INTRODUCTION

This report was prepared for the Energy Partnerships Program under an agreement between the National Park Service (National Capital Region) and James Madison University. A Memorandum of Agreement (see Appendix 4) between the two parties outlines generally the scope of work to be conducted.

Over the two months of the project, we conducted designs for photovoltaic (PV) systems at three different parks, C&O Canal, Antietam National Battlefield, and (Fort Washington Park) National Capital Parks East. These designs ranged from lighting for a bridge, a parking lot, and a flagpole to providing electricity for the entrance booth at Fort Washington Park.

We also conducted an audit of the lighting system at the Antietam National Battlefield Visitor Center. Time and information constraints kept us from completing a full audit (including HVAC systems and building envelope measures) of the facility, although we do make some recommendations toward that end.

What follows is a report of our activities. First, we discuss our PV system designs. Second, we discuss the lighting audit. Third, we review the summer's work and make recommendations. More detailed discussion of the PV design analyses and the audit calculation can be found in the appendices.

I. PHOTOVOLTAIC SYSTEM DESIGNS

Photovoltaics (PV) can be used essentially anywhere in the United States where there is an open space that receives sunlight (is not shaded). The technical effectiveness increases of PV increases closer to the equator, where maximum solar insolation[1] is received year-round (with more sunshine there is more electrical output).

A system is generally more cost-effective closer to the equator because solar insolation is greater, and any PV system will produce more electricity and be able to pay back (itself off) quicker. Cost-effectiveness can be evaluated either for stand-alone or for grid-connected systems. With grid connection, you eliminate the need for costly system components (batteries, battery chargers,

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[1] "insolation" is the amount of solar energy incident on the earth at any point; we determined this by using a spreadsheet that calculates the amount of solar power reaching the earth’s surface for any angle of the sun’s rays.

generators, and wiring). Stand-alone systems can also be small enough to eliminate components like generators, charge controllers, and inverters because there is less need to control the electric output (because it is smaller). Greater cost-effectiveness is usually achieved because panels (and other components, such as batteries) are usually discounted by retailers for bulk purchases.

In general, the most cost-effective PV systems are large, grid-connected systems in areas with significant solar insolation. However, if the system must stand alone (like most of the designs we developed), the smaller systems are usually more cost-effective.

PV systems are used for many different applications in National Parks across the country. For example, Everglades National Park of Florida uses 73 PV systems for powering monitoring stations, and PV is used in cooler climates, such as Denali (Alaska), which has 11 systems. PV is also used in parks with climates similar to the National Capital Region. Six PV systems in the Great Smokey Mountain National Park of Tennessee and North Carolina are used for communications, monitoring, and lighting.

The PV designs (below) were developed by first conducting a site visit to gather information, and then by using "Solar Sizer"[2] software to develop basic design parameters. We provide estimates on: 1) the total size of the system (including the number of components needed); 2) the cost to install the system; 3) calculation of the simple payback (if possible) to compare the estimates of alternatives with the existing or conventional systems; and 4) calculation of the life-cycle cost (LCC) of the system (the cost of the system including inflation and depreciation rates of the components over a certain life span). The size and cost estimates we present below should be seen as close approximations of any ultimate design; in themselves they do not represent a final analysis and should be the basis only for decisions on whether further analysis is warranted. [3]

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[2] Solar Sizer™ is a professional tool for designing and sizing photovoltaic systems. It uses a graphic interface to simplify the process of choosing components and making cost and energy calculations.

[3] It should also be noted that the National Parks Fine Arts Commission must approve all structural changes implemented in the National Parks. The commission determines the historical relevance and appropriateness of all modifications to National Park facilities. For example, to get approval for implementation of PV, the solar panels may need to be hidden from view. This is often more costly and is not always feasible.

C&O Canal--The Arizona Avenue Bridge

Our first design was for a PV system to power security lighting at the C&O Canal's Arizona Avenue Bridge, a footbridge used as part of the running and walking path alongside the C&O Canal. The bridge is a black iron structure that spans about 75 feet with a height of about 20 feet, and serves as a pass over a busy road. There are lights illuminating the street below on either side of the bridge; any light fixtures added to the bridge may need to consider the possible glare to the drivers below.

The most feasible design for the bridge PV system was to mount the panels on the top rails of the bridge, with 10 lights running down the center. The lights could be powered by a grid connection or by a stand-alone PV system. A voltage drop from PEPCO would be needed to power the grid at a location from the street below. The economic question is whether the PV system would be more cost-effective than the voltage drop. Estimates of around $36,000 have been made regarding the cost of grid-connected lighting. We assessed the feasibility of a PV system with the appropriate power load requirements and compared it to these costs.

The (C&O) Arizona Avenue Bridge design used insolation data to help determine the necessary system size. The estimates for the "design" month (the month of least solar insolation) of December were an average of 3.30 kWh/ m^2/day. This minimum power estimate was used to design a system that could provide 500 Watts of electricity even during the low solar insolation of the design month.

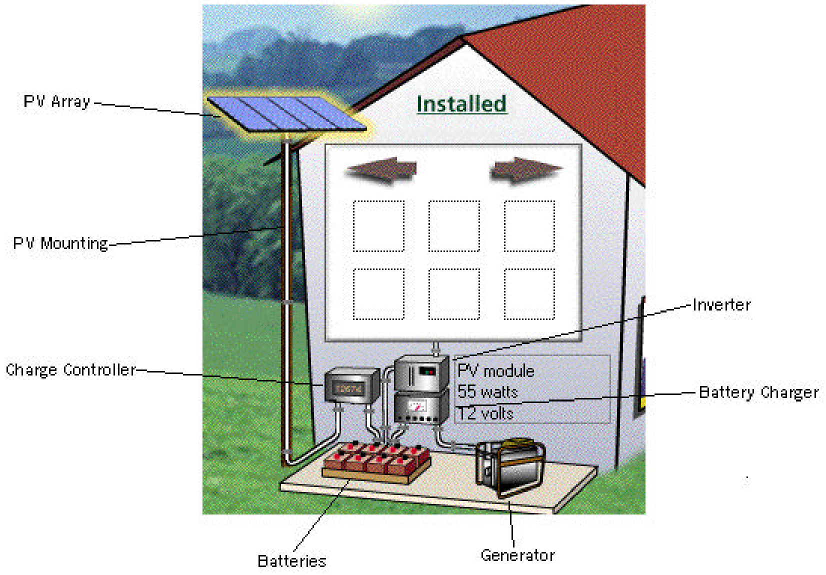
To design the system we used the "Solar Sizer" software. The software uses commercial averages for both PV cost and component efficiency, which allows the user to gain a ballpark figure of the cost and output of the system they could purchase. For example, if a prospective PV user were to enter a home improvement store they may find several PV system components from various manufacturers. The Solar Sizer report would indicate the power requirements of the PV panel and the approximate cost. The software also provides specifications for each component of the system and its approximate cost.

We used a spreadsheet model (explained in greater detail in Appendix 1) for calculating solar insolation as a supplement to the Solar Sizer software. This model calculates the amount of incoming solar insolation at any point on the Earth based on latitude and a specific day of the month. This value is used as the most representative day of each month and can be input into

Solar Sizer to give more accurate estimations of incoming daily solar insolation. The output from that model was substituted for the Solar Sizer values for insolation.

The system we designed includes 25 modules (a module is an individual solar panel that absorbs the sun's rays to convert to electricity) wired in parallel, and two series of seven lead-acid batteries wired in parallel, to produce 500 Watts during the design month.

Figure 1. PV system description from Solar Sizer



The life-cycle cost (LCC) of this system over a 20-year period is $29,014, with an average electricity cost of $1.40/kWh, which compares with a cost of grid connection of about $15,000 (lights would be $21,000 in both cases). The PV system is technically viable, but depends on whether tree branches near the bridge would shade the PV modules, if they were mounted on the top rails of the Bridge. There is no practical alternative site for the system because of the number of trees around the area and a lack of flat space on which to mount PV panels.

