ALCATRAZ OFF-GRID SOLAR PHOTOVOLTAIC PROJECT
TWO-YEAR MONITORING REPORT

Golden Gate National Recreation Area
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1. Executive Summary

Providing electricity on Alcatraz Island has always been a challenge for the Golden Gate National Recreation Area. For forty years, the National Park Service used diesel generators to power the island until a hybrid solar microgrid system was installed in 2012. The 305 kW system is comprised of 959 solar panels atop the Main Prison building. The other components of the project include a battery array, diesel generators, power inverters, and a controller.

This report presents the first comprehensive analysis of the data from the system. Data was collected from the PV controller and building meters on the island and this data was used to calculate the energy costs on the island. The building energy data was also used to prioritize energy conservation measures that will result in additional cost savings on the island.

The design goal of the hybrid solar microgrid system was to generate 60% of the electricity from solar, yet between January 2013 and June 2014 the average renewable fraction has been 44%. Peak energy production from the solar panels occurred in June 2013, with over 70% coming from solar. In the winter months, solar contribution reaches as high as 35%. In 2013, an estimated 31,900 gallons of fuel were offset by solar energy production. This replacement of diesel with solar saved over $200,000 and offset 325 metric tons of carbon dioxide equivalent.

The cost of energy was calculated two different ways. The levelized cost of energy includes the capital investment spread out over the lifespan of the solar panels. This value of $1.52/kWh can be used to secure reimbursement from special events and contractors who tap into the microgrid. The incremental cost does not include the capital investment of the project but includes the cost of fuel. This value of $0.58/kWh can be used in energy conservation savings calculations.

This effort also included some recommendations for energy efficiency measures. These fell into three categories of improving the performance of the microgrid, improving Alcatraz operations via minimal changes in operations and end use behavior modification, and completing energy conservation projects.

The results of the analysis show that solar has made a significant impact in making the island more energy independent; however, there is room for improvement. With optimization of the controller, solar energy production can be maximized and diesel fuel consumption can be further reduced. Implementing energy conservation methods can further reduce the island load and boost battery performance throughout the night.

This report represents a snapshot of the early stages of the overall project lifetime. NPS will continue to monitor the system and use the most recent data in ongoing decision-making, including such future endeavors as replacement of the battery bank.
2. Introduction

Once a military site and best known for supporting one of the most renowned federal prisons in the United States, Alcatraz Island is now a National Historical Monument open for the public to learn about its dynamic past. Nearly 1.5 million visitors come to experience this historic site, located 1.5 miles offshore in the San Francisco Bay. The island’s isolation from the mainland has posed a unique challenge: fulfilling the island’s energy load in an efficient, environmentally friendly, and cost-effective manner while preserving its historical qualities. Due to increased interest in sustainability on the island, solar panels were installed to offset diesel fuel usage, reduce the risk of fuel spills, lower energy production costs, and offset a large portion of emissions coming from the island. Alcatraz is an example of how new microgrid technology (on-site generation, storage power conditioning, and controls) can be integrated with historic sites and is now home to one of the United States’ largest microgrids at 305kW.

3. History of Power Generation on Alcatraz

Powering Alcatraz has always been a challenge, since all of the fuel must be brought by boat. The first power on the island was generated from coal-powered boilers in the powerhouse, built in 1912, that still stand today. Coal was only used for a short time before being replaced by an even more energy-rich product: oil (Alcatraz, Martini, et al.). In a project aimed to increase the industrial capability of the island, a diesel engine and electric generator was added in 1920 to provide DC power to the carpentry and electrical shops. Shortly thereafter, in 1924, another diesel-powered 100 kW DC generator was installed when demand began to exceed the electrical output of the existing boilers. In 1932, a fourth boiler was added to the three already in place.
The Bureau of Prisons (BOP) officially took over control of Alcatraz from the War Department in 1934 and added another 150 kW generator shortly after. Between 1938 and 1940, the Public Works Administration (PWA) spurred many new projects and buildings, including structural and equipment upgrades to the powerhouse which were vital in supplying the island with power.

Alcatraz was discontinued as a federal prison in 1963, largely due to the high cost of running the prison on an island. The Coast Guard, left to maintain the lighthouse on the island, was concerned that two recently-installed 75kW AC generators were in jeopardy of becoming unusable without regular maintenance. They installed an undersea cable that supplied power to the remaining people on the island, and it functioned until the 1969 American Indian Occupation of the island. It is unclear why the power was cut off; the Indians claimed the government was at fault and the government maintained the Indians did it (Alcatraz, Martini, et al.).

