules necessary to collect the same amount of energy. However, trackers with their moving parts add to the complexity of a PV system and can be expensive. As a rule, trackers do not gain enough energy during the winter (especially in northern climates) to pay for their added expense. How-ever, if a load's energy requirements are highest in summer, a PV array mounted on a solar tracker may be the least expensive option.

Engine Generators — When an engine generator is paired with a PV array as energy sources for a power supply, the resulting system is called a hybrid PV generator system or simply hybrid system. A hybrid system often provides a power solution with a lower initial cost, lower cost of energy, more flexibility, and more reliability than a PV system or generator alone. A generator can provide backup energy when the sun doesn't shine or for times when more energy or power is required. Because the PV array and battery need not provide all the energy, they can be sized smaller to save on initial costs. Hybrid systems can be designed to provide any mix of energy from the PV system and generator, but the most common practice is to size the PV array to provide 60%–90% of the required annual energy; the generator can make up the difference. Minimizing generator run time cuts down on required fuel and maintenance. (Generators are notorious for their high maintenance requirements.)

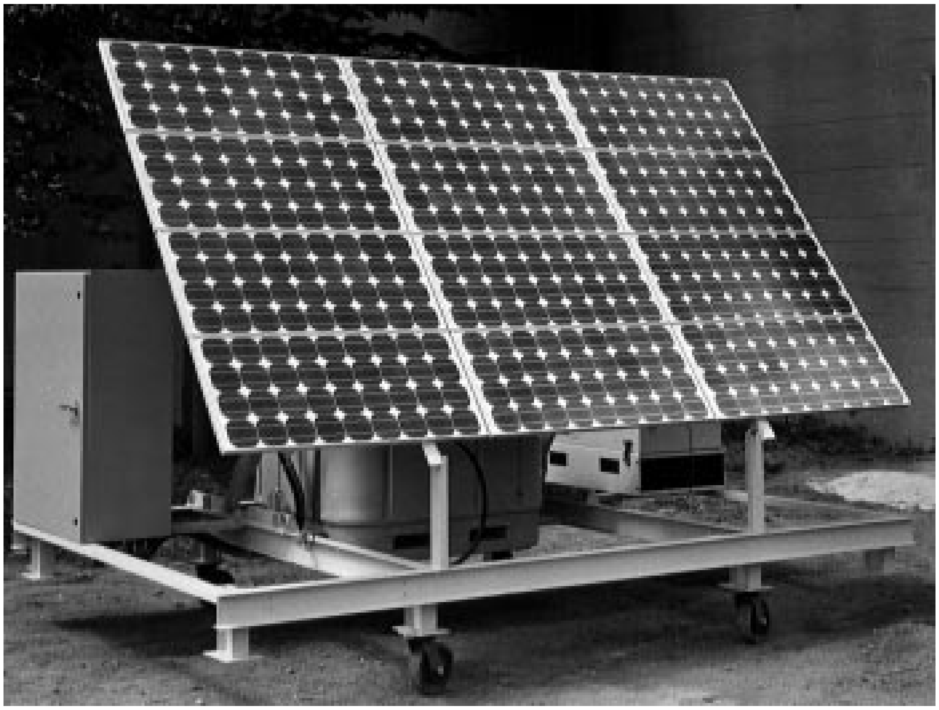
Most inverters available today include circuitry that allows the power from the generator to be transferred to the load with part of it used to charge the batteries. Many inverters also have automatic generator start capabilities. This feature automatically turns on the generator to charge the batteries when they reach a low state of charge (low voltage).

Prepackaged versus Custom-Designed Systems

When PV systems were less available than they are today, most installed systems were custom designed and specified for each application. The PV array was typically mounted on the roof if there was a convenient structure on site, and the batteries and other components were housed indoors or in a custom-built enclosure. This approach ensures that the PV system exactly suits the needs of the application, but the time and effort required for each custom design adds to the cost of the system. Installation is also more complicated when the system needs to be assembled and wired on site and integrated into a structure.

This approach is still important for very large applications, applications with non-typical loads, or systems that need to be integrated into structures for aesthetics, but prepackaged systems are available today to meet the needs of most applications. These systems are typically preassembled and pre-wired with all components (except the array) housed in a weatherproof enclosure. The array is usually mounted either on the enclosure or on a pole or rack adjacent to it. See Figure 5 for an example of a packaged PV system. Packaged systems for specific applications such as outdoor lighting or water pumping also include the load (lamp and luminaire or water pump).

Because system manufacturers have experience integrating, assembling, and wiring their standard packaged systems, they are more likely to have any "bugs" worked out. And because the packaged systems are sold as a complete product,



PV Services Network/PIX04576

Figure 5. An example of a packaged PV-powered system by SunWize Energy.

the manufacturers are usually willing to warranty the function of the entire system instead of passing through component warranties.

Benefits

- **Increased siting flexibility** — Load siting is not limited by the availability of grid power, utility easements, or difficult-to-access locations.
- **Decreased installation lead time** — When a utility line does not have to be constructed, there is no need to obtain utility easements, and building permits are seldom required for small PV systems. There is less disruption of the land, so environmental impact studies are simplified (if required at all). In addition, packaged PV systems are readily available; shipping lead times range from next day to 6–8 weeks, depending on the supplier and the type and size of system.
- **Installations cause fewer disruptions** — No heavy construction equipment (utility line trucks, trenchers, pole setters) is required for installation, so there is less impact on the land. Also, traffic is not disrupted by stringing power lines across roads or pathways and there is much less construction noise.
- **Improved aesthetics** — PV systems eliminate the need for overhead power lines that interfere with scenic views or clutter facility grounds.
- **Increased reliability** — When the available electric service is prone to disruptions, PV systems can be designed to be more reliable for critical applications such as emergency warning sirens and security lighting.
- **Portability** — PV systems can be designed to relocate easily and can be used for temporary applications and emergency power.
- **Progressive "green" image** — Environmental degradation is becoming a growing concern. Electric utilities have found that customers are willing to pay more for renewable energy, which PV systems visibly use.

Variations

Three types of PV cells are manufactured and assembled into commercially available modules: single-crystal silicon, polycrystalline silicon, and amorphous cells (includes silicon and cadmium telluride). Modules made with the single-crystal and polycrystalline silicon cells are most commonly used in stand-alone PV systems. Amorphous modules can be used, but they are used mostly for consumer products such as calculators, watches, flashlights, walk lights, and battery chargers. In the United States, 91% of the PV modules manufactured are crystalline; the rest are amorphous silicon, cadmium telluride, ribbon silicon, and concentrator modules.

Concentrator modules are simply high-efficiency PV cells housed under concentrating lenses that focus a large area of sunlight onto a small area of cell. This technology may reduce the cost of electricity by substituting lower-cost lens and housing materials for the more expensive PV cells. However, concentrator modules require accurate tracking mechanisms to keep the sun focused on the small PV cell area and are not commonly used for stand-alone PV applications.

Installation

The installation of PV systems can vary greatly depending on the application, the size of system, and whether the system arrives packaged and preassembled or as separate components that need to be integrated into a structure on site. Because the packaged systems are almost completely assembled and pre-wired, usually all that is required is to set the component enclosure on a pole, simple foundation, or level ground, mount the PV array to the enclosure, and wire it to the rest of the system. This can take as little as 2–4 hours for small systems (such as outdoor security lighting, livestock water pumping, communications, and traffic warning flashers). Installing large site-integrated systems (such as generator hybrid systems to power NPS visitor facilities) can take several weeks and have special requirements for foundations and structures to house the equipment.

Regardless of type or size, each system has very specific requirements for array siting. The array must be installed in a location that is free of shadows during peak sunlight hours. As a rule for a fixed PV array (without a tracker), those hours are from 9:00 a.m. to 3:00 p.m. (solar time). The sun may shine before and after these hours, but it is either too low in the sky to provide much energy (during the winter) or too far north to shine directly on the array (during the summer).

Federal-Sector Potential

PV technology has been assessed by the New Technology Demonstration Program as having significant potential for cost savings in the Federal sector.

Technology Screening Process

New technologies were identified through advertisements in the *Commerce Business Daily* and trade journals and direct correspondence. Responses were obtained from manufacturers, utilities, trade associations, research institutes, Federal agencies, and other interested parties. Based on these responses, the technologies were evaluated in terms of potential Federal-sector energy savings and procurement, installation, and maintenance costs. They were also categorized as either just coming to market ("unproven" technologies) or as technologies for which there are already field data ("proven" technologies).

The energy savings and market potentials of each candidate technology were evaluated by Pacific Northwest National Laboratory with a modified version of the Facility Energy Decision Screening software tool, developed for the U.S. Department of Energy's (DOE) Office of Federal Energy Management Program (FEMP), the U.S. Army Construction Engineering Research Laboratories, and the Naval Facilities Engineering Service Center.

Laboratory Perspective

PV is a valid and proven technology that the U.S. government is committed to support via assistance to PV users and manufacturers. Sandia's PV Design Assistance Center (PVDAC) in Albuquerque, New Mexico, is a national resource for information about PV systems. Established in 1984 as part of DOE's National Photovoltaic Program, the center is involved in all aspects of PV system design, procurement, installation, and evaluation. Its engineers provide information about the cost-effectiveness and reliability of PV systems gained from evaluating system components and operating systems. With cooperation from the PV industry, the center promotes the acceptance of a mature (if somewhat unfamiliar) technology.

The National Renewable Energy Laboratory (NREL), which has recently been designated as the site for the National Center for Photovoltaics, is the counterpart to the PVDAC for PV assistance and research on the cell and module levels. NREL's scientists and engineers help lower PV costs and improve performance and reliability by developing prototype PV cells; improving cell efficiency (the amount of sunlight the device converts to electricity); testing solar cell and module performance, and helping industry develop better, less expensive manufacturing technologies. While working with PV manufacturers, NREL has helped participating companies reduce manufacturing costs by almost 50%. The goal of NREL's PV assistance is to help commercialize the technology by improving module efficiencies and bringing PV costs down.

Application

This section addresses the technical aspects of applying PV, which include screening potential applications for cost-effectiveness and the locations where PV may best be applied. Also covered are PV's advantages and limitations, equipment and installation costs, procurement, maintenance impacts, relevant codes and standards, and utility PV service programs.

Application Screening

PV systems can be designed to power any electrical load regardless of size or location as long as sunlight is available. The primary reason more PV systems are not used is cost. The economic feasibility of using a PV system to power a specific load is determined by three primary factors:

- The size and nature of the load
- The availability of the solar resource
- The cost of power alternatives.

Size and Nature of Load

The size and nature of an electric load must be well understood to properly select a packaged PV system or to design and specify a custom system. Whether the system selection/design function is being performed by Federal facility personnel, PV design contractors, or PV system suppliers, the load's power and energy requirements, and its daily and yearly schedule of operation, must be properly assessed.

The magnitude of the load (power and energy) is often difficult to pin down, especially for larger applications that are composed of multiple loads with variable operation schedules (such as residences and ranger stations). For any application, both the maximum power needed at any one time (W) and the maximum daily energy requirement (kWh) must be known. The maximum power requirement determines the size of inverter needed for AC applications and the system wire sizes.

The daily energy requirement and the availability of the solar resource during each season of use determine the size of the required PV array. The daily energy requirement is simply the load's instantaneous power requirement in watts multiplied by the number of hours it operates each day. (load W x hours = load watt-hours [Wh]). The daily energy requirement, the required availability of the load, and the nature of local weather patterns (typical number of days without sunshine) determine the size of the battery bank.

If a load is operated 24 hours per day, 365 days per year (as with water flowmeters), the energy and power requirements are constant and easy to calculate. However, few loads are that simple. At the other extreme, large applications such as NPS visitor facilities usually require professional energy audits to properly assess the load. The purposes of the audit are to accurately assess the current energy and power requirements, and identify means of reducing electrical energy use.

For loads between these two extremes, worksheets can be used to estimate the load's daily energy consumption. For more information on load calculation and a sample calculation, see the box on page 12.

Availability of Solar Resource

Another factor that influences the size of the array (and the cost of the system) is availability of the solar resource. Although cost-effective PV systems are being installed everywhere in the United States, they are economically feasible most often where there is an abundance of sunshine. PV modules convert sunlight to electricity, so fewer PV modules are required when more light energy is available.

For example, a small PV system designed to operate two 36-W lamps for 8 hours each evening would require two 60-W PV modules in Tucson, Arizona, but would require four 60-W modules in Madison, Wisconsin. That's because the lowest average daily solar insolation in Tucson is 5.6 kilowatt-hours per square meter (kWh/m^2) versus 2.8 kWh/m^2 in

Madison (in December on a surface at latitude +15º tilt). At approximately $6/W for PV modules, the lighting system in Madison would cost at least $720 more.

Figure 6 is a map of the United States that shows the average daily solar radiation incident on a surface that faces south and is tilted up from the horizontal at an angle equal to the latitude. As shown on the map, the Southwest receives much more insolation (solar radiation incident on an area over time) than the East or Northwest. The Southwest also has a low utility grid density, which makes it an ideal location for off-grid PV applications.

The solar resource also varies by time of year, so PV systems for year-round applications must be sized to provide enough energy during the time of lowest insolation (typically December in the continental United States). If an application is used only during the warmer months (such as for campground host trailers and livestock watering pumps), a smaller PV system is required. As shown in Figures 7 and 8, the insolation in any location in the United States can be 50%–100% greater in June than in December.

For a more accurate assessment of the insolation available in 239 locations in the United States, consult the *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*, published by NREL. A sample page from the manual is shown in Appendix A.

Cost of Power Alternatives

The third factor that determines the economic feasibility of PV power is the cost of the power alternatives. In most cases, the first choice for power is a utility line connection. When utility power is not an option because of high line-construction costs, PV systems and other sources of power such as engine generators become more economical in comparison. Factors that contribute to high line-construction costs include:

- Long distance to the nearest utility distribution line
- Unavailable utility easements
- Roadways or parking lots that block access or complicate construction
- Steep or rugged terrain
- Requirements for buried lines
- Requirements for environmental impact studies
- Requirements for archeological studies.

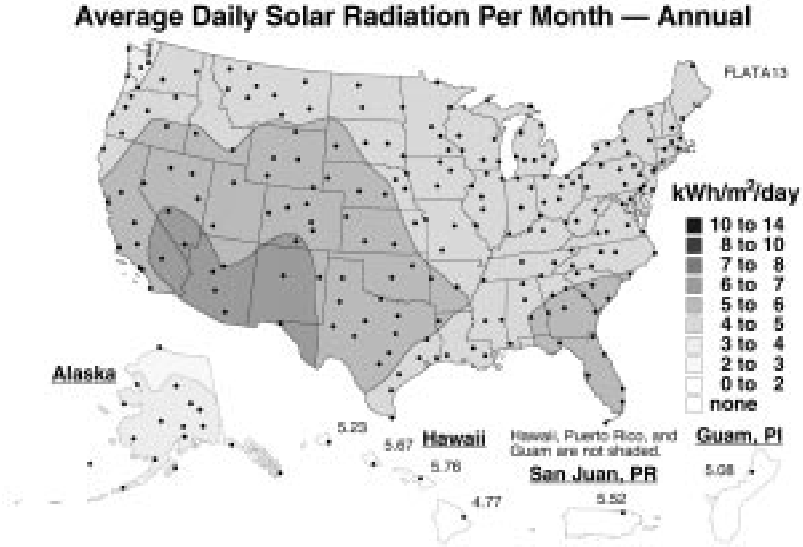


Figure 6. Map of average daily global solar radiation on a south-facing flat surface at latitude tilt.