The table below is a summary of the security lighting design at Arizona Avenue Bridge. The table is based on Solar Sizer output.[4]

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[4] Number of panels is the actual number of PV panel needed to power the load application. Number of batteries is the amount of batteries needed to store enough electrical charge to power the load application. Both battery and panel size is defined in the Solar Sizer Reports in appendix{}. Yearly power production is

Number of Panels	25
Number of Batteries	14
Yearly Power Production (kWh)	1,418
Life-Cycle Cost	$29,016
Cost per kWh	$1.40

Table 1, Security Lighting at Arizona Avenue Bridge
PV Design Summary

Antietam National Battlefield

We assessed the possibility of using PV modules to power the parking lot lights at the Antietam National Battlefield Visitor Center; we also assessed the feasibility of using PV to provide the lighting for a flagpole at Antietam National Cemetery. The parking lot is 75 x 25 yards and contains one flagpole. This flagpole is at the entrance walkway of the Visitor's Center and contains the only outdoor light for the parking lot. A viable option for the parking lot would be post-mounted PV systems with battery storage. According to Richard Brown, Chief of Cultural Resources at Antietam, the site needs four more posts, two on the side of the flagpole and walkway, and two more across the parking lot (in addition to the one existing light). Systems that could provide the needed power generally run about $2500.

The type of system designed for the Antietam Visitor Center parking lot is used nationwide for purposes ranging from parking lots to major highways. The system includes a post with a pole-mounted PV module connected to a battery that leads directly to an energy-efficient light (direct current). This design may or may not have an arm that extends the light from the post to the area being illuminated (the decision to use the arm would be at the park's discretion). Such systems are used nationwide at such places as Miami International Airport. In fact, just 21 days before opening day, the Atlanta Committee for the Olympic Games (ACOG) ordered 64 lights from Solar Outdoor Lighting, Inc. to illuminate 8 parking lots covering 8,000 parking spaces, comprising over 2 million square feet.

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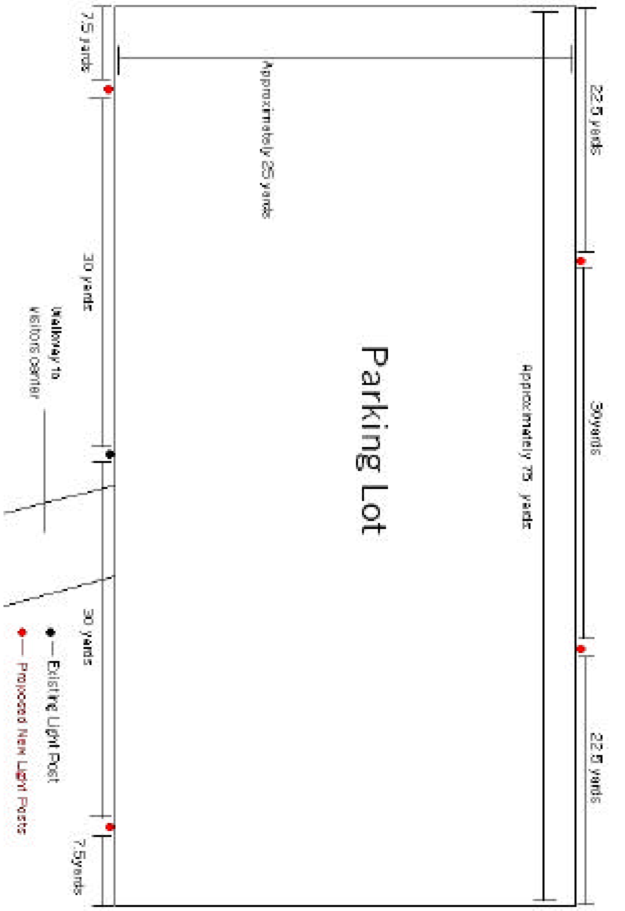
the amount of electrical energy that will be produced by the designed system in kilowatt-hours. The LCC is the life-cycle cost for the 20-year life of the PV system and includes estimates for maintenance and replacements. The cost per kWh is the amount you are paying to produce one kilowatt-hour of electricity and can be compared to the amount paid per kilowatt-hour, which is near $0.07.

Figure 2. Antietam Parking Lot Schematic



The Flagpole at Antietam National Cemetery

Near Antietam National Battlefield is the Antietam National Cemetery. The cemetery has a flagpole that is lit by a floodlight (shining from a gazebo at the base of the flagpole). We conducted an analysis to evaluate the feasibility of using a PV system to power this light. The design is for a much smaller load than the other designs in this report-- about enough to power a 150-Watt floodlight that runs from 6 p.m. to 6 a.m. daily. If a high-density sodium or halogen floodlight were installed, the light could run at about 50 Watts, thereby requiring a much smaller PV array and system; with reflectors, an even smaller bulb (e.g., a 25-Watt compact fluorescent light) could be used.

A 150-Wwatt bulb would require a system of 10 panels and six batteries. With a 50-Watt load, the system would require four panels and two batteries. With the CFL, just two panels and one battery would be needed. In all cases, the load is small enough that several of the components needed for larger systems could be left out, including a battery charger, generator, and inverter (if direct current lighting is used). This would improve the cost-effectiveness of the project, as inverters cost over $600, where a DC fixture and bulb could be installed for under $100.

These system options are all small enough to be placed on the gazebo at the base of the flagpole, where they would receive ample insolation. It would be counterproductive to continue using high-Wattage lighting with a PV system, as this adds to the PV system's power requirements. An approximately 20-ft^2 area would be needed for the largest system (10 panels).

The table below provides a summary of the flagpole spotlight designs. This table is based on Solar Sizer output.

Design	**Existing**	**Energy Efficient Spotlight**	**CFL Spotlight**
Number of Panels	10	4	2
number of Batteries	6	2	1
Yearly Power Production (kWh)	1,038	415	207
LCC	$9,084	$3,897	$2,301
Cost per kWh	$0.54	$0.70	$0.82

Table 2, Flagpole Lighting Designs at Antietam National Cemetery
PV Design Summary

Fort Washington National Park

We assessed the possibility of designing a PV system to provide the electricity needs of the entrance booth (or "fee booth") for the Fort Washington National Park. We developed four designs, partly because the entrance booth requires a lot of power and our original system design (to power the whole booth) was very costly. Our second design was a system that powered only the lights. The third design was a system that powered the HVAC equipment (in the summer months from May to October) and the fourth design was a system using rooftop PV shingles to provide supplemental electric power.

The fee booth is a 72-ft^2 building with two rooms, a main room where NPS personnel collect money, and a bathroom. The building has two outlets in the main room (into which a cash register and television set are plugged). The bathroom has a hand blow dryer and an additional outlet. There are four lights inside and a fourth outside.

We visited the site with Jeff Young, Senior Electrical Engineer, to determine he total load requirement for the facility. We also needed to know whether there was an unshaded area where PV modules could be placed. Finally, we needed to know the size, area, and spatial orientation of the booth in order to evaluate it for the use of PV shingles.

For this design we used the engineering schematics of the area around the Fee Booth, and the electrical layout with the load requirements for all equipment used in the booth. We obtained drawings for the fee booth from Jeff Young on the electrical and structural layout, which we used to determine the electrical loads for the building. (All our assumptions were made in reference to these drawings.)

The first step of this procedure is to input the electric load into the Solar Sizer Software and make assumptions as to the amount of time each piece of electricity is used on a yearly basis in order to design the system to meet the total demand in the least productive month of the calendar year for the PV cells.

The initial design--to power the entire building with PV at peak load times--required an extraordinarily large system that would cost on the order of $280,000. This facility is a small yet energy-intensive building. It has two rooms: a cashier's room and a bathroom. The building is used the entire time the park is open and is usually occupied by only one person that is collecting the entrance fee. Using PV to power the entire building was clearly impractical, so we explored alternatives.

The second design was a system that powered the HVAC system during the summer months (when the solar panels are at their peak output). The system would receive the most power at peak times (when most would be demanded). The HVAC system is electric, and draws about 2.5 kilowatts of power.

The third design was a system to power the booth's interior and exterior lights**.** We designed a system that would require the PV panels to only power the lights, thereby decreasing the overall wattage that the system would need to produce. This allows for the system to be smaller and cheaper. These lights include no more than four indoor and four outdoor lights, all of which should be replaced with standard 15-Watt CFLs before PV installation.