In 1972 Alcatraz Island was included in the establishment of the Golden Gate National Recreation Area (GGNRA). As early as the 1990s, the GGNRA began looking at Alcatraz to improve its energy generation methods. In 1996 the National Renewable Energy Laboratory (NREL) produced a preliminary assessment for an energy strategy for the island. Renewable energy was deemed the most viable option to reduce fuel consumption and greenhouse gases as well as to make the island more energy independent. The Lawrence Berkeley National Laboratory (LBNL) also completed a comprehensive study that reported the energy efficiency of the island by measuring energy consumption from lighting and appliances. These were the first steps in a long process to design a new energy generation system specifically tailored to the needs and constraints of Alcatraz.

4. Alcatraz Solar Project

The origins of the current solar photovoltaic (PV) project date back to 2001, when an attempt was made to install solar panels on the roof of the New Industries Building. Sponsored by US Department of Energy Federal Energy Management Program (FEMP), NREL and National Park Service staff installed instruments on the Main Prison building roof and recorded 14 months of solar resource and climate data, preparing a feasibility study in 2001. In March 2002, Kiss + Cathcart Architects prepared renderings of initial solar PV design alternatives for the historic preservation process that illustrate a plan to mount solar arrays atop the Main Prison building and New Industries (Laundry) Buildings on Alcatraz. The Washington Contracting and Procurement Office (WCP) in collaboration with FEMP and the director, public utilities, and General Services Administration (GSA) developed a Utility Energy Service Contract (UESC) with the Sacramento Municipal Utility District to install a system and sell the NPS power at a rate of $0.01/kWh less than generator power. As part of the historic preservation review, panels were mounted temporarily in a mock installation on the New Industries Building, and were soon vandalized by kids throwing rocks. A new roof and roof stanchions were installed, but the project was canceled due to historic/cultural preservation concerns regarding use of the roof of the New Industries Building.

In 2008, a GGNRA greenhouse gas (GHG) inventory found that the generators on Alcatraz produced 632 MTCO2e (metric tons of carbon dioxide equivalent), nearly half of the total GHGs from electricity generation for the entire park. This generated renewed focus on finding an alternative to the diesel generators. Later that year, the University of Washington produced a report that suggested various methods of powering the island with renewable energy sources including wind, tidal, and solar and the feasibility of each. Three options were considered the
most feasible way for Alcatraz to be powered in the future: the current stand-alone generator system, a hybrid diesel-solar power system with battery storage, and a grid-tied solar system.

From 2008 to 2010, the assessment of renewable energy sources continued with the focus narrowing to solar-generated power being the most applicable approach while protecting both the natural and cultural resources on the island. The assessment continued with consideration of each roof top and parcel of flat ground available on Alcatraz. Areas were eliminated because they structurally wouldn’t support a PV array or because they had an undesirable impact on the cultural or natural significance of the island. Two locations were determined to be the most favorable: the roofs of the Main Prison building and the New Industries Building. A detailed investigation of both locations resulted in the elimination of the New Industries Building due to an additive combination of structural, natural and cultural impacts.

Serious discussions about the project were just getting underway when collaboration between the White House and Congress led to the American Recovery and Reinvestment Act (ARRA) of 2009 becoming public law. The funding was intended for “shovel-ready” projects, but the National Park Service used some of its funds to support design work on several projects that it described as “over-target”. Over-target considerations included the responsibility for accelerating the project performance to meet the schedule of the ARRA program. In consideration of the size of the project, and speed of execution required, GGNRA engaged the NPS Denver Services Center (DSC) to provide project management, quality assurance, and contracting services. From that point on, through the completion of the project, DSC provided the focus and staffing to oversee all planning, contracting, design and construction. In 2009, HDR was contracted to rapidly prepare a schematic design and a competitive request for proposals to advance the project through completion. This design and request for proposals served as the basis of project approval and final detailed design of the system. The full project was approved and officially funded in October 2009.

The initial schematic design included a "grid-tied" system with an undersea cable running under the San Francisco Bay and connecting to the Pacific Gas and Electric Company (PG&E) distribution system in San Francisco. The intent was to install the cable and turn it over to PG&E to maintain. The benefit of a grid-tied system is that the grid itself functions as a “battery”, storing energy and balancing supply and demand. Excess energy produced could be sent back to the grid, reducing the Alcatraz meter reading. In winter, the reduced output from the Alcatraz solar system is balanced by accepting power from the PG&E grid.