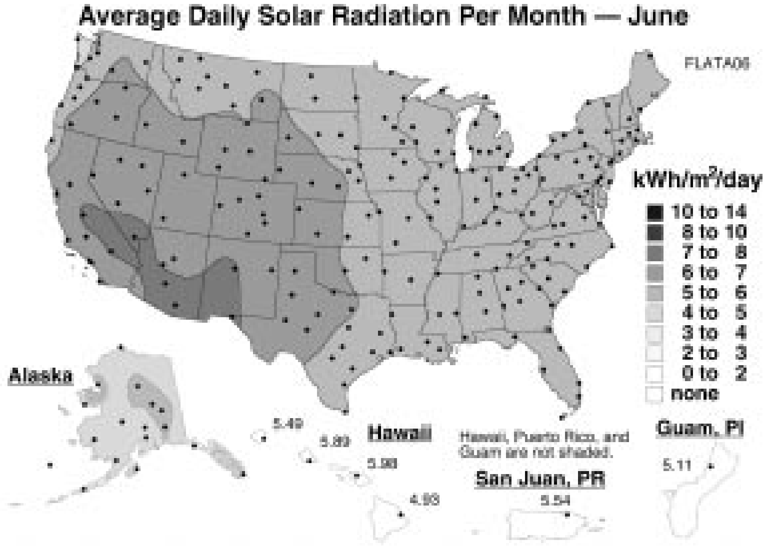


Figure 7. Map of average daily global solar radiation in June on a south-facing flat surface at latitude tilt.

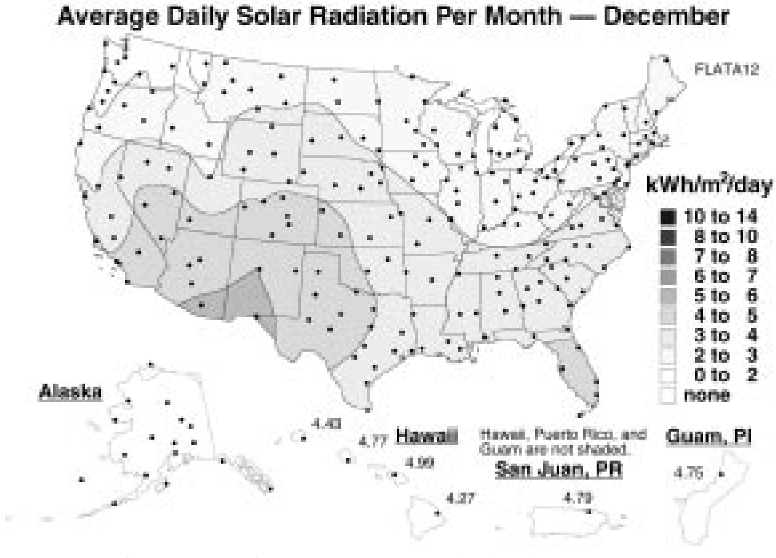


Figure 8. Map of average daily global solar radiation in December on a south-facing flat surface at latitude tilt.

The actual cost for a line extension to a particular load can be obtained from the local utility company. Many utilities also offer PV service as an alternative to uneconomical line extensions and may be able to provide cost estimates for PV systems.

Engine generators are popular when line extensions are not feasible. Although generators have a relatively low initial cost compared to PV systems, they have a number of disadvantages:

- They require frequent and regular maintenance (oil changes, tune-ups, and rebuilds).
- Fuel must be transported and stored on-site.
- They produce air emissions.
- They are noisy.

When these disadvantages and maintenance and fuel costs are taken into account, engine generators are not the bargains they may initially seem.

Load Reduction

Energy-saving measures and switching heating loads to propane or other fuels are often used in conjunction with PV systems to reduce the size of electric loads so smaller and less expensive PV systems are required. One easy energy efficiency measure is to change incandescent lightbulbs to compact fluorescents, which use approximately one-fourth the energy to produce the same amount of light and last 10 times as long.

Another important measure is to eliminate "ghost loads" (small loads that are not obvious users of electricity). Because they are on 24 hours per day, ghost loads can consume quite a bit of energy. Examples of ghost loads include remotely controlled appliances, equipment with small plug-in transformers, and equipment with light-emitting diode clocks and displays. Other efficiency measures include using energy-efficient tools and appliances (pumps, motors, and refrigerators) and simply turning off appliances when they aren't being used. Another way to save electricity is to switch large heating loads such as water heaters, furnaces, and stoves to other fuel sources. These fuels (propane or oil) can provide heat at a much lower cost than a PV system and may be used to fuel a backup engine generator.

In some cases, special DC lights, equipment, and appliances are used to improve system efficiency and reduce the size and complexity of systems by eliminating the need for inverters.

Economic Analysis

Once you have assessed the size of an application's electric load, you can obtain cost estimates for PV power systems from PV suppliers. These suppliers have solar insolation data available for most locations in the United States and can size and cost a PV system for specific load and local insolation levels. Most PV system suppliers can also size and provide estimates for PV/generator hybrid systems if they appear to be good options.

Engine generator suppliers can provide cost estimates for generators to handle your load and provide guidelines for estimating fuel consumption and maintenance costs.

After you have determined the costs for all power alternatives, you should perform an LCC analysis that compares the options. LCC analysis calculates the present value of the initial investment, operations and maintenance (O&M) costs, replacement costs, and energy/fuel costs, minus salvage value of replaced parts. For more information on LCC see Appendix C. An LCC manual (National Institute of Standards and Technology [NIST] handbook 135), an annual set of prescribed energy prices and discount rates (NISTIR 85-3273), and building life-cycle cost (BLCC) software (NIST 4481) are all available by calling the FEMP Help Line at 800.DOE.EREC. (Some agencies allow simpler life-cycle calculations, but the BLCC is required if FEMP funding is involved.)

Although standard LCC analysis does not include a way to take credit for environmental externalities such as benefits of reducing fossil fuel consumption, these may be important considerations if the economic efficiency calculation is close. NPS has developed guidelines for calculating and including avoided air emissions that result from reduced electrical power production in its internal economic evaluation of large energy projects. Some agencies have chosen to relax the economic evaluation criteria somewhat for showcase buildings in new facilities or demonstration projects at current facilities. Projects must be basically cost effective, however, or they do not make good demonstrations.

Where to Apply

There are cost-effective PV applications everywhere. One key to finding them is to always consider the PV alternative before constructing a line extension or installing an engine generator. This is possible only if those in charge of providing electric utilities are educated on PV's capabilities and limitations. The following situations indicate possible cost-effective PV applications:

- When small loads are located in remote or difficult-to-access sites
- Where long power lines to small loads need to be rebuilt
- Where only high voltage transmission lines are available (large step-down transformers are very expensive)
- Where utility line construction is very costly due to terrain, lack of easements, stringent building codes, or environmentally sensitive locations
- Where engine generators are currently being used
- Where stringent air quality, fuel transportation, or noise regulations prevent the use of engine generators
- In difficult-to-access locations where delivery of fuel for generators is a problem
- Where old livestock-watering windmills need to be replaced
- Where water has to be hauled for livestock or wildlife
- Where an application needs to be portable or temporary.

What to Avoid

The following are situations where PV is less likely to be cost effective:

- Locations without good access to sunlight (in forests, canyons, and ravines; on north slopes of steep hills and mountains; on the north sides of large buildings)
- Applications with large heating loads that cannot be easily switched to other fuels
- Applications with large air-conditioning or refrigeration loads
- Applications in northern states with loads that peak during the winter.

Maintenance Impact

PV systems by themselves (without engine generators) require very little maintenance. Typically only a visual inspection of the system and simple battery maintenance are required if flooded batteries are used.

Calculating the Daily Load

The first step in selecting or designing a PV system is to determine the load's daily energy requirement. That involves the following steps:

- Identify all the electrical devices that will rely on the PV system for power.
- Determine each device's power usage (in watts).
- Estimate the average hours each device is used each day.
- Multiply each device's wattage by the daily hours of use to obtain its daily energy requirement (watt-hours).
- Sum the watt-hours for all devices to get the total daily energy requirement.

An example of this calculation for a small home is shown below.

If the energy requirement varies from season to season, it must be calculated for each season to determine the largest requirement relative to the available insolation (solar radiation incident on an area over time). Residences tend to use more energy during the winter when the days are shorter, because lights and other appliances such as televisions are on longer.

The wattage of an electrical device is usually stamped or printed on a nameplate on the rear or bottom of the appliance. If the appliance lists VA (volts x amps) instead, that number approximates the wattage. If only amps are listed, multiply the amps by the voltage to find the approximate wattage (e.g., 3 amps x 120 volts = 360 watts). Nameplate ratings are generally maximum design limits of the device, which could be two to four times the actual power consumed. Whenever possible, measure (or have a technician measure) the actual power consumption of every electrical device to be used.

For a blank load calculation worksheet see Appendix B.

Example

Appliance	Watts		Daily Hours of Use		Daily Watt-Hours
Fluorescent light (shop light with [2] 40-W tubes)	80	x	3	=	240
Compact fluorescent lights (2) 18 W each	36	x	6	=	216
Compact fluorescent light	11	x	6	=	66
Incandescent light	60	x	2	=	120
Microwave oven	1,200	x	0.25	=	300
Refrigerator (19 cf super efficient)	64	x	12	=	768
Water pump (1/2 hp centrifugal)	1,280	x	0.5	=	640
Vacuum cleaner (3/4 h/wk)	800	x	0.1	=	80
Washing machine (2 loads/wk)	920	x	0.2	=	184
Coffee maker (4 cup)	625	x	0.167	=	104
Computer (486 with color monitor)	160	x	2	=	320
Printer (inkjet) — Printing	30	x	0.25	=	7
Printer (inkjet) — IDEL (ghost load)	16	x	1.75	=	28
Television (19” color with remote) — TV on	58	x	4	=	232
Television (19” color with remote) — TV off (ghost load)	6	x	20	=	120
VCR	25	x	2	=	50

Total Daily Energy Requirement — 2,844 Wh

Whether a PV system adds to the maintenance burden of a facility or application depends on the power supply.

From the user's perspective, utility line extensions require no maintenance. (The utility's perspective is another matter.) Compared to utility power, PV systems take a little more effort. How much effort depends on the specifications of the system, but most small PV systems typically take no more than 2 to 4 hours each year. If the PV system uses maintenance-free batteries, the maintenance is usually limited to visually inspecting and testing the system output.

However, compared to engine generators, PV systems represent a great saving in maintenance time and effort. The maintenance factor is quite often the reason for PV systems being chosen instead of, or in conjunction with, generators.

When PV systems are paired with generators in hybrid systems, the generator maintenance requirements are greatly reduced because the intervals for generator oil changes, tune-ups, and rebuilds are directly related to the hours of generator run-time. Instead of running 24 hours per day, when paired with a PV system, a generator usually operates for only a few hours per day or week, depending on the system design.

In addition to cutting generator maintenance requirements, PV systems improve their operating efficiencies. Generators in hybrid systems are usually turned on only when batteries need supplemental charging (a large load), so the generators are almost fully loaded whenever they are turned on. This optimizes the generator's fuel efficiency and reduces emissions relative to the energy produced.

Following is a partial list of maintenance activities that may be performed on PV systems.

- Inspect the PV array surface for excessive dirt or debris. (A thin layer of dust is not a concern.) If the surface needs cleaning, a gentle rinse with plain water or mild detergent is recommended.
- Inspect the array for damaged modules or shading by trees, weeds, and other obstructions.
- Measure the array output current and voltage to verify proper operation.
- Seasonally adjust the PV array tilt angle to optimize energy output (cost effective for larger systems only).
- Inspect the battery for corroded terminals. Clean the terminals if required.
- Add distilled water to flooded batteries if the electrolyte level is low.
- Measure the battery voltage to verify state of charge.
- Inspect trackers to verify proper tracking of the sun.
- Inspect the entire system for loose or damaged wiring.

PV systems with maintenance-free batteries should be inspected approximately once each year. However, to cut down on maintenance costs for small noncritical applications (such as pathway lighting), some agencies simply allow the PV systems to run until they fail and then replace all worn-out components. Others schedule maintenance visits only when the batteries or short-lived loads such as lamps are expected to need replacement.

PV systems with flooded batteries should be inspected every 3 to 6 months to ensure the electrolyte levels are maintained. However, batteries with catalytic recombiner caps or extra-large electrolyte reservoirs may operate for as long as a year between maintenance visits.

Equipment Warranties

PV modules currently carry 10- to 20-year manufacturer warranties against degradation of power output. The other electronic components (inverters and charge controllers) typically carry 5-year warranties. Batteries, because of their variable uses (or abuses), typically only have 1-year warranties.

For complete packaged systems, the system manufacturers will often warranty the operation of the entire system for as long as 2 years and have some optional extended warranties available.

Codes and Standards

PV systems can and should be designed and installed to provide years of safe, reliable service. Systems not installed safely could result in fire, personal injury, and even death. The National Electrical Code (NEC) was developed to ensure safe electrical systems and addresses PV systems in a special section (section 690). This section specifies the required wire sizes, fuses, disconnects, and other considerations that make a safe system possible. PV systems should be installed by qualified licensed electricians who are familiar with NEC requirements.

Costs

The cost of PV modules has steadily declined since the mid-1970s (when they cost more than $100/W) to less than $6/W today. Efforts are currently under way by U.S. laboratories and PV manufacturers to further reduce PV module costs by making manufacturing processes more efficient and by introducing new, less expensive PV technologies.

Lower-priced modules will help lower PV system costs, but the impact on stand-alone PV systems will not be great because PV modules account for only about one-third of the initial cost of these systems. (Batteries typically account for another third and the inverter and balance of systems the final third.) During the lifetime of a stand-alone PV system (about 20 years) the batteries account for the greater part of system costs because they need to be replaced two to three times.

According to the current GSA schedules for PV equipment, crystalline PV modules in the 50- to 120-W size range are available for $4.80 to $5.70/W, depending on the make and size of the PV modules. The cost for sealed maintenance-free batteries in the 100- to 500-ampere-hour (Ah) size (at 12 volts [V]) ranges from $1.50 to $5.25/Ah of capacity, depending on the make, type of technology, and size. Flooded-battery prices are generally lower and average $1.50/Ah for the 500- to 1,500-Ah size (at 12 V). Inverter prices range from $0.40 to $0.75/W of capacity, depending on the size, type of waveform, and available features.

The GSA schedules also include complete, integrated, packaged PV power systems that can be used for various applications. Prices average about $14/W for mid-sized DC systems (100- to 600-W PV arrays) and $18/W for larger AC systems (900- to 1,800-W PV arrays).

Some utilities have recently made large purchases of grid-tied systems for as low as $6/W installed, but these systems do not include batteries or charge controllers and these prices are available for large-quantity purchases only.

Most PV system components are available from suppliers within 1 to 2 weeks unless certain items are out of stock. Complete systems take longer for delivery (typically 4–8 weeks) because the supplier has to assemble and test the systems.