The fourth design was a system that used PV shingles on the south-facing slope of the booth's roof. The cost of this alternative is similar to the second system design at about $12,000 yet provides very little power in comparison at approximately 360 Watts of rated power. Further, this system would be less practical since its efficiency would be decreased because the roof does not face vertical south (towards the sun for most of the day) and the mounting angle would be about 45°, when optimal would be closer to 50°.

Table 3 is a summary table for the fee booth at Fort Washington. It gives Solar Sizer output for the first three options, which we explored.

Design	**Fee Booth**	**Fee Booth HVAC**	**Fee Booth Lights**
Number of Panels	500	115	15
number of Batteries	428	108	14
Yearly Power Production (kWh)	28,931	6,568	797
LCC	$285,896	$78,427	$10,687
Cost per kWh	$0.68	$0.74	$0.86

Table 3, Fee Booth Options at Fort Washington
PV Design Summary

For the Future

As we look at our designs, it is clear to us that the primary issue for the PV systems is more education than cost-effectiveness. That is, the systems need to be justified on not just an economic basis, but on their role in educating the public; while this role is important, it is not easily quantified. We suggest that one of the simpler, cheaper designs should be selected for implementation. A first step would be to contact a company (such as Siemens, or Solar Outdoor Lighting) to discuss the intended project. (In fact, many of the companies that we contacted gave discounts for government and educational projects such as the ones that we designed.) The cost estimates for the designs in this report are very close to the actual costs of the implementation. Projects can be selected and tailored to fit into available budgets.

II. ANTIETAM ENERGY AUDIT

Introduction

The purpose of an energy audit is to assess a building's energy use and make recommendations regarding any changes that could be made to reduce the overall use and cost of electricity in the building. For a lighting audit, an auditor needs to go through the building to determine the different kinds of lights, how long they are used, and the amount of electricity they use.

The Lighting Audit

Visitor Center Description

The Antietam National Battlefield Visitor Center, Sharpsburg, VA, was built in 1961. The two-story facility houses a lobby area, auditorium, bookstore, employee breakroom and boiler room, museum, restrooms, offices, and an observation room.

Existing Lighting--By Room

Lobby. Ten 65-Watt flood lights, eight compact fluorescent lights (CFLs), and three halogen lights (illuminating the exit signs and other directional signs).

Restrooms. Lighting in the restrooms us provided by two two-bulb 40-Watt fluorescent tube light fixtures. Two skylights in each restroom provides significant daylighting.

Employee break room and boiler room. These two rooms are attached and have no windows. Two 65-Watt floodlights in the boiler room and two four-bulb 40-Watt fluorescent tube lights in the break room provide lighting.

Auditorium. Twelve 60-Watt incandescent light bulbs and two 65-Watt floodlights provide lighting in the auditorium.

Bookstore. The relatively small bookstore is lit by 10 fixtures with 4 x 40-Watt fluorescent tube light fixtures. The windows in the bookstore are covered either by blinds or bookcases, reducing available daylighting.

The museum. The museum has 27 35-Watt halogen lights illuminating the displays, and two flood lights (one of which is covered with a black screen). The stairs to the museum have two 60-Watt incandescent bulbs.

Offices behind the bookstore. Lighting in each of the two offices is provided by four 4 x 40-Watt fluorescent tube fixtures.

Offices off the museum. Off the museum there is: 1) a reception area that is lit by five 4 x 40-Watt fluorescent tube fixtures; 2) a hallway lit by two 4 x 40-Watt fixtures; 3) a library area with eight 2 x 40-Watt fluorescent fixtures; 4) four offices each with four 4 x 40-Watt fluorescent fixtures; 5) a closet with a 65-Watt flood light.

Observation room. Three 40-Watt incandescent lights illuminate the stairway to the observation room. The observation room itself has eight 4 x 40-Watt fluorescent fixtures. A closet contains one 200-Watt incandescent bulb.

Auditorium. Used 12 60-Watt incandescent lights in four rows of three, and two 65-Watt floodlights in the back corner.

Other. A handicap elevator shaft that is lit by one 60-Watt fluorescent light tube.

Lighting Audit Results

We made several observations during our tour of the Visitor Center, noting in particular that:

- some areas were over-lit
- some areas with adequate day lighting were lighted
- lights were on in unoccupied rooms

To begin the lighting audit of the Visitor Center, we recorded the fixture, bulb type, hours of daily usage (generally 11 hours for most lights in the building), and the purpose of each light within every room and closet. During the site visit we discovered that the entire facility uses only six different types of lights.

Number Of Lights	Description of Fixture	Wattage
56	Fluorescent light with four 48" bulbs	40 Watts per tube 160 Watts per fixture
17	Incandescent Spotlight (one bulb)	65 Watts
30	Halogen Display Spotlight (one bulb)	35 Watts
10	Compact Fluorescent (one bulb)	18 Watts
15	Standard 1" fixtures (one bulb)	60 Watts**
1	Standard 1" fixture (one bulb)	200 Watts

**12 with reflecting dishes

Table 4, Types of Lights at Antietam Visitor Center

(We should note that the downstairs museum was recently outfitted with an entirely new lighting scheme using 35-Watt halogen bulbs for display lighting. Any energy conservation measures implemented there would need to retain a similar color and light output.)

We created a spreadsheet (se Appendix 3) that included, for each of the six lighting types: 1) a fixture description; 2) the total number of each fixture used; 3) the total power draw of each fixture; 4) the hours of daily use; and 5) the total daily energy used. This data was compiled and used to make calculations of the annual lighting energy use, the maximum electric demand, and the total annual lighting electricity costs.[5] These values can be seen in the table below:[6]

Annual Energy Use (kWh)	49,766
Electric Demand, Max (kW)	12.395
Annual Electric Cost	$3,732.44

Table 5, Existing Lighting Energy Use
Antietam Visitor Center

It is our belief that simply decreasing the number of lights in several areas--mostly in rooms with multiple fixtures containing 4 x 40-Watt fluorescent tubes--would not only be more efficient, but more pleasing to the eye. In our spreadsheet we simply used two bulbs instead of four to test this assumption (in many places there were already only two bulbs operating as the others were burnt out). These rooms included the upstairs and downstairs hallways, breakroom, Library, observation room deck, and upstairs offices.

The next ECM we adopted was to install motion sensors in the two upstairs and four downstairs offices, the copy room and the library. The implementation of occupancy sensors is a viable option based upon the usage of the offices at Antietam National Battlefield Visitor's Center. According to an employee at the Visitor's Center we learned that people work from 8:00 in the morning until 4:00 at night. Richard Brown told us that the lights go on about 7:00 in the morning and then are turned off again at 6:00 at night. Personnel are also out of their offices for up to two additional hours per day for random things such as lunch. This leaves the occupancy at six of the eleven hours that the lights are on. Furthermore, personnel in the offices do not always work on weekends. In looking at the spreadsheet with the cost of implementing such sensors, it seems as though this would be an opportunity in which they would be needed and necessary. The effectiveness of them lies in how conscientious employees are at turning off the lights when they leave the room. In the offices that are upstairs with windows serving as one of the walls, the natural day lighting in the working hours could serve as lighting for many of the sunny days.

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[5] The total lighting electricity costs annually was found using $0.075/ kWh based on the values given by Richard Brown for annual electricity use and cost. This value was then multiplied by the total annual energy use to find total annual cost.

[6] These values reflect only existing conditions based on all available information given to us during the site visit to Antietam Visitors Center on Monday August 9, 1999.

	20-Year Life-Cycle Cost
Existing	$61,407
Proposal	$51,208
Proposal with Sensors	$42,718

Table 6, Lighting Audit Results
Antietam Visitor Center

This process would require an investment of only $117 for all eight offices (plus labor, which was quoted by General Electric at only 20-30 minutes per installation). The simple payback period for the implementation (installation included) would be about 2 months. The use of occupancy sensors is both cost effective and practical, saving over 5,000 kWh each year.