As detailed design and negotiations with PG&E advanced regarding the undersea cable in 2009, it became obvious that the costs would be prohibitive. The determining factor was that PG&E requested redundant undersea cables be installed in case one electrical feed is disrupted, which would effectively double the already-high cost of construction. At this point the design shifted to an off-grid system consisting of the PV panels, batteries, and generators. The design benefited greatly by advances in the solar PV market. Utilizing the new model of Sunpower 318 watt panels allowed the project team to match the system capacity once planned for two buildings to fit on one building, the Main Prison building. The benefit of installing the panels on the Main Prison building is that it is the highest building on the island and thus not visible to the public. It also has a parapet wall around the entire periphery of the roof, further shielding the panels from view. This allowed the GGNRA staff, responsible for enforcing the National Historic Preservation Act, to approve the project without needing specific approval from the State Historic Preservation Office (SHPO).
In late 2009, DSC issued the request for proposal for a nationwide solicitation for performance of the design-build contract to complete the project. The solicitation gathered responses from contractors throughout the United States. The qualifications of each contractor were reviewed by a team of GGNRA and DSC project experts. The selection process identified the three most qualified submittals and ultimately determined that the proposal from Hal Hays Construction Inc. (HHCI) provided the best value for the government. HHCI was subsequently contracted to prepare the final system design and execute the construction of the project. The HHCI team was supported by Lee & Sakahara Architects who served as the Designer of Record, Wright Engineering providing engineering, Princeton Power providing inverters, control systems and programming, Conley Equipment Company, providing the battery storage system, and others that played various other important roles in the success of the project.

Other Components of the Project

Prior to installing the PV panels, a full replacement of the roofing was required. Removal of the existing roofing revealed areas of structural distress in the roof slab. The scope was expanded to remove and repair these bad sections. These efforts beyond the PV system itself ensure that the panels would not need to be disturbed before their own replacement is necessary. In addition, installation of a system of water tanks and piping to the roof allowed the PV panels to be cleaned regularly.

Cost of Project

The total cost of the Alcatraz Solar Project included several aspects that are unique to construction at Alcatraz. Workers that have done construction on the island refer to the distance from the San Francisco pier to the Alcatraz dock as "the longest mile and a half on earth". Personnel, equipment, and materials are transported across land, transferred to barges or boats, shipped to the island, transferred to the dock, and then carried to the construction location. With limited site available for laydown, storage and staging shipments must be small and frequent. The additional care that must be taken to protect the historic buildings and landscape, and the extensive avian habitat increased the cost of all work.

The overall project scope included improvements that were separate from the solar energy system, but critical to the resiliency of the installation or critical to optimizing the systems performance.

- Cost of re-roofing Main Prison building: $1,474,983
- Cost of solar panel system (including panels, ballasts, wiring, installation, etc.): $2,623,809
- Cost of Energy Storage Battery Bank: $1,507,562
- Electrical Control and Distribution System: $1,798,041
- Backup Electrical Generator Replacement: $511,804
- Energy Conservation Measures (ECMs): $126,919
- Design-Build Detailed Engineering: $729,596

Cost of project, hybrid solar installation only: $7,170,813
Total cost of project, including roofing and ECMs: $8,772,715
5. Technical Specifications

The solar panel array stationed on the Main Prison building is just one component of the system, providing power to the island and charging the battery bank in the powerhouse. This energy is sent through power inverters where it is transformed into usable AC current. When power from the solar panels is insufficient for the island load, diesel generators turn on to power Alcatraz and the battery bank until it is charged enough to sustain the island load alone. The heart of the system is a controller which manages where the main source of energy is coming from, prioritizing the solar panels and batteries before activating the generators.

![Microgrid Schematic](image)

**Figure 1 – Microgrid Schematic**: A schematic of the essential microgrid components that transform solar energy to AC energy and provide it to power the island.

### Photovoltaic Solar Panels

The photovoltaic system consists of 959 PV monocrystalline solar panels manufactured by Sunpower Corp. These were the latest, most efficient E19/318 model at the time, capable of generating 318 watts of direct current (DC) power with 19.5% conversion efficiency per panel (“SunPower Announces New, Maximum Efficiency”). Each panel produces as much as 65 Volts, so seven panels are wired in series to provide a voltage approaching 480 V DC. The series strings are then combined and are capable of delivering up to 305 kilowatts of power on a clear, sunny day. They are separated into four separate sectors consisting of either 238 or 245 panels.
When photons of light emitted from the sun strike the solar panels, electrons are knocked free of the ultra-pure silicon into a conducting state providing the current (amps), and an electric field caused by adding layers of impurities to the silicon provides the voltage (volts). The PV panels have long lifetimes and low maintenance and continue to generate electricity without noise or pollution as long as they are exposed to light. Since DC power is produced by the panels, the electricity must travel through four designated power inverters to become useful alternating current (AC) power (Levinson). When the power produced by the panels exceeds the island load, the excess is transferred to the battery bank for charging.