Procurement

Federal facilities have several options for procuring PV systems. They include GSA schedules, electric utility companies, and the Photovoltaic Services Network (PSN), energy savings performance contracting (ESPC), and traditional procurement through Requests for Quotes.

The amount of PV equipment available through GSA schedules has increased considerably in the latest edition, which covers December 1, 1996, to November 30, 2001. In the schedule for PV equipment (class 6117), eight suppliers now provide components that range from PV modules to trackers to complete systems. The prices on the schedules are guaranteed to be the lowest for the specific makes and models of the equipment offered. Table 2 identifies the GSA PV equipment suppliers and the equipment they offer. (Call each supplier to obtain a GSA PV products catalog.) If the equipment and systems on the schedule meet your requirements, this is the most straightforward means of procuring a PV system.

If funding for capital equipment is not readily available, the electric utility or ESPC option may be more appealing. Electric utilities have begun to offer services such as equipment leases, financing, and sales of PV equipment. For a description of these services, see the next section, Utility Incentives and Support.

ESPC may soon become available to Federal facilities for PV projects. With ESPC, facilities pay the up-front costs for determining the economic feasibility of a PV project. If feasible, a private energy services contractor designs and installs the PV

Table 2. GSA suppliers and equipment

	Components					
	Complete Systems	PV Modules	Batteries	Charge Controllers	Inverters	Trackers
American Sunco Blue Hill, ME; 207.374.5700						●
Applied Power Corporation Lacey, WA; 360.438.2110	●	●	●	●	●	
Atlantic Solar Products, Inc. Baltimore, MD; 410.686.2500		●	●	●		
BP Solar, Inc. Fairfield, CA; 707.428.7800	●					
Photocomm, Inc. Scottsdale, AZ; 800.223.9580	●	●	●	●	●	
Siemens Solar Industries Camarillo, CA; 805.388.6389		●				
Solar Electric Specialties Santa Barbara, CA; 805.963.9667	●					
Sunwize Energy Systems, Inc. Stelle, IL; 815.256.2222	●					

system; the costs of equipment and installation labor are paid by the contractor or financed by a third party. The contractor is responsible for all system O&M, staff training, and saving verification. Once the system is installed, the contractor is paid a percentage of the facility's O&M savings for a specified contract period. After the period is over, the facility retains all savings and equipment.

The advantages of ESPC are: limited initial investment, no capital investment, no O&M responsibilities, and no technical or financial risk for the success of the project. However, monitoring and paperwork make it unattractive for smaller projects that can be funded in other ways.

FEMP is now developing a Super ESPC program for Federal facilities. Contact FEMP for details.

Utility Incentives and Support

Electric utility companies have begun to recognize that constructing or maintaining line extensions to every small load does not make economic sense for them or for their customers. The customer may be willing to pay the initial high cost for line construction, but small loads often do not generate enough revenue in electricity sales to cover the utility's cost for line maintenance. In the case of rural utilities that serve remote loads, the lines that were built during the era of rural electrification are now aging and need to be repaired or replaced. Many lines that once served ranches and farmsteads now serve only a stock watering pump or other small loads. Also, many publicly owned utilities, such as rural electric cooperatives, still have generous line extension policies that do not charge the customer the full cost for new line construction.

When small loads do not generate enough revenue to cover the cost of line construction or maintenance, the entire customer base pays the difference. Utilities want to serve their customers as equitably and cost effectively as possible, so some offer PV-based electric services when line-tied power doesn't make sense. Also, in this era of utility deregulation and increased competition, PV is viewed as a service that promotes customer loyalty.

PV customer service programs vary from utility to utility, but two basic options are usually offered: (1) PV system leases; and (2) direct sales. With the lease option, the customer is usually billed a monthly charge that covers the cost of PV equipment, regular maintenance visits, and replacement components. This option offers the customer an easy way to become familiar with PV technology without making a large up-front investment.

For the same reason, leases may work for Federal agencies that have an immediate need for PV systems but inadequate capital to purchase them. Facilities that do not want the responsibility of PV system maintenance may also decide to exercise this option.

The second option, sales, is often offered because there may be no PV system suppliers in the area or because customers prefer to obtain PV systems from their own utility.

If either option is of interest to you, call your local utility and ask whether it offers a PV program. If it does not, other utilities in the region may be able to help you because PV represents "service without a wire," and utility PV programs are not necessarily limited to their traditional service territories.

The goal of two utility organizations, PSN and the Utility PhotoVoltaics Group (UPVG) is to promote and support the use of PV by utilities. These organizations have utility members throughout the United States who are interested in implementing PV services and projects, and they may be able to help you locate a regional utility that offers PV. Also, PSN may be able to provide PV system financing and sales directly on behalf of its member utilities if a local utility cannot. For the phone numbers and contact persons of these two organizations, see the Organizations subsection on page 23.

Separate from cost-effective, off-grid applications, some utilities offer PV systems because their customers want renewable energy and are willing to pay for it. Therefore, some utilities offer grid-tied PV systems for a cost beyond what customers would usually pay for electricity. These systems use "green" power very visibly and make good demonstrations projects for schools, parks, libraries, and other public facilities.

Building-Integrated Photovoltaic Systems

Building-integrated photovoltaic (BIPV) systems incorporate solar electric arrays directly into a building envelope. BIPV enables a building to generate its own energy, and its arrays can be designed as a curtain wall and to generate electricity, so they are considered multifunctional building components.

For BIPV to be economically feasible, the following issues must be considered:

- For residential systems, BIPV systems must be able to sell back to the utility at or near the customer cost of power, rather than at the utility avoided cost.

- Variations in commercial rate structures must be defined.
- Some high-value niche markets, such as strained areas of the utility grid and selected sloped glazing and skylight systems, can be cost effective in the near term.
- The PV industry, DOE, and the public utility companies should work together to evaluate BIPV benefits.

Technology Performance

Sandia has conducted studies of PV system use in three Federal agencies—NPS, the BLM, and the Forest Service. Their objectives were to:

- Identify and characterize PV systems by application
- Assess acceptance and satisfaction with the systems
- Identify barriers to PV system use
- Identify potential applications.

The results of these studies are reported in *Renew the Parks, Renew the Public Lands*, and *Renew the Forests*. Some results are summarized below.

Field Experience

As part of the studies, facilities with PV systems were asked to identify the ages of the systems, and to evaluate each system component and the system as a whole. Table 3 shows the approximate ages of the PV systems at the time the studies were conducted.

Table 3. Ages of PV systems identified by three Federal agencies

Agency	Less than 2 years	2–5 years	5–10 years	Older than 10 years
NPS	23%	28%	34%	15%
Forest Service	19%	49%	14%	19%
BLM	42%	26%	17%	15%

In the NPS study, responses indicated that 97% of the systems met their use objectives. Problems associated with the remaining 3% included:

- Operating errors (turning off the systems during the winter)
- Poor design (insufficient charging capacity or battery storage)
- Component failure
- PV panel theft or vandalism.

Component problems reported by the parks include battery problems (19 systems), PV panel problems (10 systems), and controller problems (8 systems).

There was no correlation between the ages of the troubled systems and the problems they were experiencing. Most problems were evenly distributed between the 2- to 4-year and 5- to 9-year categories. Only three systems less than 2 years old had any problems.

In the Forest Service study, overall satisfaction with the systems was higher than 98%. Of the 2% unsatisfactory systems, the problems focused on panels and batteries; most resulted from theft and vandalism. Proper siting and security measures such as fencing and vandal-resistant hardware were responsible for the low theft and vandalism rate. Battery performance and accurate load calculations, which are critical for proper system sizing, appear to be the main factors in the few deficient systems identified.

There were few reports of significant damage to the Forest Service PV systems, but weather appears to be the greatest source. Most damage can be prevented or minimized with properly designed array supports and inclination, component insulation and heating, and proper grounding.

Maintenance

NPS facilities staff were asked about their annual PV system O&M costs. When divided into three categories, their responses were as follows:

- 39%—less than expected or none
- 60%—as expected
- 1%—more than expected.

The following responses were received from the BLM:

- 12%—no O&M costs
- 34%—less than expected
- 50%—as expected
- 4%—more than expected.

As seen from these responses, PV system maintenance was much less of an issue than initially expected.

Barriers

The other significant finding of the three studies constituted the perceived barriers to the expanded use of PV systems.

The single largest perceived barrier for NPS and the Forest Service and second largest for the BLM is the initial cost of PV systems. PV systems generally have higher initial installation costs than alternatives such as engine generators, but they are much less expensive to operate and maintain. LCC analysis often favors PV. To overcome this barrier, partnerships and cost-sharing arrangements can be formed with other groups and agencies such as DOE, NREL, Sandia, the U.S. Environmental Protection Agency (EPA), environmental groups, and the PV industry. DOE's FEMP was established to fund viable renewable energy and energy and water conservation projects undertaken by Federal agencies.

The largest barrier to PV use for the BLM and second largest for NPS and the Forest Service is lack of familiarity with PV by designers and operating staff; related to this is uncertainty with PV's performance record. Technical training for design and maintenance staff can help them understand PV technology with its advantages and limitations. Training can also help staff recognize potentially cost-effective PV applications and provide sources for obtaining equipment, services, and assistance. The PV Systems Assistance Center at Sandia can provide PV training and identify classes and workshops.

Other perceived barriers include vandalism, visual-quality concerns, conflicts with historical resource context, adverse climate, procurement restrictions and problems, and inability to locate contractors.

Case Study

Facility Description

Pinnacles National Monument in California is a popular destination for rock climbers who take advantage of the park's large rock formations. Peak park visitation occurs during the summer, although Pinnacles is staffed and open to visitors year round. The climate is mostly hot and dry with a good solar resource.

The park facilities are in an agricultural region with many vineyards, and are located 5 to 6 miles from utility power. Because the park's power lines must be underground and because power line easements through the surrounding territory are difficult to obtain, utility power was ruled out as being prohibitively expensive.

The park's facilities include:

- A visitor contact station
- An 18-unit campground with restroom facilities
- A ranger station
- An information kiosk
- Two ranger residences
- A maintenance building.

An energy audit conducted by Sandia revealed the main electrical loads to be water and effluent pumps, three old refrigerators, evaporative coolers, an air conditioner, a water heater, a cook stove, and many incandescent lights. The energy use was approximately 90 kWh/day.

Conventional Technology Description

The park's electrical needs were served by two 60-kW diesel generators. To provide continuous power, a generator had to be run 24 hours per day, 365 days per year. Each generator was cycled every 2 weeks so maintenance could be performed on the other. Because the generators are large, the electrical load could not be reduced significantly without affecting generator operation (frequency and voltage). Therefore, to keep the generator stabilized, dummy loads (numerous incandescent lights) had to be kept on 24 hours per day.

Diesel fuel was delivered to the park about once each week by truck over 15 miles of narrow winding access road. The possibility of a fuel spill was a concern because of frequent deliveries and the dangerous nature of the road during poor weather.

The generators also diminished visitor and staff enjoyment of the park. Their noise could be heard throughout the park, even from the tops of rock formations. Staff received frequent complaints about the noise.

The diesel fuel for the generators cost the park approximately $12,000 per year and maintenance another $4,000. Also, the generators needed to be replaced every 5 years at a cost of $50,000.

New Technology (PV) Description

The case study described here is an example of a large PV/engine generator hybrid system funded by NPS. This system, installed at Pinnacles National Monument near Salinas, California, provides power for a cluster of park facilities on an isolated mini-grid. Originally powered by two diesel generators, the park converted to a PV hybrid system with a propane generator to save on fuel and maintenance costs and to eliminate the possibility of a diesel fuel spill.

Savings Potential

The first step before sizing a PV system was to implement energy efficiency measures to decrease the load. The refrigerators were replaced by super-efficient Sunfrost refrigerators that require about 80% less energy. The single air conditioner was replaced with an evaporative cooler, and the old evaporative coolers were replaced with newer, more efficient models. The electric water heater and cook stove were replaced with propane models, and all incandescent lightbulbs were changed to compact fluorescents.

Water-saving measures such as low-volume toilets and shower and faucet flow restrictors were used to decrease the volume of water and effluent that needed to be pumped. After these measures were implemented, the electrical energy use was reduced to about 40 kWh/day.

Once the size of the reduced load was determined, the system requirements were turned over to a PV systems supplier who designed and specified the PV/generator hybrid system. The system included:

- A 9.6-kW PV array with 160 Solarex MSX 60 modules
- A 4,200-Ah battery bank with 12 GNB Resource Commander flooded lead acid batteries
- A Kohler 20-kW propane generator
- Six 4-kW Trace 4048 inverters
- An Ananda APT 5-44-48 power center with two charge controllers.

A specification for a PV system similar to the Pinnacles system is included in Appendix D.

The PV hybrid system, all energy efficiency measures, and installation cost $150,000. The annual cost for propane fuel is approximately $1,500 per year, and the maintenance costs are about $750 per year. The batteries need to be replaced about once every 8 years at a cost of $22,000.

Life-Cycle Cost

When the capital investment and O&M costs of the two alternatives are entered into

National Park Service/PIX04924

Figure 9. The PV array mounted on the roof of the maintenance building at Pinnacles National Monument.

the 1998 BLCC program, the results show that the PV system has a net saving of $146,711 for the 20-year study period. The savings-to-investment ratio (SIR) is 4.51 and the adjusted internal rate of return (AIRR) is 12.24%. Simple payback occurs in year 5, and discounted payback in year 6. For a printout of comparative LCC with the BLCC software, see Appendix E.

Implementation and Post-Implementation Experience

The PV array was mounted on the roof of the park maintenance building where the old generators were housed (see Figure 9). The rest of the components, including the new generator, were installed inside the building. The PV array provides all the energy needed for 5 months of the year (from May through September), so the generator is not used during those months. During the coldest winter months, the PV array provides approximately 30% of the required energy; the generator makes up the difference. During those months the generator operates 2 to 3 hours a day to charge the batteries.

After the PV system was installed, the park staff commented on how many birds there were in the park. The birds had always been there, but the staff hadn't noticed them because they couldn't be heard over the noise of the old generators.

Case Study

Facility Description

Meadows Group and Buffalo Creek are unstaffed Forest Service campgrounds near the Colorado Trail, a popular hiking destination. Facilities are limited to water, toilets, picnic tables, and fire pits at each campsite.

The average daily water requirements for the two campgrounds are supplied by a single well located at Meadows Campground. The well is 80 feet deep; the static water level (when the well isn't being pumped) is 50 feet below the ground surface. The water level drops another 10 to 15 feet while the well is being pumped. The water is piped a short distance from the well to a water meter housed in a small shed and then piped uphill (about 75 feet of elevation gain) to a 1,000-gallon storage tank. Piping from the tank gravity feeds faucets at the two campgrounds.

The pumping head was calculated as follows:

Static water level	50 ft
Water drawdown	15 ft
Discharge head to tank	75 ft
Total pumping head	**140 ft**

Conventional Technology Description

The water was originally pumped with a submersible AC well pump powered by a 4-kW gas-fueled generator. Forest Service staff from the nearby Buffalo Creek work station visited the campground about once every 3 days to fuel and start the generator. Once started, the generator could be left to run until it ran out of gas, or it was switched off automatically when the water tank filled. A full gas tank (5 gallons) could pump about 500 gallons of water. The 5-mile drive between the work station and the campground over a rough gravel road takes about 30 minutes each way, and the generator is operated for 30 minutes, for a total of $1^1/_2$ hours of staff time per visit.