We also explored the adoption of compact fluorescent lights (CFLs) in place of incandescent bulbs. A summary of these results are as follows:[7]

	Existing	Proposed	Savings	Savings (%)
Annual Energy Use (kWh)	49,766	31578	18188	37
Electric Demand Max (kW)	12.4	9.1	3.2	26
Annual Electric Cost	$3,732	$2,368	$1,364	37

We performed a 20-year life cycle cost analysis assuming an inflation rate of 3%, a discount rate of 9%, and an escalation rate in electricity costs that was constant with the inflation rate. This LCC calculation required that all bulbs would be replaced at day one of the first year, and the replacement intervals were tied into the life of each bulb. At present all bulbs run for the entire 11-hour operating day. We varied the replacement intervals for the bulbs used with motion sensors.[8] The LCC calculation included a 15-minute changing time and the associated labor cost of $15 per hour. All costs were inflated and discounted based on the year that any cost would be incurred.

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[7] These results are all actual based on commercially produced products and do no t include calculations for the use of electric versus electromagnetic ballasts.

[8] The motion sensors were a GE product costing $14.62 and turn on when someone enters a room and off 90 seconds after activity ceases and include a manual override control as well.

One might expect that more savings would be incurred, and this may be true if certain areas of lighting could become less energy intensive. For instance, for the low lumen output of the halogen lamps in use a very low wattage CFL could be used; however, there would be a need for this change to show the same color for proper displays. Secondly, further reductions in the use of florescent tubes can be made with further implementation of better reflecting shells and electric rather than electromagnetic ballasts. Finally, this LCC calculation does not include variations in the cost of technologies such as CFLs that are likely to decrease as the technology's market advances.

Unresolved Issues--Lighting Audit

In doing the lighting audit, we mainly dealt with the lobby area, offices, hallways, auditorium, and observation room. The problem that is here is that there are a many other parts to this building. Though these are the main areas and were many of the main problems lie, for instance there were 27 halogen lights located in the museum. This seems to be unnecessary considering that not all of the lights were being used. Furthermore, with this room it would be interesting to see if the floodlight actually could be turned off and have just the halogens used. This is mainly a viewing concern and would need to be the opinion of the people that work there. It was also noted that the light in the handicap elevator shaft was left on at all times. This did not seem to be used that often where it would need to have been left on at all times. The fact that these areas were not specifically looked at in terms of the audit does play a role in the final output.

Furthermore, electronic ballasts are more efficient than electromagnetic ballasts because they operate at 20,000 Hz and above, as compared to conventional electromagnetic ballasts, which operate at 60 Hz. The 40-watt fluorescent lamps in the 4-foot fixtures should be replaced with energy efficient T8 lamps. The current 40-watt fluorescent lamps have magnetic ballasts that consume 160 watts for four lamps. T8 lamps, that have electronic ballasts, will consume only 109 watts while producing the same light. This change was examined, however the commercial pricing of such items was not obtained (as a result, this could not be put into the lifecycle cost). However, doing some calculations with the numbers that we do have with energy usage it was found that there would be a cost of $967.98/year with the system listed above. Conversely, if you were to use the lights with the electromagnetic ballasts then there would be a cost of $659.44/year.

We found five different bulb types at the Visitor's Center: incandescent light bulbs, fluorescent light bulbs, halogen lights, compact florescent lights, and incandescent floodlights. We first assessed light fixtures that contained four fluorescent light bulbs. In many of these fixtures the lighting was excessive for the area. We changed some of these to contain only two of the four lights, reducing the total wattage from 160 to 80 watts per fixture. The areas that we found this to be suitable were the breakroom, library area, hallway both upstairs and downstairs, the observation deck and the offices upstairs. The library area is not used as a reading room, but really a containment unit, so high-intensity light is unnecessary. The two hallways are also overlit. Many offices have windows lining the exterior wall; using natural light as opposed to the fluorescent lights would be feasible.

A Note on the Full Audit--ASEAM

At the start of this project we intended to do a full energy audit of one of the facilities in the National Parks Capital Region area. We obtained a copy of ASEAM (A Simplified Energy Analysis Method) from FEMP (the Federal Energy Management Program). The software is designed for users to input variables such the dimensions of a building and information about its heating and cooling systems; the software then provides output about the potential ECMs to improve energy efficiency.

Note on the Trial Audit

We conducted a preliminary energy audit of the Narum household, in Harrisonburg, Virginia, so see if we could get the software running. We spent a morning going through the household counting lights, discussing building structure particulars, and assessing hours of use. We then tried to input the variables into ASEAM. Unfortunately, we were unable to get the software to run and produce output. We spent close to a week trying to debug the software, but were unsuccessful.

The data collected (window and wall dimensions and materials to roofing insulation to HVAC BTU output) at the Narum household was input into ASEAM in the (seemingly) appropriate manner. We then ran the program, only to receive an error dealing with the load diversity factor (an input parameter for the percentage of time mechanical systems are in use). After inputting actual values for this parameter a run error occurred. After trying sample values (in an effort to get the program to run), we were still unsuccessful. We came to the conclusion that this may be a software problem.

III. PROJECT RECOMMENDATIONS

We discuss our recommendations in two parts. First, we look at ideas for specific energy-related projects that the Partnership could pursue in the years ahead. Second, we provide our comments on the process and content of the program delivery.

The Years Ahead

We believe that in future years the program should focus on high-visibility areas. It is our understanding that the National Capitol Region National Parks include the Mall as well as traffic circles, such as Chevy Chase. These areas are seen by residents of Washington and by tourists. As noted earlier, the cost-intensive nature of PV systems suggests that much of their value may be in a more educational purpose. There are many PV systems in high-visibility National Parks that could be implemented. For example, the area between the Washington Monument and the Capitol has hundreds of lights used for night lighting. Why not use PV in part (or all) of this area? While there may be issues with the Fine Arts Commission, they need to be balanced with the power, practicality (and necessity) of using PV systems. A clean source of power is a thing of beauty compared to electric power from coal-fired plants.

Further, the issue of education is important and fulfills part of the mission of the National Park Service. Greater public awareness of renewable energy is the first step toward its widespread use. Without people converting to such renewable energy it is more difficult for markets to grow and for the costs of PV systems to benefit from economies of scale.

A Recommendation. We believe that the Partnership program should focus on: 1) public education; 2) issues with the Fine Arts Commission; and 3) implementation of a high-visibility PV system in the National Capitol Region. The emphasis should be to refocus the program from energy conservation in the parks to energy conservation by the public (inasmuch as the renewable energy market requires public education). The parks could even become completely powered by renewables over time. As the National Parks have a significant educational purpose, we see the use of such a platform as the National Capitol Region parks as a natural.

Commitment. These projects will need the personnel involved (students, faculty, park personnel) to have strong commitment to seeing renewable energy implemented nationwide. Park personnel and the University advisor need to be dedicated to the cause, both to inspire them and their students to devote as much time and energy as possible to this program, and to inspire a desire to see actual implementation of the projects.

Program Process Recommendations

Because this is a pilot program, we would like to make recommendations to on how the program was delivered. These are not meant to criticize, but to suggest how the program could run more smoothly.

After the people are chosen to work on the project, there should be a meeting between the advisor, students working on the project, and the NPS personnel, in particular the energy coordinator, to meet and discuss possible options for projects. This meeting will allow all parties to express their ideas as to what they would like done over the summer.

After the kick-off meeting, students should write a brief description of the projects they would like to work on, and propose it to the energy coordinator (or other person in charge). This proposal could include how the students' experience could be most useful (such that the projects suit their abilities). NPS personnel should then respond by further defining the projects. This interaction should occur before the end of the school year such that full project descriptions are agreed on before the completion of final exams. Project descriptions should also include project timelines and milestones to serve as goals for the students.

Before the end of the school year, it would also be helpful if the students identified possible software and got acquainted with it. This would allow more of the summer to be spent working on project results, rather than trying to determine how software works or even if it is useful for the project.

Weekly Meetings. There should be a set day of the week whereby students will meet NPS personnel. This visit will include a site visit as well as a meeting to discuss any necessary technical information requirements resulting from that site visit or past reports. The students should return from these meetings with the technical information they need to continue their work. Further, the students should be prepared to revise any past reports that were reviewed by NPS personnel and returned to the students at this weekly meeting.

Once the summer begins, close contact between the NPS personnel and the students is imperative. This involves timely feedback on reports as well as meetings to discuss the progress of the project weekly; lack of feedback can result in project delays.

Lastly, we believe that both students and advisors should be technically knowledgeable in the area of the projects. For instance, if the project were dealing with system design, an engineer with experience in this area would be appropriate. If the project is mostly concerned with policy, regulations and economics a suitable advisor should be chosen with experience in these areas.