### Power Inverters

The primary function of the eight power inverters is to convert DC current from the solar panels and battery bank to AC current for island energy load use. Four of the 100 kW power inverters manufactured by Princeton Power Systems Inc (Model: GTIB 480·100 kW) are tied to the solar panels and the other four are connected to the battery bank. The power inverters also serve to measure the island load which assists the controller in regulating how much energy is injected into the grid in case extra is generated. They have a built-in MPPT controller, or Maximum Power Point Tracking controller, which facilitates the solar panels in producing the maximum amount of power to meet the island’s energy load by seeking out the highest power production for each string of solar panel that might otherwise be subjected to change depending on cloud cover and temperature (Cullen). The additional energy produced from this optimization is stepped down in voltage to supply the batteries with charge.

When powering the island, eight Hammond 112.5 kVA dry type step-up transformers follow the conversion of power to the desired AC voltage. These ramp up the voltage in order to efficiently distribute energy throughout Alcatraz (“Transformer”). They also serve to even out the power so electrical equipment can function properly without surges or shortages.

### Battery Bank

Stored in the Quartermaster building, 480 Deka Unigy II valve-regulated lead acid batteries manufactured by East Penn Manufacturing Company (Model: 2AVR125·331l Gel) power Alcatraz during the night when solar radiation is absent. The batteries are wired in two strings of 240 battery cells each, for a battery voltage of around 480 V (battery voltage is around 2 V per cell depending on state of charge). Each battery is rated for 2,000 amp-hours, and has two two-volt cells per battery unit. Thus the total storage capacity of the battery system is 1,920 kWh. The battery system is designed to not only provide the island with the most stored solar energy, but to extend the lifetime of the batteries. Being an array of lead-acid gel batteries, they are the best type for constant discharge and recharge cycles. A special controller designed by Princeton Power Systems ensures the batteries are protected from overcharge and complete discharge which pose safety dangers and significantly impacts their lifespan (“How Lead Acid Batteries Work”).

### Diesel Generators

When the solar panels and batteries cannot meet the island’s energy load, one of two 250 kW MTU Onsite Energy diesel generator activates to take over. They are utilized mostly during the night when the batteries are depleted from sustaining the island’s load. The generators are run on ultra-low sulfur diesel fuel and are powerful enough to meet the island load and charge the batteries. Since AC current is produced, the energy does not need to undergo inversion and
experience inherent loss. The controller puts the lowest priority on the diesel generators to maximize the usage of solar energy

**Controller**

The ICOP, or Intelligence Carry-On Program controller, coordinates energy distribution and storage on Alcatraz. The device works as a logic-based system; it is responsible for prioritizing energy sources to maximize the amount of solar energy utilized to power the island and reduce generator usage.

When the solar energy is available and plentiful, it is utilized for directly powering the load and charging the battery bank. When an insufficient amount is produced, the batteries kick on to supplement the remainder of energy required. This combination is sufficient until the battery bank reaches 50% remaining charge; this is when the diesel generator kicks on to sustain the island load and charge the battery bank until it is able to sustain the island load. Once charged to 80%, the batteries take over the island load until solar energy is sufficient to support the island again and charge the batteries. While the generator is signaled to shut off when the batteries reach 80% state of charge, the batteries are able to continue charging from solar generation up to 100% state of charge; excess solar production is automatically curtailed when 100% state of charge is reached. The 50% lower limit on the battery bank is to assure adequate power is available when peak power demand occurs and to protect the batteries from the accelerated degradation that would occur if discharged below 50% on a regular basis. The 80% upper limit is set to have remaining storage capacity for the early morning solar generated power that may not be needed to support the demand at that time. These set points were established during design, and are adjustable as actual system performance information is acquired.

**Monitoring Systems**

In order to measure how much energy is utilized on Alcatraz, two different instruments are present: the Princeton Power Systems (PPS) power inverters and Shark 200T Meters. All of the energy generated on the island travels through the power inverters which records readings in 10-minute increments. This measurement differs from the Shark meters because of their location in the microgrid. Nine Shark meters monitor the energy usage for each building and record data in 15-minute increments. These measurements are taken after inherent energy losses from conversions and storage, making their results lower than the PPS measurements.