Forest Service staff changed the generator's oil about every other week and performed a tune-up once each season. The oil changes took 15 minutes and 2 quarts of oil. The tune-ups took approximately 2 hours. The generator was replaced once every 5 years at a cost of about $1,500. The average rate for staff time is about $50/hour.

New Technology (PV) Description

This is an example of a PV-powered pumping system used to pump water for two campgrounds in the Pike National Forest near Denver, Colorado. The pumping system provides Meadows Group and Buffalo Creek Campgrounds with potable water during the summer camping season (mid-May to mid-September). The original generator-powered pumping system was replaced with the PV pumping system to save on operating labor and maintenance.

The engineering staff of the regional Forest Service office worked on the plans and requirements for replacing the pumping systems and specifying the new equipment. Before the PV pumping system was selected, the well was checked to verify the static water level and water drawdown. The design point for the pumping system was delivery of 500 gallons per day at a total head of 150 feet. A submersible centrifugal pump was specified to minimize pump maintenance, and trackers were specified to take advantage of the long summer days. The system was procured through the local utility, Intermountain REA. Intermountain's PV system supplier, PSN, was able to help size, specify, and install the system.

The PV pumping system includes:

- A 616-W PV array with eight Solarex MSX 77 modules
- A Grundfos centrifugal solar pump with brushless AC motor
- A SunSub pump controller
- Two Zomeworks passive trackers.

Savings Potential

The system includes all array mounting hardware, wiring, and connectors; a grounding kit; and disconnect switch for $7,587. The cost of installation, which included a pitless adapter for the well, new piping, and a new shed, was $4,250. No routine maintenance other than visual inspection (which takes about 1 hour each year) is required,

Life-Cycle Cost

Generator O&M was very costly. The staff visited the system about once every 3 days from mid-May to mid-September (40 visits) at 1.5 hours per visit about 60 hours each year to operate the generator. Two more hours were required for oil changes and 2 more for tune-ups. The total annual O&M time was approximately 64 hours. At $50/hour, O&M labor cost the Forest Service about $3,200/year. Gas cost another $240 (5 gallons/visit x 40 visits x $1.20/gallon) and oil about $20 (2 quarts every two weeks x $1.25/quart). The total generator O&M cost was almost $3,500/year.

In comparison, the PV pumping system takes virtually no time to operate or maintain. The pump operates during the day whenever the water level in the tank activates a float switch, and annual inspection of the system takes about 1 hour each year at a cost of $50.

When the above figures are entered into the 1997 BLCC program, the results show a net savings of $44,000 for the 10-year study period. The SIR is 7.2 and the AIRR is 14.57%. Simple payback occurs in year 3 and discounted payback in year 4. For a printout of comparative LCC with the BLCC software, see Appendix F.

Implementation and Post-Implementation Experience

The PV pumping system was installed in May 1997 just before the campgrounds opened. The pump was installed in the well by a local well service contractor and the array was installed by an electrical contractor with assistance from a PSN technical representative. The installation took 5 people approximately 5 hours to complete. It included installing a new pitless adapter on the well (instead of the old pump house) and piping to and from a new shed to house the water meter and pump controller. After the installation, the PV array and the shed were enclosed by a 6-foot chain-link fence to discourage vandalism and theft. At the time of this writing, the system had operated for about 1 month with no problems.

Case Study

Facility Description

The Thoreau Center is an incubator for nonprofit environmental groups. It is housed in an historic former Army hospital at Presidio National Park in San Francisco, California.

Conventional Technology Description

The developers renovated the building and included an atrium at the entryway. PV cells that produce electricity and form an element in the shading and daylighting design are now laminated to the skylight glass. This project was funded through a partnership between FEMP; NREL; NPS; Equity Community Builders (San Francisco, California); Solarex, Inc. (Frederick, Maryland); Atlantis Solar (Grass Valley, California); Trace Engineering (Arlington, Washington); and Tanner, Leddy, Maytum, Stacy Architects (San Francisco, California).

New Technology (PV) Description

The PV glazing system consists of 24 PV modules. The spacing of the cells within the modules allows approximately 17% of the sunlight into the entryway, which reduces the need for electric light. The module panels are laminates that are constructed with:

- Six-mm Solarphire glass
- Thirty-six polycrystalline silicon PV cells
- Ethylene vinyl acetate
- A translucent Tedlar-coated polyester backsheet
- Two sealed and potted junction boxes with a double pole plug connector.

The cells are laminated in a six-cell by six-cell matrix, with a minimum spacing of 0.5 in. (1.25 cm) between cells. The dimension of each module is 32 in. by 37 in. (81 cm by 94 cm). The gross area of the entire structure is 200 ft^2 (18.8 m^2).

The power will be converted to high-quality AC electricity and will supplement power supplied to the building by the utility. The system is rated at 1.25 kW, and each module generates 8.5 V of DC at approximately 5.0 amperes. The modules are connected in a series to feed the sine-wave inverter, which is configured to 48 V and rated at 4,000-W capacity.

Savings Potential

The electrical energy delivery for the atrium is estimated at 2,237 kWh/year. At $0.09/kWh, this corresponds to an annual cost saving of $201.37/year.

Life-Cycle Cost

The present worth of the 25-year life cycle saving is $3,363, using the NIST 3.4% discount rate.

Implementation and Post-Implementation Experience

Implementation issues included code acceptance and regulatory barriers. Although testing indicates structural performance comparable to other glazing products, for this first-of-a-kind demonstration the overhead PV glazing was mounted above skylight glass accepted by California codes. The design had to be reviewed and accepted before the system could be connected to the Pacific Gas & Electric (PG&E) grid.

Technology in Perspective

The Technology's Development

The commercialization of PV power is fairly recent, but the PV effect was discovered long ago in 1839. A French physicist named Edmond Becquerel found that certain materials produced an electric current when they were exposed to light. Later, in the 1870s, selenium PV cells were developed with conversion efficiencies of 1%–2%. (Conversion efficiency is the percentage of light energy that a PV cell or module converts to electrical energy.) These cells were used by photographers to measure light levels.

The first crystalline silicon PV cells, the precursors of those most commonly used today, were developed in 1954 by scientists at Bell Laboratories. These cells had conversion efficiencies of about 4% and received their first cost-effective application in the space program. A small array of PV cells was sent into space on the U.S. Vanguard satellite to power its radio. The cells worked so well that PV technology has been a part of the space program ever since.

The space race of the 1950s and 1960s spurred improvements in PV cell design and efficiency, but the drive to make space-qualified PV cells lightweight and efficient led to high costs that were uneconomical for terrestrial applications. During the world energy crisis in the mid-1970s, PV was recognized as a possible energy solution. The PV industry attracted the interest of large energy companies and government agencies. With their investment capital, module development accelerated tremendously and PV module costs began to decrease.

Crystalline PV cells were the main focus of this effort, but other promising materials and manufacturing processes were explored. PV modules that use materials such as cadmium telluride and amorphous silicon (thin-film technologies) are now commercially available and promise to further decrease PV costs.

Today PV modules are available with conversion efficiencies that range from 5% (thin films) to 15% (single-crystal silicon), and laboratories have achieved cell conversion efficiencies as high as 24%.

Technology Outlook

As the cost of PV drops and the cost of conventional power generation increases, PV will become economical for more and more applications, including customer-owned grid-tied systems and bulk utility power.

A continuing expansion of PV use in the utility sector is described in an Institute of Electrical and Electronics Engineers (IEEE) conference paper by Joseph Iannucci and Daniel Shugar ("Structural Evolution of

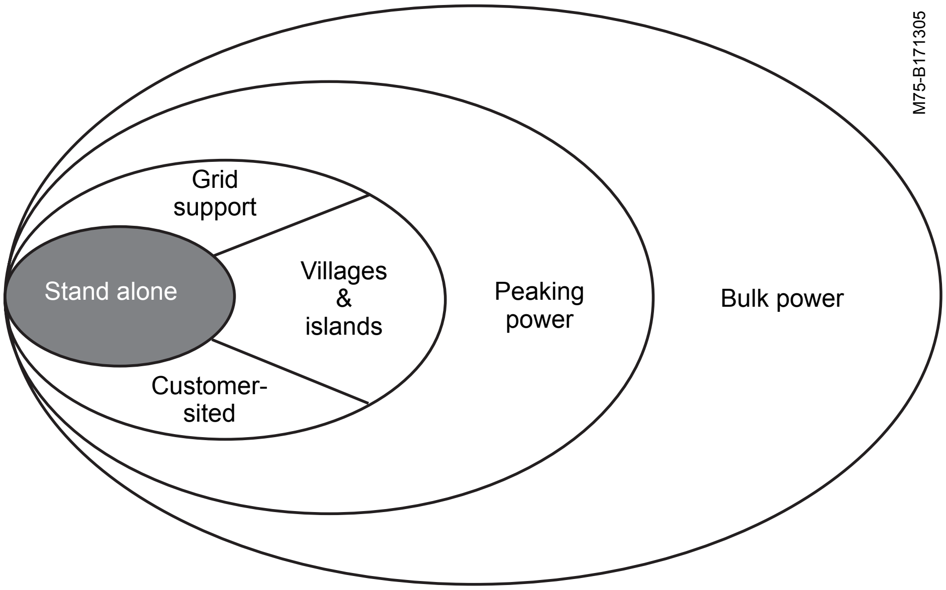


Figure 10. The diffusion model for utility PV.

Utility Systems and Its Implications for Photovoltaic Applications," *1991 IEEE Photovoltaics Specialists Conference*). They propose that a slow diffusion in the use of PV applications from the small scale to utility bulk power will take PV from its current stage to that of energy significance. The multi-stage process is shown in Figure 10.

The small stand-alone applications shown in the figure are cost effective today. They are typically remote applications that pay for themselves within 6 months to 2 years. These applications provide utilities (and other facilities) with familiarity and successful experience with PV. They also provide a small but stable and growing market for the PV industry.

In the next stage, grid-support applications are novel utility PV applications that can support the utility distribution grid in cases where the solar resource matches the need for added energy, capacity, reliability, or voltage support. An example of this type of system is the Kerman substation PV system installed by PG&E. This system was installed as a demonstration to support a distribution feeder with summertime overloading problems. When all the benefits of the project, including environmental externalities, were considered, the project was nearly economical.

Village and island power systems are currently being installed throughout the world. They usually involve small, isolated distribution grids and a backup engine generator. They may or may not include batteries. The Pinnacles National Monument case study is an example of this type of system. These systems are cost effective today.

Customer-sited rooftop PV systems are used where land would otherwise be a large part of the system expense. They could be installed and financed by the local utility (or qualified contractor) and serve the dual purpose of producing power for the customer and utility system support. The rooftop systems installed by the Sacramento Municipal Utility District (SMUD) are examples of this type of system. SMUD's purchase of large quantities of PV is stimulating the PV industry and bringing down costs, so customer-sited PV systems may become cost effective in the near future.

SMUD offers its grid-connected utility customers the option to participate in the PV Pioneer Program, in which the utility-owned PV system is installed on the customer's premises. Many customers are willing to pay a "green fee" (an additional 15% or about $4–$6 on their monthly electricity bills) to help facilitate the early adoption and commercialization of this technology.

The customers provide SMUD with free roof space for its array, and the power is fed directly into the grid. So far, SMUD has installed more than 600 rooftop systems that total nearly 2 MW of PV. Despite its cost, demand for these systems continues to exceed supply.

The natural progression of customer-sited PV is to integrate the PV system where it is used, into the structure of the building. The attractive incorporation of PV in architectural design provides the opportunity for the technology to become a multifunctional building element. BIPV products and systems currently available from manufacturers on a turnkey basis include building facades,

SAtlantis Energy, Inc./PIX04780

Figure 11. PV integrated into a skylight system at the Thoreau Center for Sustainability at Presidio National Park in San Francisco.

curtain walls, spandrel panels, glazing, awnings, roof shingles, raised-seam metal roofing, batten-seam metal roofing, roof tiles, and pavers. An example of BIPV is shown in Figure 11.

The peaking-power PV application is used to support utility demand (power) peaks when they are matched by the solar resource. PV costs must drop to nearly $0.10/kWh before they are cost effective for this application. A project is now in the planning stages to provide this type of PV power. CSTRR, a nonprofit corporation supported by the Federal government and the PV industry, is involved in constructing the Solar Enterprise Zone (SEZ) in southern Nevada. SEZ plans call for the installation of more than 1,000 MW of solar thermal and PV power by the year 2003. One SEZ participant, Amoco/Enron, a PV manufacturer, has agreed to sell power from PV installed at SEZ at an unprecedented rate of less than $0.10/kWh. The first PV arrays are scheduled to be put on line by 1999.

The eventual goal and final stage in the diffusion process is for PV power to be able to economically fulfill utility bulk-power applications. Once completed, SEZ will also provide power for this application.

Manufacturers

Manufacturers of PV modules including those listed in the 1997 Solar Energy Industries Association membership directory:

ASE Americas, Inc.
4 Suburban Park Drive
Billerica, MA 01821
Phone: (508) 667-5900
Fax: (508) 663-2868

AstroPower, Inc.
Solar Park, 461 Wyoming Road
Newark, DE 19716-2000
Phone: (302) 366-0400
Fax: (302) 368-6474
E-mail: sales@astropower.com

Atlantis Energy, Inc.
233 S. Auburn, Suite 110
Colfax, CA 95713
Phone: (804) 442-3509
Fax: (804) 442-3755

BP Solar, Inc.
2300 N. Watney Way
Fairfield, CA 94533
Phone: (707) 428-7800
Fax: (707) 428-7878

Energy Conversion Devices
1675 W. Maple Road
Troy, MI 48084
Phone: (810) 280-1900
E-mail: michelle@ovonic.com

ENTECH, Inc.
1077 Chisolm Trail
Keller, TX 76248
Phone: (817) 379-0100
Fax: (817) 379-0300

EPV — Energy Photovoltaics
P.O. Box 7456
Princeton, NJ 08543
Phone: (609) 587-3000
Fax: (609) 587-5355

Evergreen Solar, Inc.
211 Second Avenue
Waltham, MA 02154
Phone: (617) 890-7117
Fax: (617) 890-7141
E-mail: farberma@aol.com

Global Solar Energy
12401 W. 49th Avenue
Wheat Ridge, CO 80033
Phone: (303) 420-1141
Fax: (303) 420-1551

Golden Genesis, Inc.
4545 McIntyre Street
Golden, CO 80403
Phone: (303) 271-7172
Fax: (303) 271-7410

Golden Photon
P.O. Box 4040
Golden, CO 80402
Phone: (303) 271-7150

Golden Technologies
4545 McIntyre Street
Golden, CO 80403
Phone: (303) 271-7177
Fax: (303) 271-7410

ISET
8635 Aviation Boulevard
Inglewood, CA 90301
Phone: (310) 216-4427
Fax: (310) 216-2908

Kyocera America, Inc.
8611 Balboa Avenue
San Diego, CA 92123
Phone: (619) 576-6247
Fax: (619) 569-9412
E-mail: apanton@kii.attmail.com

Photovoltaics International, LLC
171 Commercial Street
Sunnyvale, CA 94086
Phone: (408) 746-3062
Fax: (408) 746-3890