Appendix 1. Photovoltaic Design Methodology

In order to begin the design at either site we first needed to visit that site and have several questions answered. In the case of the Arizona Bridge Jeff Young, Senior Electrical Engineer at the Capital Region National Parks, has already retrofit the bridge with a security lighting system that consists of 10 lamps. In order for our design to begin we first needed to know the maximum power drawn by this system per day. This would allow us to design a PV-battery system that could meet this requirement for any day of the year. Second we needed to identify that there was a location close enough to the site where the PV panels could be placed such that they would not be shaded by surrounding objects thereby allowing for maximum sunlight to reach them at all hours of the day. Finally, we needed to understand the level of visibility that could not breached in order for the design to pass the Fine Arts Commission standards since this is a historical site.

The answers to these questions would allow us to begin designing the appropriate system. In designing any PV system there are three questions to answer. First, what modules and batteries will have the best cost to efficiency ratio while still remaining compatible with respect to frequency, voltage, and current of the lighting design. Second, at what angle can the panels be mounted in order to receive the maximum possible power output for each module. Third, how do we wire the modules and batteries to achieve maximum possible power output while keeping the cost as low as possible.

With these questions in mind we must first choose PV module that will be compatible to the lighting retrofit. This is simple a matter of going on Internet based databases finding those products which will be technically compatible. Then assessing the cost to efficiency ratio of compatible panels by assessing what panels will give the most output at the best price. This question will be easiest to answer once we are given an approximation of the money allotted to this project.

In order to calculate the angle of maximum efficiency for a PV module we will use either the PVF chart software or a solar radiation model that predicts incident sunlight on earth at any given place based on the angle that surface is with respect to the sun. The chosen modules from above will then be evaluated for individual power output.

This power output is calculated using Ohms Law, which states:

$$(1)\quad P = IV$$

Where P is power in Watts, I is the current in Amps, and V is the voltage in Volts. This calculation is based on the two input quantities current and voltage, which are determined by the rate at which electrons move across the PV cell. This rate is based on the amount of solar radiation incident on the cell and the efficiency of that cell to respond to incident energy and create electron hole pairs. The power output of each module will then be added to the power output of the other modules based on the wiring configuration. If the modules are wired in parallel the output current is determined by:

$$(2)\ I_{total} = I_1 + I_2 + \ldots + I_n$$

*where n is the number of modules wired in parallel

The voltage when wired in parallel is calculated by:

$$(3)\quad (V_{total})^{-1} = 1/V_1 + 1/V_2 + \ldots + 1/V_n$$

*where n is the number of modules wired in parallel

For modules wired in series the voltage is summed and the current is calculated using equation (2) where the V's are replaced with I's. This series of calculation will provide a series of ratios for number of modules in series and number of modules in parallel which can be evaluated for the maximum possible power output that is to be sent to the battery system.

The batteries will be wired using the same calculations for series and parallel such that maximum output is achieved at minimum costs.

The final components of this system are called the BOS (balance of system) components they include wiring, mounting, and connections. These items will be chosen based on the best possible quality to cost ratio.

In order to implement the system at Antietam National Battlefield the process is really quite simple. An initial examination of the site is necessary in order to view the size of the lot and to determine the number of lighting systems that are going to be needed. After this is done research needs to be done as to which companies and manufacturers produce the type of systems that we are looking for. In doing so a cost analysis is also done to compare which of the manufacturers offers the best price for the power requirement. In this case, there are very few if any calculations that need to be done as these are stand alone systems with the light that is already attached to it. The biggest issue in this case is making sure that the systems are able to be turned on and off or on a timer for nighttime use only at certain times. The lighting company that has been selected based upon price and system design is Solar Outdoor Lighting, Inc. This company offers discounts to government projects such as this and will be able to provide a system that will cost roughly slightly less than $14,000 for all five lighting units that need to be used. The labor to put these systems up is said to be about four hours per unit. This cost is included with in the $14,000 estimate that we were given.

Specific Designs

Throughout the course of the summer we have designed several Photovoltaic (PV) systems for various applications throughout the Capitol Region National Parks. In order to design these systems we had to appropriately choose and size the following components for voltage and current compatibility as well as meeting the electric power needs of those various applications. The systems design have been done using the Solar Sizer Software which provides electric power and economics outputs for the desired input parameters. Those Parameters are as follows.

Location

Location is essential to the design of any PV system. The spatial description of the exact location of the PV system to be implemented is extremely important in two aspects. The amount of incoming solar radiation varies with location according to how far north or south of the equator any location is. SO inputting the proper location with correct longitudinal coordinates is essential so that the system can be designed such that after system losses the system will provide enough electric power to its load even in the most undesirable month of use. For very similar reasons the latitude is very important. This is also important for the calculation of the amount of incoming solar radiation. However, in this case the latitude of a location effects the amount of Air Mass, which the incoming radiation must travel through. For instance, the air mass of Georgia is very different than Arizona due to humidity, population density and a variety of other factors which effect local atmospheric composition despite the fact that they are within the same longitudinal range. Elevation is another location parameter. This input is based on location and is relatively insignificant due to the distance any point on Earth is away from the sun. The other important input parameter in the location field of a Solar Sizer report is the design month. This parameter must be cautiously selected such that it represents the month of minimum incoming solar radiation. This is the month for which a PV output will be the least, but still must produce enough electric power to meet the needs of the load application.

System

The design of any system requires that all components run at compatible voltages. For this reason the system field of a Solar Sizer report includes the parameter of system voltage. For almost all cases this is 12 volts, which is the nominal voltage coming from almost all commercially produced PV panels on the market today. The second parameter is days of autonomy. Since most National Parks are open every day of the week this parameter had to be seven representing the fact that the system design had to be producing the same amount of electric power every day of the week. For instance, if a business was powering its facility and was only open five days a week this parameter would be five. The final parameter in the system field is array to load ratio. This had to one since the PV designs were to power all needs of the load application. However, if it was desired to only power the lights of a building and they represent 68% of the load then this factor would be changed to 0.68.

Load

This was the field were all electricity drawn by the application load was input. The resulting output parameters on a Solar Sizer report are for total load drawn given in Ah/day or amp-hours per day and the systems nominal voltage as input in the system field. The next parameter is maximum continuous wattage. This includes two quantities one for DC watts and one for AC watts. DC stands for direct current, which is rarely used for non-battery powered electrical equipment. Direct current is a constantly supplied current whereas alternating current alternates like a sine wave and is more compatible with heavier electric loads. The AC watts represents the total amount of power that can be drawn by all electrically powered items running at peak need within the application load. The parameter for maximum surge watts represents the amount of power the load can withstand in the case of an electrical surge, which is 120 watts AC in the United States. The final parameter for load items is summary of all appliances their daily hours of use and the number of days they are used per week.

PV Array

This field is a description of the actual number of PV panels to be sued how they are wired and the amount of power used broken down to ideal current and voltage. The most important parameter in this field is the model description. Here Solar Sizer averages commercially produced PV modules for efficiency and cost to provide an accurate estimate as to the size and cost of a PV system. This parameter explains how the modules are wired for instance 2 series x 7 parallel. This wiring configuration is used to maximize power output form the array. An explanation of how the most efficient configuration is found can be read in the design analysis chapter on methodology. This field then goes on to the O.C. voltage, which is the open circuit or ideal voltage and the S.C. current or the Short circuit or ideal current. These values are inherent within the module and represent the maximum voltage or current if the other was 0 meaning the module's resistance value is either 0 or infinite. If the resistance is infinite the ideal voltage is reached and if it is zero the ideal current is reached. Finding the most efficient ratio between S.C. current, O.C. voltage and resistance is an issue in increasing the efficiency of PV technology. The same quantities are then described for the entire array.

Array Mounting

Array mounting may be the single most critical issue in gaining the most productive output from a PV array. Direct solar radiation has more energy within it than other solar radiation, which may be diffused as it enters the atmosphere. Therefore, a meticulous calculation for the angle at which a panel was made to show that the longitude of a location plus 15^o would provide the collector with the best ability to collect direct solar radiation. This calculation has since been disregarded as default and a series of equations can now calculate the most efficient angle for mounting the module. This series of calculations produces an angel usually within a few degrees of the previous default and provides more output energy. Therefore, a Solar Sizer report uses the previous default, but we have input the power output based on the more accurate calculations. This calculation is reflected in the parameter for design month insolation. (Calculation to be shown somewhere).