The Princeton Power Systems computer on the island monitors all of the energy flow in real time for users to view. A remote access software call LogMeIn allows users to monitor and collect data from the mainland without having to travel to Alcatraz.

The following image (Figure 2) is a screenshot of the remote access to the PPS computer in the Powerhouse building on Alcatraz. At 2:39 PM, it reveals the PV solar panels generating 249.88 kW which is more than enough to supply the island load of 72.83 kW. The battery contribution is negative indicating they are being charged by the surplus solar energy. The solar array is controlled to charge the batteries to maximum capacity when it becomes available. Once charged, the power inverters will then throttle back the excess solar energy to match the island load, wasting the excess as heat. The generator will remain inactive until PV is no longer contributing energy and the batteries reach a state of charge (SOC in the green boxes in Figure 2) of 50%.
6. Operations and Maintenance

During the start-up and troubleshooting period, the PV panel system had equipment failures and monitoring issues for approximately nine months but has since been running smoothly with relatively low maintenance. Cleaning on a regular basis is necessary to remove bird guano and dirt buildup which hinders energy production performance. The generators, on the other hand, constantly need to be primed and fueled to operate, but are imperative when PV and battery power alone cannot power the island. Alcatraz Island Services (AIS) is responsible for overseeing the maintenance and upkeep of the generators and solar panels. Monthly service is performed to avoid unnecessary breakdowns and inefficiencies with energy production are avoided.
7. PV System Performance: 2012-2014

The design goal of the PV system was to generate 60% of the annual energy usage from solar. In order to determine whether the system is meeting this goal, the first two years of data were analyzed. The solar panels have been active since February 2012, but reliable and useful data was not available until November 2012. Utilizing remote access software, raw data was downloaded and manipulated in multiple ways to chart solar energy production, view day-to-day activity of the energy sources, and determine how much solar energy is contributing to the total energy production.

To determine when the peak levels of energy production are throughout the year, the total energy production per day was summed and charted on a scatterplot graph (Figure 3).

![Figure 3 - Average Daily PV Energy Production](image)

**Figure 3 - Average Daily PV Energy Production:** A 2-week rolling average graph of all the solar energy produced on a daily basis by the PV array since the beginning of reliable data collection.

Each point in the graph above represents the total energy output from the solar panel array in a single day. By adding a 14-day rolling average, a trend can be extracted from the scatter. Solar energy production begins to ramp up after December until it peaks in July before declining again. In the winter of 2013, solar energy production did not dip as low as 2012, but summer 2014 energy production has yet to match 2013. The trend throughout the year is expected due to the northern hemisphere’s tilt and proximity to the sun.

Viewing daily trends can help reveal days when the generator does not have to be used or when there is less than sufficient solar energy supply and the generator needs to work extra time.
**Daily Power Trends:** The graph in Figure 4 starts at left on midnight of June 10th: the batteries (black line) sustain the island load (green) until the solar energy (yellow) is able to power the island and charge the batteries. The battery power lasts until 10:15 pm, when the generator (blue) activates and charges the battery until the solar energy begins to power the island the next morning. The batteries have reached their maximum capacity and with extra energy being produced, the controller appears to be throttling PV energy production. That night, the battery bank sustains the island load until solar energy is produced on June 12th. Solar energy combined with battery storage is sufficiently produced until the 14th and the generator does not have to turn on at all. This 93 hour period is one of the longest time spans without generator activity. The next step is for NPS to determine whether adjusting the controller can further maximize the use of solar energy.

**Monthly Trends:** The output of the generators and solar panels can determine the efficiency of energy production. Calculating the ratio of PV energy to total energy production (Figure 5 below) reveals that 44% of the total energy produced since January 2013 has come from solar. This translates to significant cutbacks in diesel fuel consumption.

**Figure 4 - Daily Power Trend by Source:** The daily trend of power supplied to the island from the PV solar panels (yellow), the diesel generator (blue), and battery bank (black). The island load is also shown (green).

**Figure 5 - Total Energy Production:** This figure shows energy production from January 2013 to June 2014 and compiles the total amount of PV and generator energy produced each month as well as the average for the time frame. The bar on the right is the average ratio.
Operational Challenges

The hybrid system was completed in early 2012, but ran into some initial hurdles because of the challenging environment on the island (wildlife, fog, salty atmosphere, wind). Several modifications were made to provide additional protection to the equipment and optimize the control system, including completely enclosing and dehumidifying the battery room, on-site touch up painting of battery cabinets that showed signs of rust, and creating a digital monitor for a visitor’s kiosk. The system has been fully operational and consistently monitored since October 2012.