Pilkington Solar International
1615 L Street, NW
Washington, DC 20036
Phone: (202) 463-4698

PowerLight Corporation
2954 San Pablo Avenue
Berkeley, CA 94710
Phone: (510) 540-0550

Siemens Solar Industries
4650 Adohr Lane
Camarillo, CA 93011
Phone: (805) 388-6588
Fax: (805) 388-6395
E-mail: sunpower@solarpv.com

Siemens Solar Industries — Florida
6909 S.W. 18th Street, Suite. A-301-B
Boca Raton, FL 33433
Phone: (561) 416-7205
Fax: (561) 362-5513

Solar Cells, Inc.
1702 N. Westwood Avenue
Toledo, OH 43607
Phone: (419) 534-3377
Fax: (419) 534-2794

Solar International, Inc.
12533 Chadron Avenue
Hawthorne, CA 90250
Phone: (310) 970-0065

Solar Kinetics, Inc.
10635 King William Drive
Dallas, TX 75220
Phone: (214) 556-2376
Fax: (214) 869-4158

Solarex Corporation
630 Solarex Court
Frederick, MD 21703
Phone: (301) 698-4213
Fax: (301) 698-4201
E-mail: info@solarex.com

Solarex Corporation — Colorado
4089 Valley Oak Drive
Loveland, CO 80538
Phone: (970) 593-9500
Fax: (970) 593-9373

Solarex Corporation — Pennsylvania
826 Newton-Yardley Road
Newton, PA 18940
Phone: (301) 698-4200
Fax: (301) 698-4201

Solarex Corporation — Arizona
10752 N. 89th Place, Suite 210
Scottsdale, AZ 85260
Phone: (602) 451-8050
Fax: (602) 451-8040

Solec International, Inc.
970 E. 236th Street
Carson, CA 90745
Phone: (310) 834-5800

Spire Corporation
One Patriots Park
Bedford, MA 01730-2396
Phone: (617) 275-6000
Fax: (617) 275-7470
E-mail: spire.corp@channel1.com

SunWize Energy Systems, Inc.
1151 Flatbush Road
Kingston, NY 012401
Phone: (914) 336-7700
Fax: (914) 336-7172

United Solar Systems Corporation
5278 Eastgate Mall
San Diego, CA 92121-2814
Phone: (619) 625-2080
Fax: (619) 625-2083

Utility Power Group
9410 De Soto Avenue, Unit G
Chatsworth, CA 91311
Phone: (818) 700-1995
Fax: (818) 700-2518

Suppliers of complete PV systems including those listed in the 1997 Solar Energy Industries Association membership directory:

A.Y. McDonald Manufacturing Co.
4800 Chavenelle Road
P.O. Box 508
Dubuque, IA 52002
Phone: (319) 583-7311
Fax: (319) 588-0720

ADDCO Manufacturing
69 Empire Drive
St Paul, MN 55103
Phone: (612) 224-8800
Fax: (612) 224-1411

Advanced Energy Systems, Inc.
Riverview Mill
P.O. Box 262
Wilton, NH 03086
Phone: (603) 654-9322
Fax: (603) 654-9324
E-mail: info@advancedenergy.com

Advanced Thermal Systems, Inc.
7600 E. Arapahoe Road, Suite 215
Englewood, CO 80112
Phone: (303) 721-8411
Fax: (303) 721-6568

Amonix, Inc.
3425 Fujita Street
Torrance, CA 90505
Phone: (310) 325-8091
Fax: (310) 325-0771

Arcadia, Inc.
251 Township Line Road
Douglassville, PA 19518
Phone: (610) 326-9633
Fax: (610) 970-9383
E-mail: arcadia@angelite.com

Ascension Technology
P.O. Box 6314
Lincoln Center, MA 01773
Phone: (617) 890-8844

ASE Americas, Inc.
4 Suburban Park Drive
Billerica, MA 01821
Phone: (508) 667-5900
Fax: (508) 663-2868

AstroPower, Inc.
Solar Park, 461 Wyoming Road
Newark, DE 19716-2000
Phone: (302) 366-0400
Fax: (302) 368-6474
E-mail: sales@astropower.com

Atlantic Solar Products, Inc.
9351 J. Philadelphia Road
P.O. Box 70060
Baltimore, MD 21237-4114
Phone: (410) 686-2500
Fax: (410) 686-6221

Atlantis Energy, Inc.
233 S. Auburn, Suite 110
Colfax, CA 95713
Phone: (804) 442-3509
Fax: (804) 442-3755

Besicorp Group, Inc.
1151 Flatbush Road
Kingston, NY 12401
Phone: (914) 336-7700
Fax: (914) 336-7172

BP Solar, Inc.
2300 N. Watney Way
Fairfield, CA 94533
Phone: (707) 428-7800
Fax: (707) 428-7878
E-mail: sowterrv@bp.com

Direct Global Power, Inc.
1482 Erie Boulevard.
P.O. Box 1058
Schenectady, NY 12305
Phone: (518) 395-5021
Fax: (518) 395-2607

Diversified Technologies
35 Wiggins Avenue
Bedford, MA 01730-2345
Phone: (617) 275-9444

ElectriSol Ltd.
1215 E. Harmont Drive
Phoenix, AZ 85020
Phone: (602) 997-6855
Fax: (602) 943-5842

Electron Connection
P.O. Box 203
Hornbrook. CA 96044
Phone: (800) 945-7587
E-mail: econet@snowcrest.net

EPV — Energy Photovoltaics
P.O. Box 7456
Princeton, NJ 08543
Phone: (609) 587-3000
Fax: (609) 587-5355

Evergreen Solar, Inc.
211 Second Avenue
Waltham, MA 02154
Phone: (617) 890-7117
Fax: (617) 890-7141
E-mail: farberma@aol.com

FIRST, Inc.
66 Snydertown Road
Hopewell, NJ 08525
Phone: (609) 466-4495

Global Solar Energy
12401 W. 49th Avenue
Wheat Ridge, CO 80033
Phone: (303) 420-1141
Fax: (303) 420-1551

Golden Genesis, Inc.
4545 McIntrye Street
Golden, CO 80403
Phone: (303) 271-7172
Fax: (303) 271-7410

Hitney Solar Products
2655 Hwy 89
Chino Valley, AZ 86323
Phone: (520) 636-1001

Independent Power & Light
462 Solar Way
Hyde Park, VT 05655
Phone: (802) 888-7194
E-mail: indeppower@aol.com
Web site: www.independent- power.com

Integrated Power Corporation
7618 Hayward Road
Frederick, MD 21702
Phone: (301) 663-8279
Fax: (301) 631-5199

Integrated Power Corporation
7618 Haywood Road
Frederick, MD 21702
Phone: (301) 663-8279

Inter-Island Solar Supply
345 N. Nimitz Highway
Honolulu, HI 96817
Phone: (808) 523-0711

Kyocera America
Solar Systems Division
8611 Balboa Avenue
San Diego, CA 92123
Phone: (800) 537-0294

Midwest Conservation Systems Inc.
P.O. Box 397
Silver Lake, KS 66539
Phone: (913) 582-5233
Fax: (913) 232-3914
E-mail: mcsinc@parod.com

Photocomm, Inc.
7812 Acoma Drive
Scottsdale, AZ 85260
Phone: (602) 948-8003
Fax: (602) 483-6431

Photocomm, Inc. — Colorado
9850-A W. Girton Drive
Lakewood, CO 80227
Phone: (303) 988-8208
Fax: (303) 988-9581

Photocomm, Inc. — San Diego
P.O. Box 9926
San Diego, CA 92169
Phone: (619) 490-3600
Fax: (619) 490-3606

Photocomm, Inc. — Texas
c/o TX Solar Energy Center
13130 Stafford Road
Stafford, TX 77477
Phone: (713) 933-1578
Fax: (713) 933-1599

Photovoltaics International, LLC
171 Commercial Street
Sunnyvale, CA 94086
Phone: (408) 746-3062
Fax: (408) 746-3890

Photron, Inc.
P.O. Box 578
Willits, CA 95490
Phone: (707) 459-3211
Fax: (707) 459-2165

Real Goods Trading Company
555 Leslie Street
Ukiah, CA 95482
Phone: (800) 762-7325
E-mail: realgoods@realgoods.com

Siemens Solar Industries
4650 Adohr Lane
Camarillo, CA 93011
Phone: (805) 388-6588
Fax: (805) 388-6395
E-mail: sunpower@solarpv.com

Siemens Solar Industries — Florida
6909 S.W. 18th Street, Suite A-301-B
Boca Raton, FL 33433
Phone: (561) 416-7205
Fax: (561) 362-5513

Solar Depot
61 Paul Drive
San Rafael, CA 94903
Phone: (415) 499-1333
Web site: www.solardepot.com

Solar Design Associates, Inc.
P.O. Box 242
Harvard, MA 01451
Phone: (508) 456-6855
E-mail: sda@solardesign.com

Solar Electric Specialties Co.
P.O. Box 537
Willits, CA 95490
Phone: (707) 459-9496
E-mail: seswillits@aol.com
Web site: www.solarelectric.com

Solar Kinetics, Inc.
10635 King William Drive
Dallas, TX 75220
Phone: (214) 556-2376
Fax: (214) 869-4158

Solar Works, Inc.
64 Main Street
Montpelier, VT 05602
Phone: (802) 223-7804
E-mail: Iseddon@aol.com

Solarex Corporation
630 Solarex Court
Frederick, MD 21703
Phone: (301) 698-4213
Fax: (301) 698-4201

Solarex Corporation — Arizona
10752 N. 89th Place, Suite 210
Scottsdale, AZ 85260
Phone: (602) 451-8050
Fax: (602) 451-8040

Solarex Corporation — Colorado
4089 Valley Oak Drive
Loveland, CO 80538
Phone: (970) 593-9500
Fax: (970) 593-9373

Solarex Corporation — Pennsylvania
826 Newton-Yardley Road
Newton, PA 18940
Phone: (301) 698-4200
Fax: (301) 698-4201

Sunelco
P.O. Box 1499
Hamilton, MT 59840
Phone: (800) 338-6844
E-mail: sunelco@montana.com
Web site: www.sunelco.com

SunWize Energy Systems, Inc.
#1 Sun Street
Stelle, IL 60919
Phone: (815) 256-2222
Fax: (800) 232-7652
Web site:www.sunwize.com

Systems Integrators

Applied Power Corporation
1210 Homann Drive, SE
Lacey, WA 98503
Phone: (206) 438-2110

Ascension Technology
235 Bear Hill Road
Waltham, MA 02154
Phone: (781) 890-8844
Fax: (781) 890-2050
E-mail: info@ascensiontech.com
Web site: www.ascensiontech.com

Diversified Technologies
35 Wiggins Avenue
Bedford, MA 01730-2345
Phone: (781) 275-9444
Web site: www.divtecs.com

FIRST, Inc.
66 Snydertown Road
Hopewell, NJ 08525
Phone: (609) 466-4495
Web site: www.solarhome.org

Solar Design Associates, Inc.
P.O. Box 242
Harvard, MA 01451
Phone: (508) 456-6855
E-mail: sda@solardesign.com
Web site: www.solardesign.com/Çsda/

Utility Power Group
9410 De Soto Avenue, Unit G
Chatsworth, CA 91311
Phone: (818) 700-1995
Fax: (818) 700-2518

WorldWater, Inc.
117 Hopewell-Rocky Hill Road
Hopewell, NJ 08525
Phone: (609) 587-3000
Fax: (609) 587-5355

Federal Program Contacts

Federal Energy Management Program
Contact: Anne Sprunt Crawley
1000 Independence Ave, SW, EE-90
Washington, DC 20585
Phone: (202) 586-1505
Fax: (202) 586-3000

National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401
Contact: Andrew Walker
Phone: (303) 384-7531
Fax: (303) 384-7411
Web site: www.eren.doe.gov/femp

National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401
Contact: John Thornton
Phone: (303) 384-6469
Fax: (303) 384-6490
Web site: www.nrel.gov

Renew the Forests
PV Systems Assistance Center
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0753
Contact: Hal Post, MS0753
Phone: (505) 844-2154

Renew the Parks
PV Systems Assistance Center
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0753
Contact: Hal Post, MS0753
Phone: (505) 844-2154

Renew the Public Lands
PV Systems Assistance Center
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0753
Contact: Hal Post, MS0753
Phone: (505) 844-2154

Sandia National Laboratories
PV Systems Assistance Center
P.O. Box 5800
Albuquerque, NM 87185-0753
Contact: Hal Post, MS0753
Phone: (505) 844-2154
Web site: www.sandia.gov/
renewable_energy/photovoltaic/pv.html

U.S. Department of Energy
Energy Efficiency and Renewable
Energy Clearinghouse (EREC)
P.O. Box 3048
Merrifield, VA 22116
Phone: (800) 363-3732
Web site: erecbbs.nciinc.com

Who Is Using the Technology

Bureau of Land Management
Contact: Trent Duncan
Phone: (801) 539-4090

Federal Aviation Administration
Contact: Alex Gintner
Phone: (612) 463-5921

National Park Service
Contact: Kent Bullard
Phone: (805) 658-5745
E-mail: kent_bullard@nps.gov

USDA Forest Service
Contact: Fred Bloom
Phone: (602) 225-5317
Contact: Steve Oravetz
Phone: (406) 329-1037

U.S. Air Force
Contact: Larry Strother
Phone: (904) 283-6354

U.S. Army
Contact: Roch Ducey
Phone: (217) 398-5222

U.S. Navy
Contact: Chuck Combs
Phone: (760) 939-0048

U.S. Marines
Contact: Dick Walsh
Phone: (703) 696-0859

For More Information

Organizations

American Solar Energy Society
2400 Central Avenue, Suite G-1
Boulder, CO 80301
Phone: (303) 443-3130
Fax: (303) 443-3212
Web site: www.csn.net/solar

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, CO 80401-3393
Save with Solar - Million Solar Roofs Initiative
Contact: Patrina Taylor
Phone: (303) 384-7458

Photovoltaic Services Network
165 S. Union Blvd., Suite 260
Lakewood, CO 80228
Contact: Kirk Stokes
Phone: (303) 980-1969
Fax: (303) 980-1030

Solar Energy Industries Association
122 C Street, NW, Fourth Floor
Washington, DC 20001-2109
Phone: (202) 383-2600
Fax: (202) 383-2670
Web site: www.crest.org/renewables/seia

Utility PhotoVoltaics Group
1800 M Street, NW, Suite 300
Washington, DC 20036
Phone: (202) 857-0898
Fax: (202) 223-5537
Web site: www.ttcorp.com/upvg

Literature: Design, Installation and O&M

Holz, M., *Maintenance and Operation of Stand-Alone Photovoltaic Systems*, Naval Facilities Engineering Command, Southern Division; DOD Photovoltaic Review Committee; Photovoltaic Systems Assistance Center, December 1991.

Risser, V., and H. Post, Editors. *Stand-Alone Photovoltaic Systems: A Handbook of Recommended Design Practices*, SAND87-7023, Sandia National Laboratories, Albuquerque, New Mexico, March 1996.

Risser, V., *Working Safely with Photovoltaic Systems*, Photovoltaic Systems Assistance Center, July 1991.