Batteries

Batteries are the component of a stand-alone PV system where electric energy is stored for discharge at the need of the application load. Similar to PV modules the maximum battery efficiency can be achieved using a specific wiring configuration. Similarly the current, voltage and therefore power output can be increased or decreased depending on the number of modules you wire in series versus parallel. The cell type parameter was chosen because it is currently the most efficient battery type on the market today. The Maximum depth of discharge and battery efficiency parameters are inherent with the battery and are simply saying that the battery operates at 80% efficiency and they can only discharge electric power at 80% of what was initially introduced into them. The final two parameters represent the amount of energy that can be stored at each battery. Don’t be alarmed if the individual battery and the total voltages are no the same. This only means that the wiring configuration stepped the voltage up to nominal.

Charge Controller

This system field is representative of the electric device that takes the amount of electricity from the batteries and sends it to the inverter. This device control the rate at which that process happens. The number of controllers is chosen based on the size of the batteries. For instance, if the batteries are sending more electric charge to the controller than it can handle you may well need more than one controller. The parameter for each controller and Total are once again the amount of voltage and current being sent from the controller to the inverter.

Inverter

The inverter is the electronic device that converts the power being sent form the charge controller from DC to AC essentially taking energy that comes in one form and converting it to another. (This process is no different than converting an office 95 document to an office 97 document.) The number of inverters is equal to the number of controllers and must be configured with other inverters to produce electric power that is compatible with respect to waveform and nominal voltage of the application load. The input and output voltage are reflective of what is coming from the controller and what is going to application load. The efficiency is once again inherent in the inverter. The Parameters for each inverter and total represent the amount of energy that must always be running through and the amount at the node and antinode of each waveform.

Battery Charger

The battery charger is the system component that that charges the batteries with the energy produced by the PV array. It simply takes the energy and charges the batteries based on which the amount of energy already present when more comes in. Input and output voltage will be compatible with output voltage of the PV and input voltage for the batteries. The maximum charging rate is a property of the charger itself, but is proportional to the output voltage of the PV array. The charger efficiency is inherent with the product itself.

Generator

The generator is the system component that is used to provide electric power to the appliance load when the system is such down for whatever reason be it repairs or a period of severe weather where insolation is abnormally low for an extended period of time. All parameter within this field are inherent in the generator itself except that the capacity is proportional to the amount of energy that the PV system can not produce in its least productive month in order to meet the appliance load.

Wiring

All parameters within the wiring field are reflective of normal component to component distance. The parameters for allowable voltage drops are reflective of the amount of electrical energy that can be lost through the wiring and the system will still meet the appliance load. These parameters are still inherent in the wiring.

System Performance

This section of the Solar Sizer report describes the system by the amount of electric power it will produce based on the following seven parameters.

1. *Average Daily Energy Consumption*--this parameter describes the amount of energy that will be consumed by the appliance load from the system based on the amount produced.
2. *Average Daily Energy Production*--this parameter explains the amount of energy provided by the PV versus the generator for the design month.
3. *Average Yearly Energy Consumption*--this parameter is the description of the annual energy consumed by the appliance load.
4. *Average Yearly Energy Production*--this parameter tells the annual energy produced by the system explaining the amount coming from both the PV and generator.
5. *Average daily energy production from solar by month*--this table gives the average daily energy production by the PV per month. The values are given in both kilowatt-hours per day and amp-hours per day since the voltage is continuous.
6. *Percentage of load provided by solar per month*--this table gives the amount of energy that is provided solely by the PV per month. Remember that the design month is the least productive so some months may be greater than 100 and some less since they have generator backup.
7. *Generator hours of usage by month*--this table describes the total number of hours during the month that the generator will be run in order to make up for the PV production to appliance load gap that may exist in extreme or designed cases.

System Economics

The system economics is a description of a life cycle cost analysis and describes both the initial and life cycle costs including fuel and maintenance.

- Initial costs

  The initial cost is the cost that will be incurred for the initial purchase of the equipment and components for your PV system. These reflect commercially produced product averages for the efficiency and size of the components selected.

- Life Cycle Costs

  The three input parameters are system life which is based on average life of PV systems, discount rate which is usually based on the current market averages and fuel discount rate which is dependent on the fuel used to power the generator. The replacement intervals are all industry average for the selected components. Th operations and maintenance costs are similarly based on industry average and represent inflation rates during calculations. Salvage cost is representative of what one would get when they tried to sell PV systems at the end of their life which is usually close to nothing.

Appendix 2. PV DESIGN SPECIFICATIONS

Results: Solar Lighting Antietam National Battlefield

To: Antietam National Battlefield
Sharpsburg, MD 21782-0158

Submitted by: Matt Hollister, P.O. Box 158

Project: Parking Lot Lighting

Quotation Number: MH-079905
QUOTATION

ITEM NO	QUANTITY	DESCRIPTION	UNIT PRICE	TOTAL
A	5	Model PM-83 Solar Light (Per GSA Schedule) System includes: - (1) Solarex 56 W solar panel with mounting assembly - (1) Gel-Tech 80 amp battery with battery box - (1) System Controller - (1) Light Fixture w/ Mounting Arm - (1) Manual Override Switch - (1) Wiring, hardware, etc. - (1) Powder Coating All Surfaces	**$2,323.00**	**$11,615.00**
B	5	DSB 24 24' Fiberglass Mounting Poles (Per GSA Schedule)	**$388.00**	**$1,940.00**
Total Cost (On 4 Hours**)**				**$13,555.00**

Installation: By Others

Freight: Included (Per GSA Schedule, Contract GSO7F-0018H)

Results: PV design C&O Canal Arizona Avenue Bridge

Solar Sizing Report

I. System Specifications

II. Location
Site: Washington, DC, United States
Latitiude: 39.00 degrees N
Elevation: 82 meters
Design month: Dec

III. System
System Voltage: 12 volts
Days of autonomy: 7 days
Array to load ratio: 1.00

IV. Load
Total appliance load: 167 Ah/day @ 12 volts
Corrected amp-hour load: 236 Ah/day @ 12 volts

-- Maximum continuous wattage --
DC: 0 watts
AC: 500.0 watts

-- Maximum surge wattage --
AC: 500.0 watts

-- Load Items --
12.5 Typical fluorescent light; AC (120V); 40 W; 4.0 hrs/day; 7 days/wk

V. PV Array
Model: PV module
25 panels: 1 series x 25 parallel
Module derate factor: 90%

-- Each Module --
55 watts rated @ 12 volts nominal
O.C. voltage: 21.3 volts
S.C. current: 3.4 amps
Voltage at STC: 17.1
Current at STC: 3.2 amps

--Total --
1375 watts rated @ 12 volts nominal
O.C. voltage: 21.3 volts
S. C. current: 86.0 amps

VI. Array Mounting
Model: Array mount
Type: Fixed
Tilt: Latitude +15
Design month insolation: 3.30 kWh/m2/day

VII. Batteries
Model: Battery
14 batteries: 2 series x 7 parallel
Cell type: Lead acid
Max depth of discharge: 80%
Battery efficiency: 80%
Temperature derating: 90%

-- Average Daily Energy Consumption (Design month)
Total: 2.83 kWh/day (236 Ah/day @ 12 V)
Appliance load: 2.00 kWh/day (167 Ah/day @ 12 V)
System losses: 0.834 kWh/day (69.5 Ah/day @ 12 V)

-- Average daily Energy Production (Design month) --
Total: 2.87 kWh/day (239 Ah/day @ 12 V)
Photovoltaics: 2.87 kWh/day (220 Ah/day @12 V) [93%]

--Average Yearly Energy Consumption
Total: 1032.95 kWh/yr
Appliance Load: 729.99999kWh/yr
System Losses: 304.4100000000 kWh/yr

--Average Yearly Energy Production--
Total: 1418.47894
Photovoltaics: 1418.47894

--Average daily energy production from solar by month

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
KWh/ day	3.2	3.7	4.1	4.3	4.2	4.3	4.3	4.3	4.3	4.0	3.2	2.9
Ah/ day	268	311	340	355	347	355	355	362	355	333	268	239