There are some general challenges with most hybrid microgrid systems. The generators and solar array provide more energy than the island load at any given time as a safety margin to account for losses in efficiency which means additional fuel consumption. Failure to do so would create an unstable electrical grid that would provide insufficient power to the island. Storage of energy is another challenge because there are losses when storing energy in batteries. The energy produced by solar is most efficiently used right away so the peak island loads are best if they coincide with peak solar production. In addition, seagulls perch on the solar panels for their warmth on the windy island. A side effect is shading from the birds and their droppings which pile up, reducing production efficiency.

8. Environmental Benefits

Using renewable energy is an effective way to cut fuel consumption and emissions simultaneously. Alcatraz is significantly more energy independent than before because less fuel is delivered to the island. In the case of a power outage on the mainland, the microgrid will be able to continue running smoothly. In 2013, 46% of the energy that would have been produced by diesel generators has been replaced with energy from the solar panels. This equates to a reduction of 31,903 gallons of fuel and 325 MTCO2e emitted (NPS CLIP). By also reducing diesel fuel consumption, greenhouse emissions were reduced by avoiding extra delivery trips to refill the island’s fuel reserves. These environmental benefits from solar will continue throughout the life of the panels which could be upwards of 25 years.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Island Demand (kWh)</th>
<th>Total PV Generated (kWh)</th>
<th>Diesel Offset by PV Generation (gal)</th>
<th>Savings from Diesel Offset in 2013 ($)</th>
<th>Reduced Emissions (MTCO2e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>621,173</td>
<td>325,429</td>
<td>31,903</td>
<td>206,683</td>
<td>325</td>
</tr>
</tbody>
</table>

Table 1: The total island demand and the total PV energy generated was calculated using data from Princeton Power’s controller and using an average kWh/gal generation rate of the generator, estimated the estimated offset diesel and savings.

The trend in declining diesel use began in 2008, as energy conservation projects started implementation. With the installation of solar panels, diesel fuel use has been offset by over 10,000 gallons. In Figure 6 below, the trend of diesel fuel is declining, but island energy consumption jumps by approximately 15,000 gallon-equivalents produced by the solar panels. Construction projects have tapped into the grid in 2013, inflating the island load and increasing the amount of diesel fuel needed.
Figure 6 – History of Diesel Fuel Consumption: The diesel fuel consumption on Alcatraz has declined since 2008. Although energy use was at an all-time high in 2013, the energy production from the solar panels offset the amount of diesel fuel needed to continue the decline. Without the panels, the island would have surpassed its 60,000 gallon consumption limit.

9. Building Energy Usage

Shark meters installed at each building measure energy usage to help determine when a specific building is drawing electricity as well as how much electricity is being drawn. Using the monitoring data from the Shark Meters, the NPS can determine areas where energy conservation measures are needed most as well as tracking their effectiveness once installed. Shown below is a heat map of island energy use which depicts the largest energy user on the island.

The main consumers of electricity in the buildings are plug in equipment (space heaters, computers, etc.), followed by interior and exterior lighting. Additions to the electricity load include water heating, the charging of both the electric trams, and the audio tour equipment, the sewer pumps, the lighthouse, and telecom equipment.
A breakdown of each building’s electricity use is as follows:

<table>
<thead>
<tr>
<th>Building Name</th>
<th>Size (sq. feet)</th>
<th>Highest Power Draw (kW)</th>
<th>Lowest Power Draw (kW)</th>
<th>Energy Use 11/1/2012 – 07/23/2014 (kWh)</th>
<th>Electricity Use Intensity (kWh/sq. ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Prison building</td>
<td>70,125</td>
<td>68.6</td>
<td>17.3</td>
<td>763,107</td>
<td>10.9</td>
</tr>
<tr>
<td>Dock</td>
<td>18,170</td>
<td>49.8</td>
<td>8.9</td>
<td>464,660</td>
<td>25.6</td>
</tr>
<tr>
<td>Storehouse / Warehouse</td>
<td>18,144</td>
<td>29.3</td>
<td>1.1</td>
<td>151,268</td>
<td>8.3</td>
</tr>
<tr>
<td>Powerhouse</td>
<td>4,019</td>
<td>16.3</td>
<td>1.0</td>
<td>119,027</td>
<td>29.6</td>
</tr>
<tr>
<td>Carpenter Shop</td>
<td>2,294</td>
<td>3.2</td>
<td>0.4</td>
<td>31,158</td>
<td>13.6</td>
</tr>
<tr>
<td>Building 64</td>
<td>50,210</td>
<td>0.8</td>
<td>0.4</td>
<td>12,628</td>
<td>0.3</td>
</tr>
<tr>
<td>Laundry Building</td>
<td>24,261</td>
<td>7.7</td>
<td>0.4</td>
<td>11,867</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Table 2**: Parameters of the various buildings located on Alcatraz with their power draw and energy use are tabulated to investigate the biggest drainages are from.