Risser, V,. *Hybrid Power Systems—Issues and Answers*, Photovoltaic Systems Assistance Center, July 1992.

Literature: Other

Bloom, F., Post, H., and Thomas, M., *Renew the Forests—Photovoltaic Technology in the USDA Forest Service*, U.S. Department of Agriculture, Forest Service; Photovoltaic Systems Assistance Center, July 1996.

Cook, G., Billman, L., and Adcock, R., *Photovoltaic Fundamentals*, Solar Energy Research Institute, Golden, Colorado, September 1991.

Directory of the U.S. Photovoltaics Industry, Solar Energy Industries Association, March 1996.

Duncan, T., Post, H., and Thomas, M., *Renew the Public Lands—Photovoltaic Technology in the Bureau of Land Management*, U.S. Department of Interior, Bureau of Land Management; Photovoltaic Systems Assistance Center, 1996.

Renew the Parks - Renewable Energy in the National Park Service: Photovoltaic Systems, U.S. Department of Interior, National Park Service, Denver Service Center; Photovoltaic Systems Assistance Center, February 1995.

Stokes, K. and Saito, P., *Photovoltaic Power as a Utility Service: Guidelines for Livestock Water Pumping*, SAND93-7043, Sandia National Laboratories, Albuquerque, New Mexico, April 1993.

Tapping Into the Sun, Today's Applications of Photovoltaic Technology, National Renewable Energy Laboratory, Golden, Colorado, July 1994.

Thomas, M., Post, H., and Van Arsdall, A., *Photovoltaics Now—Photovoltaic Systems for Government Agencies*, SAND88-3149, Sandia National Laboratories, Albuquerque, New Mexico, November 1995.

Wiles, J., *Photovoltaic Power Systems and the National Electrical Code—Suggested Practices*, Photovoltaic Systems Assistance Center, 1996.

Appendixes

Appendix A: Page from Solar Radiation Data Manual for Flat Plate and Concentrating Collectors

Appendix B: Daily Energy Calculation Worksheet

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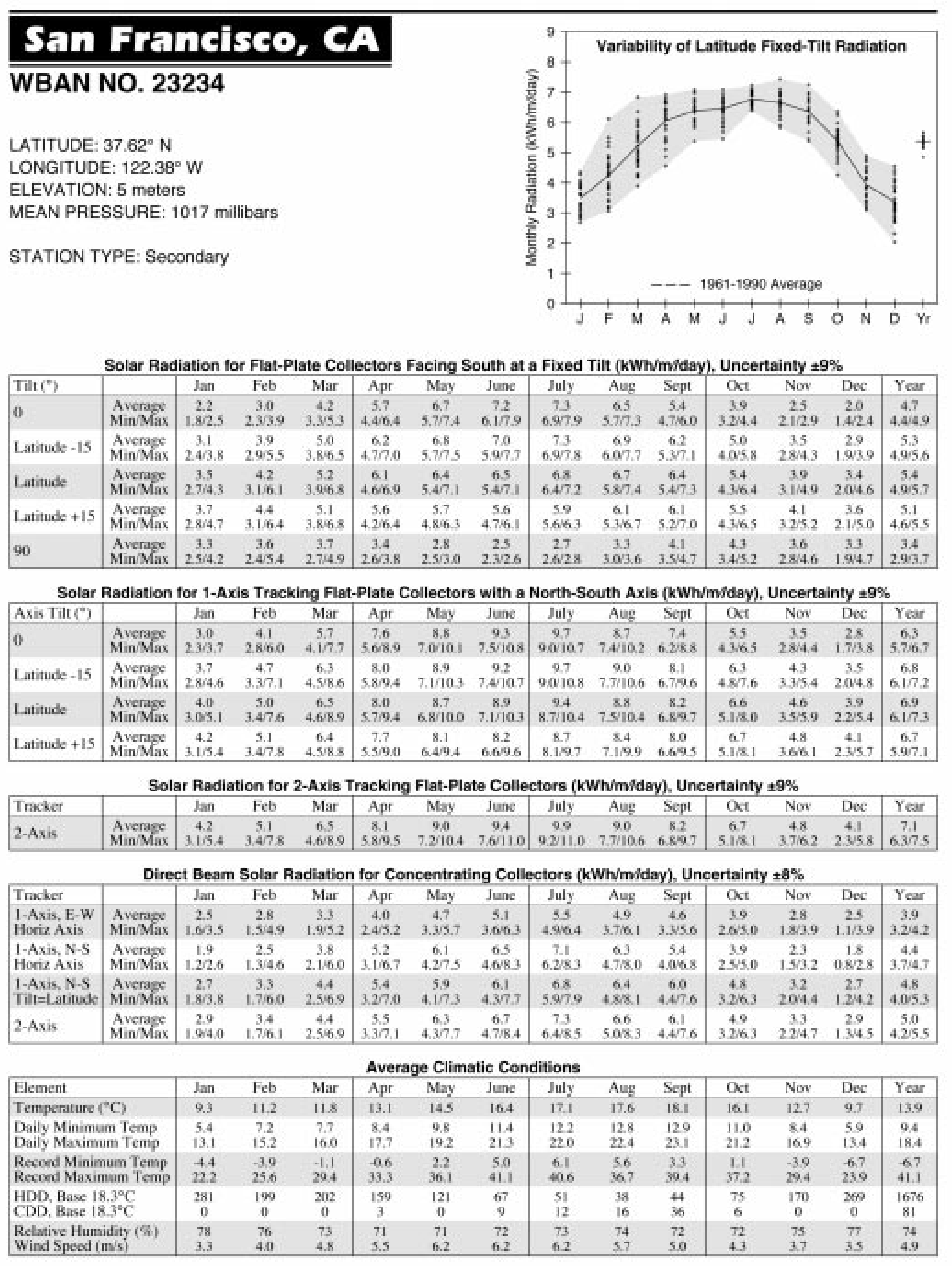
Appendix D: Typical Example PV Design Assistance Centers Sample PV/Generator Hybrid System Specifications

Appendix E: Pinnacles Case Study NIST BLCC Comparative Economic Analysis

Appendix F: Meadows Campground Case Study NIST BLCC Comparative Economic Analysis

Appendix A: Page from *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors*



San Francisco, CA

WBAN NO. 23234

LATITUDE: 37.62° N
LONGITUDE: 122.38° W
ELEVATION: 5 meters
MEAN PRESSURE: 1017 millibars

STATION TYPE: Secondary

Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m/day), Uncertainty ±9%

Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average Min/Max	2.2 1.8/2.5	3.0 2.3/3.9	4.2 3.3/5.3	5.7 4.4/6.4	6.7 5.7/7.4	7.2 6.1/7.9	7.3 6.9/7.9	6.5 5.7/7.3	5.4 4.7/6.0	3.9 3.2/4.4	2.5 2.1/2.9	2.0 1.4/2.4	4.7 4.4/4.9
Latitude -15	Average Min/Max	3.1 2.4/3.8	3.9 2.9/5.5	5.0 3.8/6.5	6.2 4.7/7.0	6.8 5.7/7.5	7.0 5.9/7.7	7.3 6.9/7.8	6.9 6.0/7.7	6.2 5.3/7.1	5.0 4.0/5.8	3.5 2.8/4.3	2.9 1.9/3.9	5.3 4.9/5.6
Latitude	Average Min/Max	3.5 2.7/4.3	4.2 3.1/6.1	5.2 3.9/6.8	6.1 4.6/6.9	6.4 5.4/7.1	6.5 5.4/7.1	6.8 6.4/7.2	6.7 5.8/7.4	6.4 5.4/7.3	5.4 4.3/6.4	3.9 3.1/4.9	3.4 2.0/4.6	5.4 4.9/5.7
Latitude +15	Average Min/Max	3.7 2.8/4.7	4.4 3.1/6.4	5.1 3.8/6.8	5.6 4.2/6.4	5.7 4.8/6.3	5.6 4.7/6.1	5.9 5.6/6.3	6.1 5.3/6.7	6.1 5.2/7.0	5.5 4.3/6.5	4.1 3.2/5.2	3.6 2.1/5.0	5.1 4.6/5.5
90	Average Min/Max	3.3 2.5/4.2	3.6 2.4/5.4	3.7 2.7/4.9	3.4 2.6/3.8	2.8 2.5/3.0	2.5 2.3/2.6	2.7 2.6/2.8	3.3 3.0/3.6	4.1 3.5/4.7	4.3 3.4/5.2	3.6 2.8/4.6	3.3 1.9/4.7	3.4 2.9/3.7

Solar Radiation for 1-Axis Tracking Flat-Plate Collectors with a North-South Axis (kWh/m/day), Uncertainty ±9%

Axis Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average Min/Max	3.0 2.3/3.7	4.1 2.8/6.0	5.7 4.1/7.7	7.6 5.6/8.9	8.8 7.0/10.1	9.3 7.5/10.8	9.7 9.0/10.7	8.7 7.4/10.2	7.4 6.2/8.8	5.5 4.3/6.5	3.5 2.8/4.4	2.8 1.7/3.8	6.3 5.7/6.7
Latitude -15	Average Min/Max	3.7 2.8/4.6	4.7 3.3/7.1	6.3 4.5/8.6	8.0 5.8/9.4	8.9 7.1/10.3	9.2 7.4/10.7	9.7 9.0/10.8	9.0 7.7/10.6	8.1 6.7/9.6	6.3 4.8/7.6	4.3 3.3/5.4	3.5 2.0/4.8	6.8 6.1/7.2
Latitude	Average Min/Max	4.0 3.0/5.1	5.0 3.4/7.6	6.5 4.6/8.9	8.0 5.7/9.4	8.7 6.8/10.0	8.9 7.1/10.3	9.4 8.7/10.4	8.8 7.5/10.4	8.2 6.8/9.7	6.6 5.1/8.0	4.6 3.5/5.9	3.9 2.2/5.4	6.9 6.1/7.3
Latitude +15	Average Min/Max	4.2 3.1/5.4	5.1 3.4/7.8	6.4 4.5/8.8	7.7 5.5/9.0	8.1 6.4/9.4	8.2 6.6/9.6	8.7 8.1/9.7	8.4 7.1/9.9	8.0 6.6/9.5	6.7 5.1/8.1	4.8 3.6/6.1	4.1 2.3/5.7	6.7 5.9/7.1

Solar Radiation for 2-Axis Tracking Flat-Plate Collectors (kWh/m/day), Uncertainty ±9%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
2-Axis	Average Min/Max	4.2 3.1/5.4	5.1 3.4/7.8	6.5 4.6/8.9	8.1 5.8/9.5	9.0 7.2/10.4	9.4 7.6/11.0	9.9 9.2/11.0	9.0 7.7/10.6	8.2 6.8/9.7	6.7 5.1/8.1	4.8 3.7/6.2	4.1 2.3/5.8	7.1 6.3/7.5

Direct Beam Solar Radiation for Concentrating Collectors (kWh/m/day), Uncertainty ±8%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
1-Axis, E-W Horiz Axis	Average Min/Max	2.5 1.6/3.5	2.8 1.5/4.9	3.3 1.9/5.2	4.0 2.4/5.2	4.7 3.3/5.7	5.1 3.6/6.3	5.5 4.9/6.4	4.9 3.7/6.1	4.6 3.3/5.6	3.9 2.6/5.0	2.8 1.8/3.9	2.5 1.1/3.9	3.9 3.2/4.2
1-Axis, N-S Horiz Axis	Average Min/Max	1.9 1.2/2.6	2.5 1.3/4.6	3.8 2.1/6.0	5.2 3.1/6.7	6.1 4.2/7.5	6.5 4.6/8.3	7.1 6.2/8.3	6.3 4.7/8.0	5.4 4.0/6.8	3.9 2.5/5.0	2.3 1.5/3.2	1.8 0.8/2.8	4.4 3.7/4.7
1-Axis, N-S Tilt=Latitude	Average Min/Max	2.7 1.8/3.8	3.3 1.7/6.0	4.4 2.5/6.9	5.4 3.2/7.0	5.9 4.1/7.3	6.1 4.3/7.7	6.8 5.9/7.9	6.4 4.8/8.1	6.0 4.4/7.6	4.8 3.2/6.3	3.2 2.0/4.4	2.7 1.2/4.2	4.8 4.0/5.3
2-Axis	Average Min/Max	2.9 1.9/4.0	3.4 1.7/6.1	4.4 2.5/6.9	5.5 3.3/7.1	6.3 4.3/7.7	6.7 4.7/8.4	7.3 6.4/8.5	6.6 5.0/8.3	6.1 4.4/7.6	4.9 3.2/6.3	3.3 2.2/4.7	2.9 1.3/4.5	5.0 4.2/5.5

Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	9.3	11.2	11.8	13.1	14.5	16.4	17.1	17.6	18.1	16.1	12.7	9.7	13.9
Daily Minimum Temp	5.4	7.2	7.7	8.4	9.8	11.4	12.2	12.8	12.9	11.0	8.4	5.9	9.4
Daily Maximum Temp	13.1	15.2	16.0	17.7	19.2	21.3	22.0	22.4	23.1	21.2	16.9	13.4	18.4
Record Minimum Temp	-4.4	-3.9	-1.1	-0.6	2.2	5.0	6.1	5.6	3.3	1.1	-3.9	-6.7	-6.7
Record Maximum Temp	22.2	25.6	29.4	33.3	36.1	41.1	40.6	36.7	39.4	37.2	29.4	23.9	41.1
HDD, Base 18.3°C	281	199	202	159	121	67	51	38	44	75	170	269	1676
CDD, Base 18.3°C	0	0	0	3	0	9	12	16	36	6	0	0	81
Relative Humidity (%)	78	76	73	71	71	72	73	74	72	72	75	77	74
Wind Speed (m/s)	3.3	4.0	4.8	5.5	6.2	6.2	6.2	5.7	5.0	4.3	3.7	3.5	4.9

Appendix B: Daily Energy Calculation Worksheet

Appliances	Watts	Daily Hours of Use	Daily Watt-hours
		Total	

Appendix C: Federal Life-Cycle Costing Procedures and the BLCC Software

Federal agencies are required to evaluate energy-related investments on the basis of minimum life-cycle costs (LCC) (10 CFR Part 436). A life-cycle cost evaluation computes the total long-run costs of a number of potential actions, and selects the action that minimizes the long-run costs. When considering retrofits, sticking with the existing equipment is one potential action, often called the baseline condition. The LCC of a potential investment is the present value of all of the costs associated with the investment over time.

The first step in calculating the LCC is to identify the costs. Installed Cost includes cost of materials purchased and the labor required to install them (for example, the price of an energy-efficient lighting fixture, plus cost of labor to install it). Energy cost includes annual expenditures on energy to operate equipment. (For example, a lighting fixture that draws 100 watts and operates 2,000 hours annually requires 200,000 watt-hours [200 kWh] annually. At an electricity price of $0.10/kWh, this fixture has an annual energy cost of $20.) Non-fuel O&M includes annual expenditures on parts and activities required to operate equipment (for example, replacing burned-out lightbulbs). Replacement costs include expenditures to replace equipment upon failure (for example, replacing an oil furnace when it is no longer usable).

Because LCC includes the cost of money, periodic and a-periodic O&M and equipment replacement costs, energy escalation rates, and salvage value, it is usually expressed as a present value, which is evaluated by

$$LCC = PV(IC) + PV(EC) + PV(OM) + PV(REP)$$

where PV (x) denotes "present value of cost stream x",
IC is the installed cost,
EC is the annual energy cost,
OM is the annual non-energy cost, and
REP is the future replacement cost.