--Percentage of load provided by solar by month

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
%	113	132	144	150	147	150	150	153	150	141	113	101

System Economics

Initial Costs:
PV Array: $8,750
PV mounting: $1,375
Batteries: $2,366
Charge Controller: $52
Inverter: $625
Battery Charger: $1,125
Wiring: $0
Other: $0

Installation Cost: $10,000

--Total--
Total initial costs: $24,293

Life Cycle Costs
--Economic Parameters
System Life: 20 years
Discount rate: 9%

--Replacement intervals
Batteries: $2366 every 5 years (3 replacements)
Charge controller: $52 every 10 years (1 replacement)
Inverter: $625 every 10 years (1 replacement)
Battery charger: $1125 every 10 years (1 replacement)
Generator rebuild: $388 every 5000 years (0 rebuilds0

--Operations and maintenance

Labor: $0/year
Materials: $0/year
Insurance: $0/year
Other: $0/year

--Salvage
System salvage value: $0

--Total
Total life cycle costs: $29,016
Energy cost: $1.40/kWh

Solar Sizing Report
Fort Washington Fee Demo Booth

VIII. System Specifications

IX. Location
Site: Washington, DC, United States
Latitiude: 39.00 degrees N
Elevation: 82 meters
Design month: Dec

X. System
System Voltage: 12 volts
Days of autonomy: 7 days
Array to load ratio: 1.00

XI. Load
Total appliance load: 3,410 Ah/day @ 12 volts
Corrected amp-hour load: 4833 Ah/day @ 12 volts

-- Maximum continuous wattage --
DC: 0 watts
AC: 660.0 watts

-- Maximum surge wattage --
AC: 660.0 watts

-- Load Items --
11 Incandescent Lights; AC (120V); 60 W; 62.0 hrs/day; 7 days/wk

XII. PV Array
Model: PV module
500 panels: 1 series x 500 parallel
Module derate factor: 90%

-- Each Module --
55 watts rated @ 12 volts nominal
O.C. voltage: 21.3 volts
S.C. current: 3.4 amps
Voltage at STC: 17.1
Current at STC: 3.2 amps

--Total --
27500 watts rated @ 12 volts nominal
O.C. voltage: 21.3 volts
S. C. current: 1720.0 amps

XIII. Array Mounting
Model: Array mount
Type: Fixed
Tilt: Latitude +15
Design month insolation: 3.30 kWh/m2/day

XIV. Batteries
Model: Battery
428 batteries: 2 series x 214 parallel
Cell type: Lead acid
Max depth of discharge: 80%
Battery efficiency: 80%
Temperature derating: 90%

-- Average Daily Energy Consumption (Design month)
Total: 58.0 kWh/day (4,830 Ah/day @ 12 V)
Appliance load: 40.9 kWh/day (3,410 Ah/day @ 12 V)
System losses: 17.1 kWh/day (1,420 Ah/day @ 12 V)

-- Average daily Energy Production (Design month) --
Total: 58.0 kWh/day (4,830 Ah/day @ 12 V)
Photovoltaics: 57.3 kWh/day (4,780 Ah/day @12 V) [99%]
Generator: 0.677 kWh/day (56.5 Ah/day @ 12 V) [1.2%]

--Average Yearly Energy Consumption
Total: 21170.0 kWh/yr
Appliance Load: 14928.5 kWh/yr
System Losses: 6241.5 kWh/yr

--Average Yearly Energy Production--
Total: 28390.6 kWh/year
Photovoltaics: 28369.6 kWh/year [100%]
Generator: 21.0 kWh/year [0.074%]

--Average daily energy production from solar by month

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
kWh/ day	64.3	74.7	81.6	85.1	83.4	85.1	85.1	86.8	85.1	79.9	64.3	57.3
Ah/ day	5355	6224	6803	7092	6947	7092	7092	7237	7092	6658	5355	4776

--Percentage of load provided by solar by month

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
%	111	129	141	147	144	147	147	150	147	138	111	99

System Economics

Initial Costs:
PV Array: $175,000
PV mounting: $27,500
Batteries: $32,956
Charge Controller: $491
Inverter: $2,485
Battery Charger: $300
Wiring: $0
Other: $0

Installation Cost: $0

--Total--
Total initial costs: $240,112

Life Cycle Costs
--Economic Parameters
System Life: 20 years
Discount rate: 9%
Fuel discount rate: 9%

--Replacement intervals
Batteries: $32956 every 5 years (3 replacements)
Charge controller: $491 every 10 years (1 replacement)
Inverter: $2485 every 10 years (1 replacement)
Battery charger: $300 every 10 years (1 replacement)
Generator rebuild: $690 every 5000 years (0 rebuilds)

--Operations and maintenance
Labor: $0/year
Materials: $0/year
Insurance: $0/year
Generator fuel cost: $1/year
Generator service cost: $1/year
Other: $0/year

--Salvage
System salvage value: $0

--Total
Total life cycle costs: $285,896
Energy cost: $0.68/kWh

Scenario 1 (PV for lighting)
Solar Sizing Report

XV. System Specifications

XVI. Location
Site: Washington, DC, United States
Latitiude: 39.00 degrees N
Elevation: 82 meters
Design month: Dec

XVII. System
System Voltage: 12 volts
Days of autonomy: 7 days
Array to load ratio: 1.00

XVIII. Load
Total appliance load: 100 Ah/day @ 12 volts
Corrected amp-hour load: 142 Ah/day @ 12 volts

-- Maximum continuous wattage --
DC: 0 watts
AC: 120.0 watts

-- Maximum surge wattage --
AC: 120.0 watts

-- Load Items --
4 Compact Fluorescent Light; AC (120V); 15 W; 8.0 hrs/day; 7 days/wk
4 Compact Fluorescent Light; AC (120V); 15 W; 12.0 hrs/day; 7 days/wk

XIX. PV Array
Model: PV module
14 panels: 1 series x 14 parallel
Module derate factor: 90%

-- Each Module --
55 watts rated @ 12 volts nominal
O.C. voltage: 21.3 volts
S.C. current: 3.4 amps
Voltage at STC: 17.1
Current at STC: 3.2 amps

--Total --
1375 watts rated @ 12 volts nominal

O.C. voltage: 21.3 volts
S. C. current: 48.2 amps

XX. Array Mounting
Model: Array mount
Type: Fixed
Tilt: Latitude +15
Design month insolation: 3.30 kWh/m2/day

XXI. Batteries
Model: Battery
14 batteries: 2 series x 7 parallel
Cell type: Lead acid
Max depth of discharge: 80%
Battery efficiency: 80%
Temperature derating: 90%

-- Average Daily Energy Consumption (Design month)
Total: 1.70 kWh/day (142 Ah/day @ 12 V)
Appliance load: 1.20 kWh/day (100 Ah/day @ 12 V)
System losses: 0.501 kWh/day (41.7 Ah/day @ 12 V)

-- Average daily Energy Production (Design month) --
Total: 1.70 kWh/day (142 Ah/day @ 12 V)
Photovoltaics: 1.60 kWh/day (134 Ah/day @12 V) [94%]
Generator: 0.0958 kWh/day (7.99 Ah/day @ 12 V) [5.6%]

--Average Yearly Energy Consumption
Total: 620.5 kWh/yr
Appliance Load: 438.0 kWh/yr
System Losses: 182.9 kWh/yr

--Average Yearly Energy Production--
Total: 797.3 kWh/year
Photovoltaics: 794.3 kWh/year [100%]
Generator: 3.0 kWh/year [0.37%]

--Average daily energy production from solar by month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
kWh/ day	1.8	2.1	2.3	2.4	2.4	2.4	2.4	2.4	2.4	2.2	1.8	1.6
Ah/ day	150	174	190	199	195	199	199	203	199	186	150	134

--Percentage of load provided by solar by month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
%	106	123	134	140	137	140	140	143	140	132	106	94

System Economics

Initial Costs:
PV Array: $4,900
PV mounting: $770
Batteries: $1,078
Charge Controller: $453
Inverter: $425
Battery Charger: $300
Generator: $775
Wiring: $0