Figure 7 displays the top four buildings that consume the most energy on Alcatraz, most notably the prison building. It consumes more energy than all the others, even during the night. This data, collected by the shark meters, can assist in pinpointing where energy conservation measures can be effectively implemented for reducing the island load efficiently.
10. Cost of Energy

Two values were calculated to reflect the cost of energy on Alcatraz: the levelized cost of energy and the incremental cost of energy. See Appendix A for the calculations for the following:

The Levelized Cost of Energy incorporates the cost of energy generation over the usable life of the system and includes the cost of capital investment. According to NPS guidance, the park is required to recover costs for utilities including operations and maintenance, component renewal, and capital investment (Director’s Order 35B). Non-NPS users including lessees, special event holders, and contractors would pay this rate.

**Levelized Cost of Energy:** $1.52/kWh

The incremental cost of energy eliminates the fixed costs and uses only the amount of diesel that is consumed or saved. This number would be used to calculate the savings from energy conservation projects, which would decrease the amount spent on diesel but would not save any of the fixed costs.

**Incremental Cost of Energy:** $0.58/kWh

11. Energy Efficiency Measures

With the cost of energy so high on Alcatraz, every kilowatt of energy saved results in measurable cost savings. Several energy conservation measures (ECMs) were incorporated into the ARRA project, and many more are underway or proposed that will result in additional savings.

**Completed Measures**

The energy conservation methods that were completed as part of Hal Hays’ contract included the following: install digital water heater timers, install LED exit signs, and install light sensor
controls for D-cell wall lighting. Accompanying these measures was a comprehensive energy audit, a plan for energy conserving lighting designs, and a comprehensive energy management plan that was brought to the NPS for review and approval.

**Recommended Energy Conservation Measures**

ECMs are crucial in reducing the island load and will result in additional cost savings, two major goals of the project. Follow-up work will refine these recommendations, which fit into three categories: improving the performance of the microgrid, improving Alcatraz operations via minimal changes in operations and end use behavior modification, and completing energy conservation projects.

**Recommendations to Improve Operation and Maintenance of the Microgrid System:**

- Work with Princeton Power to update battery charging parameters; refine control of diesel generator activation and shut off
- Improve dependability of building monitoring
- Work with NREL to model the island microgrid and generate efficiency recommendations
- Install load sensor to notify controller of large loads (elevator, dock lift) to minimize generator run time.
- Incorporate forecasting of solar output, allowing controller to adjust to weather predictions
- Research feasibility of utilizing “crowd-sourcing” to analyze data

**Improve Alcatraz Operations:**

- Adjust timing for charging electrical devices (Trams, audio tours) to coincide with peak solar
- Incorporate demand control over non-critical loads.
- Train staff to raise awareness of energy uses, including reducing nighttime base loads.

**Energy Conservation Projects:**

- Make improvements to wiring so that lights can be turned off at night.
- Occupancy and daylight sensors on restrooms
- Plug-load occupancy sensors
- Controller Management Software
- Building Envelope Retrofits
- Control of Exterior Lighting

12. **Conclusion**

The conversion of Alcatraz from a federal penitentiary to a historically preserved site has been dynamic, and the challenge of providing energy has proved difficult through time. The utilization of generators has proved reliable but expensive due to transportation of diesel fuel; this also results in greenhouse gas generation and a large carbon footprint. With PV solar panels successfully integrated with the Main Prison Building roof, diesel fuel consumption has been slashed nearly in half resulting in reduced fuel transportation costs, a smaller carbon footprint, and increased interest in green technology.

The installation of solar panels on Alcatraz Island is just the first step towards energy independence; other measures must be taken to rely solely on solar energy. Converting the lighting infrastructure to energy efficient LED bulbs in the buildings and educating the workforce to be conscious about using energy use in their offices can go a long way in offsetting
the amount of diesel fuel consumed. By addressing energy consumption and generation at the same time, not only can money be saved, but Alcatraz can be an example of effective solar energy use and one of the largest microgrids in the United States.