Net present value (NPV) is the difference between the LCCs of two investment alternatives, e.g., the LCC of an energy-saving or energy-cost reducing alternative and the LCC of the baseline equipment. If the alternative's LCC is less then baseline's LCC, the alternative is said to have NPV, i.e., it is cost effective. NPV is thus given by

$$NPV = PV(EC_0) - PV(EC_1) + PV(OM_0) - PV(OM_1) + PV(REP_0) - PV(REP_1) - PV(IC)$$

or

$$NPV = PV(ECS) + PV(OMS) + PV(REPS) - PV(IC)$$

where subscript 0 denotes the baseline condition,
subscript 1 denotes the energy cost-saving measure,
IC is the installation cost of the alternative (the IC of the baseline is assumed to be zero),
ECS is the annual energy cost saving,
OMS is the annual non-energy O&M saving, and
REPS is the future replacement saving.

Levelized energy cost (LEC) is the break-even energy price (blended) at which a conservation, efficiency, renewable, or fuel-switching measure becomes cost effective (NPV > = 0). Thus, a project's LEC is given by

$$PV(LEC*EUS) = PV(OMS) + PV(REPS) - PV(IC)$$

where EUS is the annual energy use savings (energy units/yr). Savings-to-investment ratio (SIR) is the total (PV) saving of a measure divided by its installation cost:

$$SIR = (PV(ECS) + PV(OMS) + PV(REPS))/PV(IC)$$

Some of the tedious effort of LCC calculations can be avoided by using the BLCC software, developed by NIST. For copies of BLCC, call the FEMP Help Desk at (800) 363-3732.

Appendix D: Typical Example PV Design Assistance Centers Sample PV/Generator Hybrid System Specifications

NOTE: This appendix is based on specifications that were developed by the Denver Service Center of the National Park Service in conjunction with the Photovoltaic Design Assistance Centers at Sandia National Laboratories. The system described here has been installed at a housing facility in Hozomeen, North Cascades National Park. It must be adjusted and modified for site-specific conditions (hardware, climate, solar resource, etc.) if it is to be used in other locations.

Hal POST 505.844.2154

SECTION 16610 **PHOTOVOLTAIC SYSTEM**

PART 1: GENERAL

1.1 DESCRIPTION: The work of this section consists of furnishing and installing a complete and operable hybrid photovoltaic (PV) system for the project site. The design intent is to have the PV array produce sufficient energy to operate all estimated electrical loads throughout the months of June through August without support from a standby generator. Two days of autonomy shall be minimum for this system during the above referenced months.

1.2 SUBMITTALS: As specified in Section 01300.

- A. Submit catalog data on all materials with complete description of components; including modules, batteries, inverters, DC load center, transfer switches, panelboard, mounting hardware, fuses, cable, connectors, and all other related equipment.
- B. Submit connection wiring diagram for complete PV system.
- C. Submit resume, references, and other data indicating qualifications as outlined under Quality Assurance.
- D. Any components fabricated by contractor for which there is no catalog cut sheet or manufacturer’s data available, submit prototype or product for review and approval.

1.3 QUALITY ASSURANCE:

- A. lnstallation and equipment shall comply with all applicable codes, including but not limited to, Articles 690, 480, and 250 of the 1996 NEC. All products that are listed, tested, identified, or labeled by UL, FM, ETL, or other National Testing Organization shall be used when available. Non-listed products are only permitted when there is no listing. Also reference 1601 0.
- B. The system shall be supplied and installed by one manufacturer (or certified representative) with an established reputation and at least 5 years experience in the manufacturing and installation of Hybrid Photovoltaic Energy Systems of 20 KVA nominal or larger, and who shall be able to provide three references of similar installations rendering satisfactory service.

1.4 OPERATION AND MAINTENANCE DATA: Provide two complete sets of the following data. Data shall be on 8 1/2-in. by 11-in. sheet or manufacturer’s standard catalog, suitable for side binding. Include full product documentation from manufacturer, installer, and/or supplier including, but not limited to, the following items. Also reference Section 01700 and part 3 of this section.

- A. DC POWER CENTER AND INVERTER, INCLUDING OPTIONAL EQUIPMENT FURNISHED:
    1. Owners manual with programming and installation instructions
    2. Emergency operating procedures
    3. Default program values and setpoints
    4. Listing of field programmed variables and setpoints
    5. Equipment wiring diagrams
    6. Product model number, with name, address, and telephone number of local representative
    7. Starting, operating, and shutdown procedures, including normal, seasonal, and emergency shutdown procedures
    8. Schedule of maintenance work, if any
    9. Replacement parts list, including internal fuses
    10. Warranty paperwork
- B. BATTERIES:
    1. Owners manual with installation, testing and charging instructions. Instructions shall be very specific as to how the batteries shall be maintained and operated to ensure long life.
    2. Emergency operating procedures, including method of handling leaking or damaged battery
    3. Recycling and salvage information
    4. Product model number, with name, address, and telephone number of local representative
    5. Starting operating, and shutdown procedures, including seasonal shutdown and storage
    6. Maintenance and testing schedule

    7. Warranty paperwork

C. PHOTOVOLTAIC MODULES, PANELBOARDS, SWITCHES, CKT BREAKERS, AND BALANCE OF SYSTEM COMPONENTS:

    1. Owners manual or manufacturer's product data sheet, as applicable
    2. Equipment wiring diagrams
    3. Product model number, with name, address, and telephone number of local representative
    4. Starting, operating, and shutdown procedures, including normal, emergency, and seasonal shutdown procedures
    5. Schedule of maintenance work, if any
    6. Replacement parts list, including fuses, diodes, etc.
    7. Warranty paperwork
    8. Cleaning agents and methods

PART 2: PRODUCTS

2.1 CONDUIT: Exposed conduit on duplex roof shall be EMT, painted to match roof. Reference 16050 for other conduit and raceway requirements.

2.2 CONDUCTORS: As specified in this section, section 16050, as shown on the drawings, and as recommended by the equipment manufacturer. DC Cables shall be super flexible locomotive/welding-type.

2.3 PHOTOVOLTAIC MODULES:

A. General: Modules shall be UL, FM , or ETL listed. High-power type, with typical peak power of not less than 64 W under standard test conditions (illumination of 1-sun at spectral distribution of AM 1.5, cell temperature of 25°C). Voltage at peak power shall not be less than 17.5 Vdc. Current at peak power shall not be less than 3.66 amps, short circuit current of 4.0 amps, open circuit voltage at 21.2 Vdc. Dimension shall not be greater than: length 44.0 in., width 20.0 in., depth 2.0 in. Model #MSX-64 as manufactured by Solarex Corporation, Frederick, Maryland, or approved equal.

B. Units shall have 20-year limited warranty that guarantees:

    1. That no module will generate less than its specified minimum power when purchased.
    2. Continued power of at least 80% of guaranteed minimum power for 20 years.

2.4 COMBINER/J-BOX: Hinged cover fiberglass NEMA 4X enclosure as manufactured by Hoffman, Anoka MN or approved equal. Unit shall be sunlight resistant, and exhibit excellent chemical, temperature, and weather resistance properties. Contractor shall determine required size of box by calculating fill from 1996 NEC using actual quantity and size of conductors used. Minimum size of 12 in. by 10 in. by 6 in. Model #A-121006CHSCFG with screw cover, or as required per fill calculations.

2.5 POWER DISTRIBUTION BLOCKS: As required for changing conductors sizes, combining multiple conductors, etc. Rated for voltage and current of system. As manufactured by ILSCO, Cincinnati, Ohio, or approved equal.

2.6 BATTERIES:

A. General: Absolyte-IIP, Module Type 3-100A21 as manufactured by GNB Industrial Battery Co., Lombard, IL 60148, or approved equal. The batteries shall have the following features and characteristics:

    1. 6V nominal per battery, minimum 1000 amp*hour capacity to 10.5 V (1.75 V/cell) at 25°C at C/24 rate
    2. Ten-year warranty, expected life shall be 20 years at full float at 25°C
    3. Lead calcium negative plate, MFX alloy positive plate, sealed valve-regulated construction
    4. For safe transportation, battery shall be classified as nonhazardous material Battery shall be rated spill and leak proof by ICAO, IATA, and DOT
    5. Battery shall be UL listed
    6. Battery shall be able to withstand freezing without damage to container or active materials
    7. Battery shall be fully recyclable, and not require watering. Manufacturer shall have certified recycling program.
    8. Battery shall have self discharge rate not greater than 1% at 25oC
    9. Battery shall have deep cycle capability of 1,200 cycles at 80% depth of discharge at 25°C
    10. Float voltage shall be 2.23-2.28 volts per Cell @ 25°C
    11. Maximum weight and dimensions are as follows: length 29 in., width 27 in., height 9 in., and weight 525 lbs/6V battery

B. Accessories: Furnish manufacturers bottom I-beam supports and installation kit including nylon straps.

C. Cables: Minimum #4/OAWG super flexible welding-type cable. Factory crimped and soldered ring terminals for battery and inverter bolted connections. Cables shall have identification labels on each end for positive and negative terminal connections. Solid copper bus/bars are also acceptable.

D. Terminals: Exposed battery terminals and cable connects must be protected against potential short circuiting. Furnish and install manufacturers transparent flame-retardant module coverer assembly.

2.7 DISCONNECTS/PANELBOARDS/ETC:

A. GENERAL: Circuit breaker and switches shall be UL listed and DC rated for load controlled. Disconnects and overcurrent devices shall be mounted in approved boxes, enclosures, or panelboards. Requirements for internal configuration of these enclosures shall comply w/NEC Article 370,373, 384 and applicable UL standards. Metal enclosures and boxes shall be bonded to the grounding conductor.

1. DC disconnects at duplex: Heavy-duty, 25O VDC, 60-amp, 2-pole fused disconnect with isolated neutral bus. NEMA 3R enclosure. Model #H222NRB as manufactured by Square-D or approved equal.
2. Panelboards: “GEN” and “LP”: As indicated on panelboard schedule. Provide equipment ground bar kit. Copper bus required.
3. Circuit Breaker Enclosures: Breaker type “QO”, size as shown on drawings. Isolated neutral bus required. Manufactured by Square-D or approved equal.
4. Transfer Switches: Number of poles as shown, load make/break and continuous duty rated. 100Amp rating, NEMA 1 enclosure. Isolated neutral bus required. Class 3140 as manufactured by Square-D or approved equal.

2.8 DC LOAD CENTER:

A. GENERAL: Model APT5-444 as manufactured by Ananda Power Technologies, Inc., Nevada City, California, or approved equal. DC power center shall have at a minimum the following features:

1. Unit must be UL listed and compatible with 48 Vdc negative ground electrical system
2. Unit shall comply with Article 690-5 of the 1996 NEC. Furnish ground fault detection and interruption device.
3. Battery/inverter/main disconnect: UL listed for up to 125 Vdc @ 400 amps per pole, 3 poles total
4. Main fuses: UL listed, Class T, current limiting, 20K AIC
5. Circuit breakers: UL listed, DC rated, 5K AIC at 65 Vdc
6. PV charge controller and load disconnect contacts: Mercury displacement type, UL listed, temperature range of -35o to 85oC
7. Operating ambient temperature range of -35° to 54°C, nonoperating temperature range of - 45° to 8°C
8. Fused main disconnect amps rated up to 400 amps input and 2/400 amp outputs, maximum input power handling ability of 1200 amps
9. Maximum solar charge control ability of 360 amps
10. Solar array disconnect with 35-amp breaker and red hipped indicator
11. Battery cable terminal lugs up to 4-#250 MCM
12. Inverter cable terminal lugs up to 2/dual #250 MCM
13. Automatic array disconnect to eliminate nighttime losses
14. Adjustable control and selection of equalize, automatic, or off battery charge modes. Field adjustable charge termination set voltage.
15. LED indicators for battery charging status for each subarray (four total)
16. Smartlight Plus battery charge indicator

B. ADDITIONAL FEATURES:

1. LCD digital display unit indicating current generated, current draw, and battery voltage. Furnish shunts as required. Model #VISTA3-SH or approved equal. Unit shall fit in door of APT5 cabinet.
2. Battery temperature compensator
3. Lightning arrestor, 48 Vdc nominal, Model #LA50k or approved equal
4. Factory calibration of battery charge controller for specified Absolyte-IIP batteries
5. Ground fault detection and interruption device
6. Furnish all other equipment and appurtenances as specified and/or required for a complete and operable system

2.9 DC FUSED PULLOUT: Model #-STP404 as manufactured by Ananda Power Technologies or approved equal. UL listed, rated at 125 Vdc, up to 400 amps per pole. Furnish Class T fuses, size as shown or required. Furnish ground bus.

2.10 INVERTER

A. GENERAL: Model #5548 as manufactured by Trace Engineering, Arlington, Washington, or approved equal. DC power center shall have at a minimum the following features:

1. ETL listed
2. Nominal DC Input Voltage of 48 VDC, AC output voltage (RMS) of 120 VAC @ 60Hz

3. Continuous power rating of 5,500 VA @ 20°C, continuous AC output rating of 46 amps @ 25°C, maximum AC output of 78 amps (RMS)
4. Peak efficiency of 96%
5. Automatic AC transfer relay rated at 60 amps
6. Maximum charging rate of 75 amps
7. DC input requirements: Search mode shall not exceed 1W. Max no load idle power shall not exceed 20Watts. At full-rated power DC input shall not exceed 137 amps. Short-circuited output shall not exceed 180 amps. Nominal DC input voltage range of 44 to 66 V.
8. AC output vharacteristics: Sinewave output, 24 to 52 steps per cycle. Voltage Regulation Å2%, THD 3% to 5% maximum. Allowed power factor from -1 to +1. Frequency regulation shall not exceed Å0.04%. Load sensing range between 16 and 240W.
9. Non-0perating temperature range -40° to 60°C, operating temperature range -40° to 60°C

B. PROGRAMMING: Unit shall be programmable, with separate user and setup menus. Unit shall have lighted back-lit LCD display on the control panel. The LCD display shall also indicate inverter amps, input amps, load amps, battery VDC, and inverter VAC. Control panel LEDs shall report the status of line-tie, ACl-in, bulk, error, inverting, AC2-in, float, and overcurrent conditions.

C. ACCESSORIES: Furnish the following optional equipment as specified. Furnish all other components as required for a complete and operable system.

1. Furnish conduit box #SWCB for each inverter
2. Furnish stacking interface cable #SWI for 120/240 three-wire power from two inverters

D. OPERATING MODES: The inverter shall be capable of parallel operation with the AC generator. The inverter shall synchronize its output waveform with that of the AC input source. The inverter shall function in the following modes for this project:

1. GENERATOR AUTO-START MODE: Unit shall be capable of automatically starting the generator when battery voltage-drops at or below 80% depth of discharge (as published by battery manufacturer). A “quite-time” feature shall also be built into the unit to restrict generator operation during programmed time periods.
2. GENERATOR SUPPORT MODE: When charging batteries from a generator, the inverter shall be capable of monitoring the generator’s output voltage and current. If the voltage or current falls outside user adjustable limits, the inverter shall shed itself as a load and reverse power flow if necessary to assist the generator. Inverters shall also be capable of operating in series for 120/240 VAC power, with 12C VAC leg capable of charging the batteries while the other unit is supporting the generator.
3. BATTERY CHARGER MODE: Unit shall have three stage temperature compensated charging algorithm for charging batteries. Unit shall have remote battery temperature probe. Unit shall operate in manual equalize mode with adjustable settings. Unit shall have automatic “back-off” system to prevent overloading of generator or nuisance tripping of input breakers.
4. INVERTER MODE: Unit shall have low battery cutout voltage with adjustable time delay to prevent damaging batteries. Unit shall have protection circuitry against overcurrent, short circuit, over temperature, low battery voltage, and high battery voltage conditions.