Other: $0

Installation Cost: $0

--Total--
Total initial costs: $8,701

Life Cycle Costs
--Economic Parameters
System Life: 20 years
Discount rate: 9%
Fuel Discount Rate: 12%

--Replacement intervals
Batteries: $1078 every 5 years (3 replacements)
Charge controller: $453 every 10 years (1 replacement)
Inverter: $425 every 10 years (1 replacement)
Battery charger: $300 every 10 years (1 replacement)
Generator rebuild: $388 every 5000 years (0 rebuilds0

--Operations and maintenance
Labor: $0/year
Materials: $0/year
Insurance: $0/year
Generator fuel cost: $1/year
Generator service cost: $3/year
Other: $0/year

--Salvage
System salvage value: $0

--Total
Total life cycle costs: $10,687
Energy cost: $0.86/kWh

Scenario 3 (PV shingles)
PV shingles for the facility we are evaluating would only be able to provide rated power of 360Watts. This would supply less then 1/20 of the total power drawn by the facility. This option seems to be feeble for providing cost effective power. This conclusion was drawn by taking the area of south facing roof 72ft^2 and multiplying by the rated power of 5 watts/ft^2. This system would provide on a clear summer day only 27 Watt-Hours which is insignificant to the load of 7400 Watt-hours.

Appendix 3 -- Energy Audit Tables

Appendix 4 -- Memorandum of Understanding

Capital Region National Parks and James Madison University--An Energy Partnership

Formally Established to Create a More Energy Efficient,
Environmentally Friendly, and Publicly Beneficial National Park System

MEMORANDUM OF UNDERSTANDING

By and Among,
James Madison University
and
Capital Region National Parks
enacted
July 2, 1999

With Support and Guidance From,
Alliance to Save Energy
U.S. Department of Energy
Federal Energy Management Program
U.S. Department of Interior
National Park Service

XXII. PURPOSE

This Memorandum of Understanding (MOU) serves to establish the framework within which Capital National Park and James Madison University can work together to accelerate the energy savings goals of Executive Order 12902, and the Energy Policy Act of 1992 (EPACT). This MOU sets forth the agreements, responsibilities, and procedures necessary to carry out the objectives of the *National Park-University Energy Partnership Program* for the following participants:

National Park: Capital Region National Parks -- Washington, DC

University: James Madison University
Integrated Science and Technology Program
Harrisonburg, VA

It is understood that certain organizations will provide support to Capital Region National Parks and James Madison University in identifying and documenting energy saving opportunities. These organizations include:

Non-profit Organization Alliance to Save Energy
Washington, DC

Federal Agencies:
U.S. Department of Energy
Federal Energy Management Program
Washington, DC
U.S. Department of Interior
U.S. National Park Service
Washington, DC

INITIATIVES

In order to meet this purpose, Capital Region National Parks will work with James Madison University to identify and implement energy saving projects. Four (4) key activities will be conducted during the Summer of 1999 to achieve this objective.

1. *CNO Canal Bridge and Tunnel energy efficient lighting retrofit*. Design and analysis of an energy efficient lighting system for the bridge and tunnel of CNO Canal. The power load for this design will either be grid connected or powered by a stand-alone photovoltaic (PV) system and of our team’s design. Further effort may be made in the area of public awareness as to the purpose and usage of the design.
2. *Antietam National Battlefield PV system design and analysis for parking lot lighting power requirement*. Design and analysis of implementing PV technology to power the lights in the Antietam National Battlefield parking lot. This design will have to fit within the confines of the historical monument where it is to be built.

3. *Energy Audit for energy efficient lighting in Capital Region National Parks facilities.* An audit of lighting usage in facilities within the Capital Region National Parks will be performed. This Audit will include technical and economic analysis toward the possibility of converting to energy efficient lighting if needs be.
4. *Identify and Develop Future Research.* Identify further possibilities within the Capital Region National Parks for PV and energy efficient implementation. Develop such ideas to facilitate prompt resumption of this project and integrate the possibility for meeting public awareness needs.

XXIII. IMPLEMENTATION

Capital Region National Parks and James Madison University will work closely with the Alliance to Save Energy, a national non-profit focusing on energy efficiency, and its Federal Energy Productivity Task Force to implement projects as they are identified.

PRINCIPAL OFFICERS

The principal points of contact with responsibility for implementing this MOU are listed below.

For Capital Region National Parks: Mike Doherty
For James Madison University: David Narum, Professor

PROGRAM RESPONSIBILITIES

This MOU commits the undersigned to work together toward achievement of *National Park-University Energy Partnership* goals. It is agreed that the undersigned will adhere to the following responsibilities:

Capital Region National Parks

- Provide leadership and best judgment in the formulation of specific energy projects.
- Identify sites and facilities to be used.
- Provide access to buildings and data necessary to conduct analyses.
- Provide insight and identification of opportunities for application of renewable energy technologies within the parks.
- Provide information, general assistance and material for public relations and promotional activities.

GUIDELINES

Project activities will be administered according to the *Project Workplace, which* identifies more specific tasks, timelines, and deliverables. See attached.

ADMINISTRATION

Public Information Coordination. Subject to the Freedom of Information Act (5 U.S.C. 552) decisions on disclosures of information to the public regarding projects and programs referenced in this MOU shall be made by Capital Region National Parks following consultation with the other parties' representatives.

Amendment and Termination. This MOU may be amended by the mutual written agreement among signatories. This MOU may be terminated by the mutual written agreement signatories. Signatories may terminate individual participation upon a 30-day written notice.

Effective Date. This MOU shall become effective upon the latter date of signature of the parties and shall remain in effect for a period of 1 year, upon which the MOU becomes eligible for renewal.

DISCLAIMER

This Memorandum of Understanding is not intended to and does not create any contractual rights or obligations with respect to the signatories of any other parties. Rather it is a declaration of understanding between two parties to join in a collaborative effort to save energy and water in Capital Region National Parks.
Signed, this day of July 9, 1999:

For the Capital Region National Parks

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Mike Doherty

For James Madison University

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David Narum

XXIV. Work Plan

All work outlined herein to be completed by August 27, 1999.

1. *CNO Canal Bridge and Tunnel energy efficient lighting retrofit*. Design and analysis of an energy efficient lighting system for the bridge and tunnel of CNO Canal. The power load for this design will either be grid connected or powered by a stand-alone photovoltaic (PV) system and of our team's design. Further effort may be made in the area of public awareness as to the purpose and usage of the design.

Tasks:

- Technical Analysis
- Systems Design
- Site Visit
- System Remodeling
- Economic Analysis
- System Implementation

Deliverables:

- Weekly reports to Dr. David R. Narum and Mike Doherty via email
- Other Research- and Work-Related Reports
- Project Final Report

2. *Antietam National Battlefield PV system design and analysis for parking lot lighting power requirement*. Design and analysis of the feasibility of using PV technology to power the lights in the Antietam National Battlefield parking lot. This design will have to fit within the confines of the historical monument where it is to be built.

Tasks:

- Power Requirement Analysis
- Systems Sizing and BOS Components Selection
- Systems Design
- Initial Presentation & Site Visit
- System Remodeling
- Economic Analysis
- System Implementation

Deliverables:

- Weekly reports
- Other Research- and Work-Related Reports
- Project final report

3. *Energy audits for energy efficient lighting in NPS Capital Region facilities.* An audit of lighting usage in facilities within the Capital Region National Parks will

be performed. This Audit will include technical and economic analysis toward the possibility of converting to energy efficient lighting if needs be.

Tasks:

- Site Visit & Determination of Current Usages
- Energy Efficient Retrofit and System Design
- Site Visit and Presentation
- Remodeling & Economic analysis
- System Implementation

Deliverables:

- Weekly reports
- Other Research- and Work-Related Reports
- Project final report

4. *Identify and Develop Future Research.* Identify further possibilities within the Capital Region National Parks for PV and energy efficient implementation. Develop such ideas to facilitate prompt resumption of this project and integrate the possibility for meeting public awareness needs.

Tasks:

- Site Visit
- Analyze Initial Possibilities
- Site Visit
- Develop Possibilities
- Documentation of Ideas for Future Research

Deliverables:

- Weekly reports
- Other Research- and Work-Related Reports
- Project final report