Contained in the mission statement of the National Park Service is “to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.” The NPS has stepped forward to meet the challenges of preserving the historical, cultural, and natural resources in the GGNRA for future generations to enjoy by embracing sustainability and renewable resources throughout the park, most notably on Alcatraz Island.
13. Works Cited


MSDS - Valve Regulated Lead Acid Battery, Non-Spillable. Lyon Station: East Penn Manufacturing Co., Inc., 30 Apr. 2013. PDF.


Appendix A: Energy Cost Calculations

The Levelized Cost of Energy (LCOE) is used to determine the cost of energy generation over the usable life of the system. The following table was taken from the Reference Manual for Director’s Order 35B:

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Personal Services - (Pay and Benefits)</td>
<td>$36,801</td>
</tr>
<tr>
<td>2 Leave Surcharge - 16% of line 1</td>
<td>$5,888</td>
</tr>
<tr>
<td>3 GSA Leased Space</td>
<td></td>
</tr>
<tr>
<td>4 Parts, Materials, Supplies, Tools, Vehicle Tool Costs</td>
<td></td>
</tr>
<tr>
<td>5 Fees and Contracted Services (Including fuel costs but no vehicle fuel)</td>
<td>$237,286</td>
</tr>
<tr>
<td>6 Energy Costs (Including fuel costs but no vehicle fuel)</td>
<td>$241,860</td>
</tr>
<tr>
<td>7 Training</td>
<td></td>
</tr>
<tr>
<td>8 All Other Expenditures</td>
<td></td>
</tr>
<tr>
<td>9 Total of Lines 1 through 9</td>
<td>$521,835</td>
</tr>
<tr>
<td>10 15% of Line 10</td>
<td>$78,275</td>
</tr>
<tr>
<td>11 Costs (Total of Lines 10 and 11)</td>
<td>$600,110</td>
</tr>
<tr>
<td>12 Number of Units Produced</td>
<td>621,173 kWh</td>
</tr>
<tr>
<td>13 O&amp;M Rate (Dollars per unit of Measure) Line 12 Divided by Line 13</td>
<td>$0.97 per kWh</td>
</tr>
<tr>
<td>14 Cyclic Maintenance (Amortized Portion)</td>
<td></td>
</tr>
<tr>
<td>15 Yearly Cyclic Maintenance (from Cyclic Maintenance Amortization Schedule)</td>
<td>$ - per kWh</td>
</tr>
<tr>
<td>(note that cyclic maintenance is included in the Contracted Services)</td>
<td></td>
</tr>
<tr>
<td>16 Component Renewal Rate (Line 15 divided by Line 13)</td>
<td></td>
</tr>
<tr>
<td>Recapitalization/ New Capital</td>
<td>$345,426</td>
</tr>
<tr>
<td>17 (from Recapitalization/ New Capital Amortization Schedule)</td>
<td></td>
</tr>
<tr>
<td>18 Capital Recovery Rate (Line 17 divided by Line 13)</td>
<td>$0.56 per kWh</td>
</tr>
<tr>
<td>Utility Rate</td>
<td></td>
</tr>
<tr>
<td>19 Total Rate ((Line 12 + Line 15 + Line 17) Divided by Line 13)</td>
<td>$1.52 per kWh</td>
</tr>
</tbody>
</table>

Annual Cost of Energy

A simpler measure would look at just the annual operating costs, considering that the infrastructure costs are “sunk costs” that occurred in the past. We calculated an incremental cost of energy that included fixed costs as well as variable costs. Fixed costs are those costs that are consistent and independent of how much energy is being produced. In this case, the fixed costs are the costs of maintenance of the entire electrical generation system and fuel delivery system for the entire year, amounting to $237,286. The total energy used in 2013 was 621,173 kWh so the fixed costs are calculated by dividing the fixed costs by the units of energy used.
Annual Fixed Cost = $237,286 / 621,173 kWh = $0.38/kWh

Our variable fuel costs are calculated from an average rating of energy produced per gallon (kWh/gal) of diesel in the stationary generators. The fuel efficiency of the generators was calculated by taking the average of a year’s worth of power production divided by the total amount of diesel fuel consumed by the generators that year. The variable cost of diesel was calculated by taking the price of diesel (price is negotiated in contract and includes the delivery in the cost) which is currently $7.00/gal.

Variable (Incremental) fuel cost = ($7.00/gal) / (12 kWh/gal) = $0.58/kWh

Total cost combines the fixed and variable costs and reflects the entire cost of energy including fuel, operations, and maintenance on a yearly basis.

Total Annual Cost of Energy = $0.38/kWh + $0.58/kWh = $0.96/kWh