PART 3: EXECUTION

3.1 GENERAL: Install all equipment in accordance with manufacturer’s recommendations and as required by 1996 NEC or other applicable codes. A permanent label shall be posted near the main PV disconnect switch that contains the following information per NEC 690-52:

A. Operating current (system’s maximum power current)
B. Open-circuit current
C. Operating voltage (system’s maximum power voltage)
D. Open-circuit voltage

3.2 GROUNDING: As indicated on the drawings and section 16450. Maintain a single point, negative ground throughout the PV system.

3.3 MODULES:

A. GENERAL: Individual modules shall be prewired into four-module panels and tested before being installed on roof. Record open-circuit voltage and short-circuit current for each panel. Submit these test results to COR. Panels shall be installed to mounting brackets as shown on the drawings. Gravity shall hold the panels in place. Do not lighten attachment pins to mounting brackets unless directed by COR. lnstallation and attachment structure shall be able to withstand snow loading typical for the area.

B. WIRING: All wiring shall be neatly routed and secured with wire ties to underside of array. Wire routing shall be such that maximum protection from the elements is provided. Installation must be approved by COR.

3.4 BATTERIES:

A. Batteries shall be stacked horizontally on I-beam supports and attached to wall, as recommended by manufacturer for compliance with UBC Seismic Zone IV installations. Cover terminals of batteries with manufacturers module cover assembly to prevent short circuit conditions. Installation shall comply with 1996-NEC, including Articles 480 and 690-71,72,73.

B. Install temperature measurement device between battery racks as recommended by manufacturer (temperature compensation from charge controller).

3.5 INVERTERS:

A. GENERAL: Each stacked inverter system and the single unit shall be programmed to charge the batteries when the generator is operating. Each inverter shall be custom programmed for charging the specified Absolyte-IIP batteries. Charging algorithm used shall be customized to match charging specifications as recommended by battery manufacturer. Other inverter features shall be custom programmed in the field as directed by COR.

B. GENERATOR AUTO-START MODE: Unit shall be programmed to automatically start generator when battery voltage drops at or below 80% depth of discharge, as published by battery manufacturer. A “quite-time” shall also be programmed into the unit to restrict generator operation during time periods as provided by the COR. The generator start sequence shall be programmed to match the specified generator for auto-start. Unit shall be programmed to shut down the generator when the batteries are charged. Do not overcharge batteries. See above for battery charging requirements.

C. GENERATOR SUPPORT MODE: When charging batteries from a generator, the generator’s output voltage and current shall be monitored. If either voltage or current falls outside user adjustable limits, the inverter shall shed itself as a load and reverse power flow if necessary to assist the generator. When operating two inverters in series for 120/240 VAC power, one 120 VAC leg shall be capable of charging the batteries while the other unit is supporting the generator.

3.6 DC LOAD CENTER: Install according to manufacturer’s instructions for negative ground system. Unit shall be configured to charge batteries from PV array. Unit shall disconnect array when batteries are fully charged. Unit shall disconnect array at night to prevent negative power flow from batteries. Fusing and cable sizes shall be as recommended by the manufacturer and as shown on the drawings.

3.7 TESTING: When installation is complete, inverter manufacturers representative (TRACE Engineering) shall test entire installation in the presence of contracting officer. Coordinate test a minimum of 1 week in advance with the contracting officer. Notify contracting officer immediately of any problems discovered during testing. Test shall include as a minimum:

A. Complete inverter function test ensures that each individual and stacked inverter set performs all features as specified.

B. Battery charging test: Verify that the DC power center properly charges batteries from array per battery manufacturer’s recommendations. Verify that the inverter(s) property charge batteries with AC input from the gen-set per battery manufacturer’s recommendations.

C. Verify that each inverter and stacked inverter set will automatically start the gen-set as specified.

D. Verify that each inverter and stacked inverter set will automatically operate in parallel with the gen-set.

E. Test each inverter under typical and maximum load conditions for each dwelling unit served.

F. The total testing period shall not be less than 5 hours.

G. Retest entire system and associated equipment if initial test requires corrective action.

H. Record and provide a brief written summary of all programmed values and set points after completing final testing for each inverter and the DC load center. Also provide written record of all current and voltage readings.

3.8 DEMONSTRATION AND TRAINING: Also reference section 01670. Provide 4 hours of operating instructions for entire PV energy system, including operation of gen-set, inverters, DC load center, transfer switches, batteries, panelboard, disconnects, and other features as requested by the park. Also discuss maintenance of batteries. Instruct park personnel in removing and installing panels, including wiring and all connections. Provide park with written instructions and procedures for seasonal shutdown and startup activities for all components of the hybrid PV power system. The park shall be permitted to videotape this training for official NPS use.

Appendix E: Pinnacles Case Study NIST BLCC Comparative Economic Analysis

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*****************************************************************************
*      N I S T  B L C C:  COMPARATIVE  ECONOMIC  ANALYSIS (ver. 4.4-97 )      *
*****************************************************************************

     Project: Pinnacles Power Supply
     Base Case: base case:
     Alternative: pvgen

     Principal Study Parameters
     --------------------------
     Analysis Type:          Federal Analysis—Energy Conservation Projects
     Study Period:           20 Years (June 1998 through May 2018)
     Discount Rate:           4.1% Real (exclusive of general inflation)
     Basecase LCC File:      PINGEN1.LCC
     Alternative LCC File:   PVGEN.LCC

                          Comparison of Present-Value (P.V.) Costs

                                                    Base Case:  Alternative:     Savings
                                                    base case:         pvgen    from Alt.
Initial Investment item(s):                         ----------  ------------  ----------
      Capital Requirements as of Service Date          $50,000      $150,000   -$100,000
                                                    ----------  ------------  ----------
           Subtotal                                    $50,000      $150,000   -$100,000
Future Cost Items:
      Annual and Nonannual Recurring Costs             $54,977       $10,397     $44,579
      Energy-related Costs                            $166,198       $22,230    $143,968
      Capital Replacements                            $101,720       $43,556     $58,164
                                                    ----------  ------------  ----------
           Subtotal                                   $322,895       $76,184    $246,711
                                                    ----------  ------------  ----------
      Total P.V. of Life-Cycle Cost                   $372,895      $226,184    $146,711

Net Savings from Alternative ‘pvgen’ compared to Base Case ‘base case:’

             Net Savings  =  P.V. of Noninvestment Savings      $188,547
                          -  Increased Total Investment          $41,836
                                                               ---------
                                             Net Savings:       $146,711

Note: the Savings-to-Investment Ratio (SIR) and Adjusted Internal Rate of Return (AIRR) computations include differential initial costs, capital replacement costs, and residual value (if any) as investment costs, per NIST Handbook 135 (Federal and MILCON analyses only).

SIR for Alternative ‘pvgen’ compared to Base Case ‘base case:’

                          P.V. of Noninvestment Savings
                 SIR  =  -------------------------------  =  4.51
                           Increased Total Investment

AIRR for Alternative PV/Hybrid compared to
Base Case ‘base case:’(Reinvestment Rate =  4.10%; Study Period = 20 years)
                               AIRR =  12.24%

   Estimated Years to Payback: Simple Payback occurs in year 5; Simple Payback negated by cost of battery replacement in year 8; Simple Payback
        occurs in year 9; Discounted Payback occurs in year 6; Discounted Payback negated in year 8; Discounted Payback occurs in year 10.

                                  ENERGY SAVINGS SUMMARY
              Energy                  —— Average Annual Consumption ——        Life-Cycle
              Type         Units     Basecase    Alternative     Savings      Savings
              ----------   ------   ----------   -----------   ----------   -----------

              Distil. Oil  Gallon     12,000.0           0.0     12,000.0     240,000.0
              Other        Gallon          0.0       1,265.0     -1,265.0     -25,300.0
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Appendix F: Meadows Campground Case Study NIST BLCC Comparative Economic Analysis

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*   N I S T  B L C C:  COMPARATIVE  ECONOMIC  ANALYSIS (ver. 4.4-97 )     *
*******************************************************************************

    Project: Meadows Campground
    Base Case: Generator
    Alternative: PV System

    Principal Study Parameters:
    --------------------------
    Analysis Type:          Federal Analysis—Energy Conservation Projects
    Study Period:           20 Years (May 1997 through April 2017)
    Discount Rate:          3.8% Real (exclusive of general inflation)
    Base Case LCC File:     MEADWGEN.LCC
    Alternative LCC File:   MEADWPV.LCC

                         Comparison of Present-Value (P.V.) Costs

                                                     Base Case:  Alternative:    Savings
                                                     Diesel Gen.  PV/Hybrid     from Alt.
Initial Investment item(s):                          ----------  ----------   ---------
      Capital Requirements as of Service Date            $1,500     $11,837    -$10,337
                                                        -------     -------     -------
      Subtotal                                           $1,500     $11,837    -$10,337
Future Cost Items:
      Annual and Nonannual Recurring Costs              $49,331        $705     $48,626
      Energy-related Costs                               $3,216          $0      $3,216
      Capital Replacements                               $3,135          $0      $3,135
                                                        -------     -------     -------
      Subtotal                                          $55,682        $705     $54,978
                                                        -------     -------     -------
      Total P.V. Life-Cycle Cost                        $57,182     $12,542     $44,641

Net Savings from Alternative PV System compared to Base Case Generator


              Net Savings  =  P.V. of Noninvestment Savings      $51,843
                           -   Increased Total Investment         $7,202
                                                                 -------
                                             Net savings:        $44,641

Note: the Savings-to-Investment Ratio (SIR) and Adjusted Internal Rate of Return (AIRR) computations include differential initial costs, capital replace-
ment costs, and residual value (if any) as investment costs, per NIST Handbook 135 (Federal and MILCON analyses only).

                    SIR for Alternative PV System compared to Base Case Generator

                                   P.V. of Noninvestment Savings
                            SIR = ------------------------------ = 7.20
                                    Increased Total Investment

AIRR For Alternative PV System compared to Basecase Generator
(Reinvestment Rate =  3.80%; Study Period = 20 years)

                                       AIRR =  14.57%

          Estimated Years to Payback: Simple Payback occurs in year 3; Discounted Payback occurs in year 4.

                                  ENERGY SAVINGS SUMMARY

             Energy                 —— Average Annual Consumption ——      Life-Cycle
             Type        Units      Basecase    Alternative   Savings      Savings
             --------   -------    ---------   ----------   ---------   ---------

             Distil. Oil  Gallon      200.0          0.0        200.0      4,000.0
             Other         kWh          0.0          0.0          0.0          0.0
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About the Federal Technology Alerts

The Energy Policy Act of 1992, and subsequent Executive Orders, mandate that energy consumption in the Federal sector be reduced by 30% from 1985 levels by the year 2005. To achieve this goal, the U.S. Department of Energy's Federal Energy Management Program (FEMP) is sponsoring a series of programs to reduce energy consumption at Federal installations nationwide. One of these programs, the New Technology Demonstration Program (NTDP), is tasked to accelerate the introduction of energy-efficient and renewable technologies into the Federal sector and to improve the rate of technology transfer.

As part of this effort FEMP is sponsoring a series of Federal Technology Alerts (FTAs) that provide summary information on candidate energy-saving technologies developed and manufactured in the United States. The technologies featured in the Technology Alerts have already entered the market and have some experience but are not in general use in the Federal sector. Based on their potential for energy, cost, and environmental benefits to the Federal sector, the technologies are considered to be leading candidates for immediate Federal application.

The goal of the Technology Alerts is to improve the rate of technology transfer of new energy-saving technologies within the Federal sector and to provide the right people in the field with accurate, up-to-date information on the new technologies so that they can make educated judgments on whether the technologies are suitable for their Federal sites.

Because the Technology Alerts are cost-effective and timely to produce (compared with awaiting the results of field demonstrations), they meet the short-term need of disseminating information to a target audience in a timeframe that allows the rapid deployment of the technologies—and ultimately the saving of energy in the Federal sector.

The information in the Technology Alerts typically includes a description of the candidate technology; the results of its screening tests; a description of its performance, applications and field experience to date; a list of potential suppliers; and important contact infor-mation. Attached appendixes provide supplemental information and example worksheets on the technology.

FEMP sponsors publication of the Federal Technology Alerts to facilitate information-sharing between manufacturers and government staff. While the technology featured promises significant Federal-sector savings, the Technology Alerts do not constitute FEMP's endorsement of a particular product, as FEMP has not independently verified performance data provided by manufacturers. Nor do the Federal Technology Alerts attempt to chart market activity vis-a-vis the technology featured. Readers should note the publication date on the back cover, and consider the Alert as an accurate picture of the technology and its performance at the time of publication. Product innovations and the entrance of new manufacturers or suppliers should be anticipated since the date of publication. FEMP encourages interested Federal energy and facility managers to contact the manufacturers and other Federal sites directly, and to use the worksheets in the Technology Alerts to aid in their purchasing decisions.

Federal Energy Management Program

The Federal Government is the largest energy consumer in the nation. Annually, in its 500,000 buildings and 8,000 locations worldwide, it uses nearly two quadrillion Btu (quads) of energy, costing over $11 billion. This represents 2.5% of all primary energy consumption in the United States. The Federal Energy Management Program was established in 1974 to provide direction, guidance, and assistance to Federal agencies in planning and implementing energy management programs that will improve the energy efficiency and fuel flexibility of the Federal infrastructure.

Over the years several Federal laws and Executive Orders have shaped FEMP's mission. These include the Energy Policy and Conservation Act of 1975; the National Energy Conservation and Policy Act of 1978; the Federal Energy Management Improvement Act of 1988; and, most recently, Executive Order 12759 in 1991, the National Energy Policy Act of 1992 (EPACT), and Executive Order 12902 in 1994.

FEMP is currently involved in a wide range of energy-assessment activities, including conducting New Technology Demonstrations, to hasten the penetration of energy-efficient technologies into the Federal marketplace.

For More Information

FEMP Help Desk:
(800) 363-3732
International callers please use (703) 287-8391
Web site: http://www.eren.doe.gov/femp/

General Contacts

Bob McLaren
NTDP Program Manager
Federal Energy Management Program
U.S. Department of Energy
1000 Independence Avenue SW, EE-92
Washington, D.C. 20585
(202) 586-0572

Steven A. Parker
Pacific Northwest National Laboratory
P.O. Box 999, MS K5-08
Richland, Washington 99352
(509) 375-6366
steven.parker@pnl.gov

Technical Contacts

Andy Walker, Mail Stop 2723
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, CO 80401
Phone: (303) 384-7531
Fax: (303) 384-7411
e-mail: andy_walker@nrel.gov

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